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Digital Technologies in Chemistry Teaching in the Journal Chemistry Education Research and Practice: an analysis through a Systematic Literary Review

Lucas Rodrigues Araújo, José Euzebio Simões Neto, João R. R. Tenório da Silva, Bruno Silva Leite*
Universidade Federal Rural de Pernambuco

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E-mail:
lucas.rodriguesaraujo@ufrpe.br
euzebio.simoes@ufrpe.br
joao.rtsilva@ufrpe.br
brunoleite@ufrpe.br

*Corresponding author

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A B S T R A C T

This work describes a systematic literature review (SLR) carried out to explore and describe the use of digital technologies in chemistry teaching, focusing on the journal Chemistry Education Research and Practice (CERP). The study follows a methodological process structured in five stages. The results point to an increase in digital production in chemistry teaching, showing a trend in this research area. A total of 704 articles related to the topic were identified, of which 45 met the criteria in the SLR. By splitting these results according to time span, it was possible to see a variation in the number of articles found in each period, making it possible to note that, even though, the distribution of publications increased by year it was still not uniform. Within the main technological resources identified in the articles, some of them include: Multimedia, Websites, Software, Computers and Mobile Phones.

Este trabalho descreve uma revisão sistemática da literatura (RSL) realizada para explorar e descrever o uso de tecnologias digitais no ensino de química, com foco na revista Chemistry Education Research and Practice (CERP). O estudo segue um processo metodológico estruturado em cinco etapas. Os resultados apontam para um aumento na produção digital no ensino de química, mostrando uma tendência nesta área de pesquisa. Um total de 704 artigos relacionados ao tema foram identificados, dos quais 45 atenderam aos critérios na RSL. Ao dividir esses resultados de acordo com o período de tempo, foi possível observar uma variação no número de artigos encontrados em cada período, possibilitando notar que, embora a distribuição das publicações tenha aumentado ano a ano, ainda não era uniforme. Entre os principais recursos tecnológicos identificados nos artigos, alguns incluem: Multimídia, Websites, Software, Computadores e Telefones Móveis.

I. INTRODUCTION

The use of technology in teaching environments (universities and schools) is growing and it is necessary to debate how technology is incorporated into teaching and learning processes. With the advances that emerge in the 21st century, the teaching and learning process has been through different (and significant) changes, regarding the digital didactic resources that are presented and that are part of the context of the students (Haleem et al., 2022; Lopes & Leite, 2023). Education and universities/schools have always tried to keep up with technological developments (Carvalho & Araújo, 2016). However, these environments sometimes need more time to adapt to technologies. Technologies have redefined the concepts of time and space, since they erase distances and enable the communication between peoples and cultures. In addition, we need to know how technologies are being used to explore ways to improve students' understanding of scientific concepts, to promote active engagement in the classroom and to analyze whether they are enabling a more effective and engaging learning.

It is notable that the inclusion of technologies in the educational sphere brings new cognitive activities into practice, as they are highly interactive and practical in the classroom. These technologies also result in the efficiency of educational processes (less time and effort) and also enable relationships with cultural knowledge (Ek et al., 2014). In addition, Digital Information and Communication Technologies (DICT) challenge educational institutions to move away from the traditional pedagogical method, where the student is considered a receiver and the teacher the center of the process, towards more participatory and integrated teaching among students, making them active agents. The rapprochement between teacher, student and technology should preferably take place during teaching practices, contributing to the construction of knowledge. Thus, acknowledging the real capacity of technologies that contribute to the teaching and learning process is a crucial step.

The educational and pedagogical paradigm has been changing. The roles and the models are now very different from what they used to be. According to Prensky (2007, p. 40), "the twenty-first century will be characterized by enormous, exponential technological change". As for Leite (2018), the adoption of DICT in the teaching and learning process has sometimes been contradictory among teachers. There are teachers who recognize the value of technologies in the process of building knowledge and face the challenges of incorporating them into their teaching practices. Technologies is a tool that is present in the universities/schools environment and has to be pedagogically dealt with. As a consequence of all these, the roles of teacher/students have changed.

In the current scenario, the use of digital technologies is a central component of most forms of contemporary educational provision and practice. Digital technologies enable the construction of knowledge, facilitate interaction and stimulate students towards meaningful learning. There are strategies for teaching with technology that can make both students and teachers comfortable, while allowing the students to go as far as they can with the technologies that characterize their age and that they love to use, and that prepare them for their twenty-first century future as well (Prensky, 2007).

Digital technologies in education have been incorporated in different ways. Digital technologies are powerful tools to support learning. Report of the Campus Technology in 2017, conducted with 232 teachers from various colleges in the United States of America, highlights the use of technology in teaching by these teachers (Kelly, 2017). The report presents an overview of the use of technologies in education, being considered by 80% of respondents as positive (Kelly, 2017). According to Bellou et al., (2018), the essential contribution of digital technologies to the learning process comes, indirectly, through their pedagogical exploitation. Furthermore, we have seen the appearance of scores of new technologies that have strong potential uses in education. Research shows that "Digital technologies have been used in education since the 1950s, at all educational levels, from primary to higher and adult education and in all disciplines, from science to humanities and social sciences, in various ways" (Bellou et al., 2018). For example, through the use of email, search, texting and instant messaging, blogs, wikis, the Wikipedia, podcasting, software, polling devices, complex computer and video games, networking, augmented reality, social media, digital cameras, smartphones, interactive whiteboards, wireless technologies, Active Technological Learning and many others (Kelly, 2017; Leite, 2018; Prensky, 2007). In this same context, the Horizon Report (Becker et al., 2017) indicated that the main technological trends in education for the next few years will Mobile Learning, Social Networks; Online Learning, BYOD, Hybrid and Collaborative; Flipped Classroom, Gamification, Virtual Reality.

Finally, digital technologies in education are playing an increasingly important role in transforming education around the world. They refer to the use of electronic devices, software, applications and online resources to facilitate and enhance the teaching and learning process. Digital technologies have the potential to improve accessibility, collaboration, personalization and the effectiveness of teaching, providing new opportunities for students and educators. Besides, digital technologies in education promote collaboration between students, as seen in online learning platforms and communication tools that allow students to work together on projects, discuss ideas and share resources. This collaboration can take place both inside the classroom and in virtual contexts, providing students with the opportunity to develop teamwork and critical thinking skills

In order to make available to researchers, teachers and students investigating digital technologies in chemistry teaching (DTChT), this review aims to investigate how digital technologies are used in chemistry teaching based on research published in Chemistry Education Research and Practice (CERP). Over the decades, CERP has contributed to various discussions involving the teaching of chemistry and among the topics covered in the journal's research are digital technologies. Therefore, in order to find out which digital technologies are being used in chemistry teaching, this article carries out a systematic literature review of the research published in CERP, considering its first volume published in 2000 until the publications in 2022.

The Chemistry Education Research and Practice (CERP) is one of the oldest and most prestigious in the context of Brazilian Chemistry Education, recognized with a Qualis A classification. Founded in 2000, the CERP not only represents a historical reference but also enjoys international recognition, reflecting trends and advances in educational research in Chemistry. It is crucial to highlight that, during the literature review, no studies exclusively dedicated to the analysis of CERP were found, emphasizing the importance of this survey in filling this gap.

Digital Technologies in Chemistry teaching

Chemistry teaching plays a crucial role in scientific education and in understanding the world around us. However, this subject has traditionally been associated with learning difficulties, due to its conceptual complexity and the abstraction of many of its principles (Bastos & Leite, 2017; Cardellini, 2012; Silva & Lyra, 2020; Kausar et al., 2022). To overcome these challenges and promote more effective chemistry teaching, digital technologies are emerging as valuable allies. On the other hand, research into the use of digital technologies in chemistry teaching has grown considerably and seeks to discuss how technologies can contribute to the process of teaching and learning chemistry.

It is interesting highlights that "until the early 1990s, computer technology was used in Chemistry Education mainly to support teachers in delivering recurring educational activities and as a means of transferring 'traditional' teaching and learning activities onto the computer" (Bellou et al., 2018). As early as the early 1990s, although a behaviorist approach was still evident and digital learning technologies were primarily used to provide tutorials and "drill and practice" environments (Bellou et al., 2018; Haderlie, 1994; Pribush, 2015), new approaches would later emerge, such as "computer-assisted instruction", "virtual experiences", or "modeling-based learning" (Tsaparlis, 1991). In the second half of the 2000s, research show that most researchers are interested in chemistry topics related to the particulate nature of matter and use digital learning technologies, to mainly create and present visualizations of simulations and models of structural elements of matter and their phenomena (Bellou et al., 2018; Pribush, 2015). In this sense, for the Chemistry education Sadykov and Čtrnáctová (2019), highlight the existence of different interactive chemistry programs in the world.

In chemistry teaching, technologies play a transformative role, providing new learning approaches, greater interactivity, accessibility to information and facilitating the understanding of abstract concepts. They have become resources for thinking, learning, knowing, representing and transmitting the knowledge acquired to students and other people. By integrating technologies into chemistry teaching, it is possible to boost student motivation and improve their academic results, since they can promote improvements in the teaching and learning processes.

Regarding chemistry education, the contribution of today's technology is well recognized and documented, according to Seery and McDonnell (2013), "Technology is accepted to be an integral part of chemistry education, with the use of videos, simulations, and student response systems well reported". A lot of studies describe "technology-based teaching led by some teachers and evaluate its impact or the professional development of teachers in terms of their knowledge, skills and beliefs" (Rap et al., 2020, p. 3278). Besides, different advantages of using technology in chemistry education has been supported by the research (Blonder et al., 2013; Rap et al., 2020; Seery & McDonnell, 2013; Tuvi-Arad & Blonder, 2019) and applied in universities and schools.

Digital technologies include a variety of tools, such as interactive simulations, educational software, mobile applications and online resources, which offer opportunities to approach chemistry concepts in a visual and practical way. Commonly, the use of technologies is associated with representing chemical phenomena in a visual and dynamic way, making abstract concepts more tangible and understandable for students (Maksimenko et al., 2021; Pribush, 2015; Rap et al., 2020). One of the Digital Technologies opportunities in teaching and learning chemistry is "to help students to visualize the spatial three-dimensional elemental and molecular structures, and allows collaborative interactions between teachers and students, and among students themselves, synchronously and asynchronously" (Awad, 2014, p. 35). Moreover, digital technologies allow a personalization of teaching, adapting content to each student's needs and offering immediate feedback. According to Seek and McDonnell (2013), "technology is accepted to be an integral part of chemistry education, with the use of videos, simulations, and student response systems well reported".

II. METHODOLOGY

This research is exploratory and descriptive in nature, exploring the research topic (which digital technologies are being used in chemistry teaching in the CERP magazine) and describing how these technologies are being used, based on a systematic search relied on predetermined criteria. To do this, a systematic literature review (SLR) was carried out, which consists of a specific data collection method that includes well-defined stages and seeks to minimize the researcher's influence on the searches.

SLR is a type of scientific research that aims to gather, critically evaluate and synthesize the results of multiple primary studies (Cook et al., 1997), and is characterized by being objective, systematic, transparent and replicable. Furthermore, in SLR, reproducibility can be guaranteed and used as a way of validating the method used, since it has parameters that are previously defined and has a research question to be answered (Juntunen & Lehenkari, 2021).

As there are no restrictions on the stages of a systematic literature review, the sequence of stages followed in this article is based on suggestions found in the literature (Donato & Donato, 2019; Kitchenham, 2004; Leite, 2021), and is carried out in five stages: Stage I - Definition of the guiding question; Stage II - Definition of the parameters; Stage III - Selection of the work papers; Stage IV - Analysis of the work papers; Stage V - Writing up and publication of the results obtained (Figure 1).

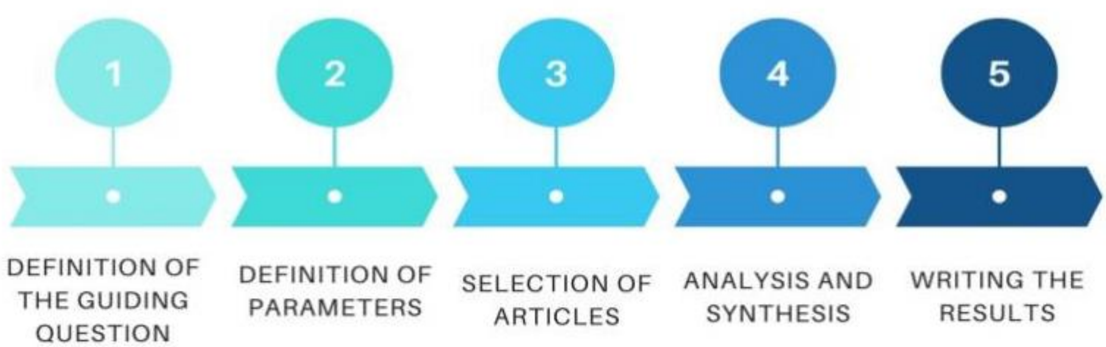

FIGURE 1. Sequence of the five parameters established for the Systematic Literary Review.

Step 1

With regard to the first stage (definition of the question), the research needs to be well defined in terms of its objective (Ardoin & Bowers, 2020; Donato &Donato, 2019; Kitchenham, 2004), with its stages justified. In this article, the research question was: "What digital technologies are used in chemistry teaching in the journal Chemistry Education Research and Practice?". Based on this question, we investigated, besides the digital teaching resources (DTS) present, which chemistry content was being addressed using digital technologies, the target audience of the articles, the research objectives and, finally, their main results.

Step 2

The second stage of the review (defining the parameters) consists of choosing the database, inclusion and exclusion criteria, keywords, Boolean operators and period of analysis. In this article, the CERP journal database was chosen, with the inclusion criteria being articles published in the journal involving digital technologies in chemistry teaching. The following exclusion criteria were then defined: repeated documents and articles that deal with technologies but do not involve discussions about chemistry teaching. The definition of keywords was based on terms related to the topic, and the following words were added to the journal's search filter: technologies; technologies in chemistry teaching; digital resources; educational tools; apps; TPACK; technological tools. We also tried to cross-reference these keywords with the terms teaching, Education, and Chemistry. Besides, we used the Boolean operator "AND" to find reports that addressed both words (Technologies and Chemistry). As for the period, we investigated all CERP publications from the time available time in the journal's database (since 2000).

Step3

The third stage (selection of the work papers) involved a survey of articles related to the research topic. At this stage, from the database of the journal Chemistry Education Research and Practice, potentially eligible papers were selected within the predefined criteria. As explained by Donato and Donato (2019), only a small proportion of these references will be included in the review. Initially, during the selection, 704 articles were found in the search. Additionally, for the selection of works, searches were carried out considering the seven date ranges (1st range - articles published between 20-30 years; 2nd range - articles published between 10-20 years; 3rd range - articles published between 5-10 years; 4th range - articles published between 2-5 years; 5th range - articles published between 1-2 years; 6th range - articles published between 6 months-1 year; 7th range - articles published between 0-6 months) available by the journal's search engine. To avoid overlapping data, articles that were identified in more than one time span will only be analyzed in one time span, for example, if the article was published in 2013 and was observed in the 5-10 year time span and in the 10-20 year time span, it will only be computed once.

Step4

The fourth stage (analysis and synthesis of studies) consisted of reading the 704 articles selected on the basis of the inclusion and exclusion criteria and which involved digital technologies in chemistry teaching. In this stage, the titles and abstracts were first read. This was the first step in identifying whether the reports converged with the research theme, enabling to check whether the articles met some of the criteria established. At this point, it was necessary to assess from the title and abstract whether the text was valid for a more in-depth analysis. If this wasn't possible, the article was read floatingly - i.e. a quick reading of the main topics - and if floating reading wasn't enough, a complete reading was carried out, followed by a record of the main information in the text. The studies were then synthesized by combining the data extracted from the articles using a quantitative and qualitative approach. According to Creswell (2009), the quantitative approach is justified as a survey providing a quantitative description of trends. The qualitative approach, on the other hand, involves descriptions, understanding and analysis of information, i.e., it is not expressed in numbers, but is also interpretative, which according to Creswell (2009, p. 164) "researchers make an interpretation of what they see". Additionally, the data analyzed must be summarized in order to draw valid and logical conclusions (Donato & Donato, 2019). In this article, considering that the keywords selected are broad in meaning, i.e., the research goes beyond the necessary to answer the question, the number of findings (45) was assessed as feasible by the authors and in the analysis and synthesis of the data, excerpts were extracted from some articles that answered the research questions of this systematic review.

Step5

In the final stage (writing up and publishing the results), the aim was to describe the data obtained in as much detail as possible, so that other researchers could independently reproduce the entire research procedure. That way, "other researchers wishing to replicate the results of the review should be able to follow the same steps described and arrive at the same results" (Okoli, 2015, p. 902). In addition, the writing must be clear and precise at this stage and all the processes must be detailed (Donato & Donato, 2019). Finally, the results will be published, describing the details of the articles selected based on the established criteria.

III. RESULTS AND DISCUSSIONS

In this section, the results of the systematic literature review will be presented. Considering the inclusion and exclusion criteria used, we found a total of 704 articles in the journal Chemistry Education Research and Practice from 2000 to 2022 in response to the keywords used.

With regard to publications on the subject of this research (digital technologies in chemistry teaching), we found that of the 704 articles found in CERP on the subject (technologies in chemistry teaching), 45 papers met the pre-established criteria. Considering the analysis of the seven time span available in the journal's search engine, the first time span (20-30 years) includes articles published from 2000 to 2003.

Thus, from the 704 articles found in CERP, in the first analysis (range 20-30 years) 54 articles were identified in response to the keywords used, but only 6 were related to the research topic. In the second range analyzed (publications in the last 10-20 years), 146 articles published between 2004-2012 were found, but only 12 articles were directly related to the research topic. In the third time span (5-10 years), 244 articles were published between 2013 and 2017, but only 13 dealt with technologies in chemistry teaching. Of the articles published between 2018 and 2020 (range 2-5 years), only 12 of the 156 articles involved the subject of our research. In the fifth range analyzed (1-2 years), of the 35 articles published in 2021 and 2022, only one involved technologies in chemistry teaching. In the sixth time span (6 months-1 year), i.e., articles published in 2022, 37 articles were found in response to the search, but only one was related to the topic. Eventually, the seventh time span, referring to the last 6 months (until December 2022), found 32 articles with the keywords used, but none of them corresponded to the research topic. Chart 1 summarizes these results. It's worth noting that we didn't overlap the time spans; in cases where the article was identified in more than one time span, we only counted it once. By means of illustration, if an article published in 2021 was observed in the 2-5 year time span (2018-2021) and in the 1-2 year time span (referring to the years 2021-2022), this article was not considered a duplicate in the sum of the publications identified in the theme, thus avoiding duplicate/repeated data.

CHART I. Overview of how articles were grouped by year based on results obtained through the CERP search engine.

Date ranges	Total Articles	Articles about DT
20-30 years	54	6
10-20 years	146	12
5-10 years	244	13
2-5 years	156	12
1-2 years	35	1
6 Months-1 year	37	1
0-6 Months	32	0
TOTAL	**704**	**45**

As to the analysis of the 45 articles that met the research criteria involving the use of digital technologies in chemistry teaching, we observed that the type of technology most used in the articles was software (mainly involving simulations), representing 42.23% (19 articles), followed by works using websites (15.55%). Two papers involved more than one type of technology (multimedia and software, and website and software). In total, CERP articles found six different types of digital technology being used in chemistry teaching. The types identified were: Multimedia, Websites, Software, Computers and Mobile Phones. Graph 1 shows the types of technology used in the 45 articles analyzed.

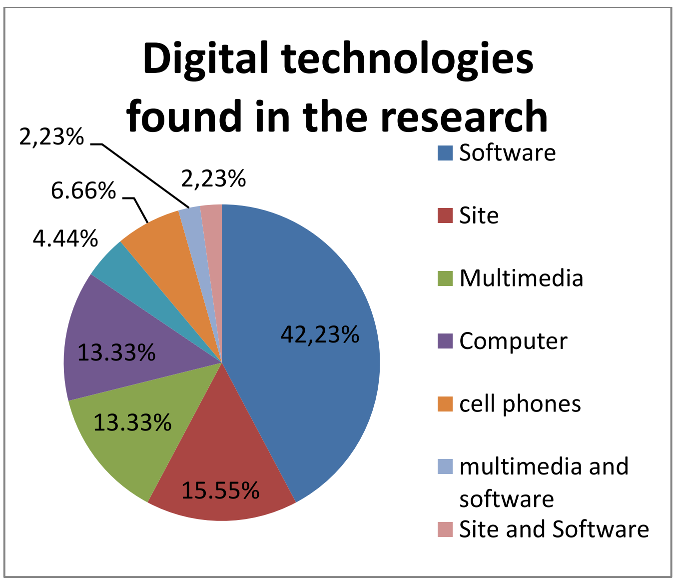

FIGURE 2. Types of digital technologies in chemistry teaching discussed in the journal's publications.

The results identified in the research are close to those found in the systematic literature review carried out by Bellou et al. (2018) involving Digital Learning Technologies in Chemistry Education. The authors found nine types of technological approaches in 48 articles reviewed, with the use of Multimedia, Simulations, Modeling, Virtual Lab, Microcomputer-Based Laboratory, Electronic tests, and tablets (Bellou et al., 2018). The findings and the conclusions of Bellou et al. (2018) suggest that Multimedia and simulations are the predominant technological approach.

Regarding the chemistry content that was covered using digital technologies in the 45 articles, we found that 6 articles (13.33%) did not explicitly state which chemistry content was being discussed in the article. On the other hand, 39 articles (86.66%) identified the chemistry content that was being addressed in the research involving digital technologies. These studies revealed a variety of contents being explored (ozone, Molecular Geometry, Biochemistry, the Periodic Table, Spectroscopy, the Physical Properties of Water, Electrochemistry, Organic Chemistry, Environmental Chemistry, pH, Viscosity, Acids and Bases, Food Chemistry, Coordination Chemistry and Organometallics, Atomic Models), in which Experimental Chemistry and Chemical Bonds were the most repeated contents in the papers, with 6 and 5 publications respectively. Besides, 5 articles (11.11%) did not directly discuss specific chemistry content, but cross-cutting themes, such as chemical education and new technologies, video editing, biotechnology, nanotechnology and sports chemistry. Much of this content was also observed by Bellou et al. (2018) who reported that the chemistry topic most present in the articles reviewed was about Structure of matter, molecules and atoms.

As for the target audience concerned, we found that most of the research was aimed at higher education, aimed at undergraduate students (27 articles, corresponding to 60%). Of these articles, we identified research involving teacher training on digital platforms and experimentation with Digital Teaching Resources in chemistry teaching aimed at higher education. Papers that involved teachers and students as the target audience for the research, but did not identify the level of education involved, were found in 8 articles (17.8%) from CERP. On the other hand, 6 articles (13.3%) targeted secondary school students when the topic involved digital technologies and the teaching of chemistry, and only two papers involved only secondary school teachers. Finally, elementary school students were the target audience for 2 articles.

Regarding the objectives of the research involving digital technologies and chemistry teaching, different focuses were observed in the publications in the CERP journal. The studies with the most recurrent objectives sought to incorporate educational technologies, such as virtual simulations, virtual laboratories, interactive applications and multimedia resources, in order to provide students with a more engaging and interactive learning experience. The papers pointed out that these technological approaches could facilitate the understanding of chemical concepts, making them more accessible and stimulating for students. During the research, 6 types of technology were identified as being commonly used in the articles analyzed: Multimedia, Website, Software, Computer, Digital Exercises, and Mobile Phones (Graph 1).

Articles in CERP involving the use of websites/virtual platforms were observed in seven papers and, in general, had the following objectives: Using websites as online resources to enrich chemistry teaching by providing access to interactive and up-to-date educational materials (Potter & Overton, 2006). Using specialized websites that allow better molecular visualization enables students to explore three-dimensional chemical structures in a clearer and more detailed way, contributing to their learning (Tuvi-arad & Gorsky, 2007). Maksimenko et al. (2021) state that recent technologies offer a wider range of visualization opportunities in chemistry. In addition, the work involving websites/platforms identified in the research also sought to use websites in a hybrid course context, combining face-to-face teaching with online resources in order to provide a more flexible learning experience that is adaptable to students' individual needs (Antonoglou et al., 2011).

When the type of technology used involved Software, we observed 18 works in CERP publications, among the objectives, the most common were about: Incorporating software as a tool in chemistry teaching (Akaygun & Jones, 2013), Using software to direct students' attention (Herrington et al., 2022) or Using software to overcome students' learning difficulties (Zohar & Levy, 2019) or Using software as support to teach chemistry subjects (Ollino et al. 2018), as well as Encouraging students' independent exploration through educational software (Herrington et al., 2022), as well as exploring the potential of software as a tool to improve the learning process (Penn & Ramnarain, 2019). As highlighted in Graph 1, the use of software in chemistry teaching is the most commonly applied in the studies investigated, whether with the aim of improving student performance or through strategies. According to Rodrigues et al. (2001), the use of software in education, especially in chemistry teaching, has been a key factor in making teaching more comprehensible to students, as simulation can help understanding an abstract concept in a more concrete way so that students can visualize the whole process at all three levels of representation.

Multimedia technology was present in six CERP articles involving digital technologies in chemistry teaching. The objectives included using multimedia as a tool to improve chemistry teaching, incorporating visual, sound and interactive elements to make lessons more engaging and effective (Turkoguz, 2012), exploring the use of sound multimedia for students with low vision, offering an inclusive and accessible approach to chemistry teaching (Supalo et al. 2016), and in recording video lessons using multimedia resources, providing students with flexible access to the content and allowing them to review chemical concepts in an interactive way (Dorfman et al. 2019), besides the use of multimedia in certain chemistry content. According to Mayer (1997), multimedia learning theory consists of three aspects that help students learn more effectively. The first is that there are two channels, audio and visual, for processing information; this is also known as the multimedia principle.

Computer use was identified in six CERP articles. The research objectives ranged from: Investigating the use of computers as a resource to enhance students' learning, exploring different applications, software and online resources that can aid in the understanding of chemical concepts (Tortosa, 2012); Analyzing the impact of computer-assisted education on students' environmental knowledge, seeking to understand how this approach can contribute to awareness and actions in relation to the environment (Morgil et al. 2004); Using the computer as a tool for student assessment, exploiting digital resources for data collection, analysis and interpretation in order to improve assessment processes in chemistry teaching (Krause et al. 2013); Evaluating the effectiveness of PowerPoint as a presentation tool for teaching chemistry, investigating its influence on student comprehension, retention and engagement during lessons (Guspatini, 2021). The computer in chemistry teaching can be considered one of the first technologies to be used in the process of building knowledge. In 1993, Brooks (1993) already highlighted the potential of computers in chemistry teaching by providing images, simulating experiments and helping to solve problems.

The creation of digital exercises was present in only two CERP articles. The aims of the papers were: Stimulating active learning in food chemistry by promoting students' active participation in acquiring knowledge in food chemistry through interactive digital exercises (Hartog et al. 2003) and exploring practical possibilities for digital learning objects by presenting a comprehensive view of the opportunities for creating digital learning objects for food chemistry, following three established practical guidelines, defining learning objectives, ensuring that the content is relevant and that the object created presents multimodality (Diederen et al., 2005).

As for use of cell phone technologies in chemistry teaching, it was observed in 3 studies. The objectives of these studies involved: Using cell phones as an effective tool for learning chemistry (Erdmann & March, 2014); Evaluating applications aimed at teaching the subject (Petterson et al., 2020); Enhancing learning about acids and bases through the use of a specific app (Ping et al., 2018). It is important to highlight that these technologies (cell phones) are increasingly cloud-based. This means that users will have access to applications, services, or resources through the Internet, and therefore it is no longer necessary to have a device with a specific software installed, you can access them from any device with Internet access, anywhere in the world (Carvalho & Araújo, 2016).

Articles that contained more than one applied technology (multimedia and software; websites and software) were observed in two articles, one of which aimed to: Offer postgraduate training in science and education for future high school chemistry teachers in Greece (Tzougraki et al., 2000) and the other with the aim of using hybrid teaching to teach the topics of coordination chemistry and organometallics (Antonoglou et al., 2011).

With regard to the main results of the articles investigated, we now present a description of the first and last article published for each of the 6 types of technology observed in the research (Multimedia, Website, Software, Computer, and Digital Exercises). The purpose of this option was to highlight the first publication in the magazine on each type of technology identified in this research and the most recent publication. In addition, due to the magazine's page limit, it would not be possible to describe all of the 45 articles identified.

The first article published on "Virtual Sites/Platforms" was published in 2000 in CERP, and its main findings dealt with the use of a website evaluation resource as a useful tool for selecting online chemistry materials, although it requires experience in its use and critical evaluation of the sites (Yates, 2000). The author points out that developing one's own material is a relevant but time-consuming option, without worrying about quality, as long as care is taken in selecting suitable students. The last work published on CERP involving "Site" was published in 2006 and had the following main result: After three weeks of handing in the tasks, the students answered a post-course questionnaire, revealing positive feedback. Despite technical challenges arising from system differences and internet access, the students showed confidence in the tasks, interest in the subject and retention of the content. The website-based learning method proved effective compared to traditional paper-based approaches, reflected in higher grades in the continuously assessed module, which included 'Chemistry in Sport'. The use of techniques such as mind mapping and problem-based learning enriched independent learning. Although some students mentioned difficulties accessing the internet, the results encourage the application of this approach in future courses, potentially addressing a variety of contexts (Potter & Overton, 2006).

Regarding the "Digital Exercises", two papers have been published by CERP. In the first paper, 108 digital exercises were created and improved based on design guidelines and requirements. According to the authors, the "guidelines were useful for aligning the exercises with the requirements, resulting in practical experience in the design of activation exercises" (Diederen et al., 2003, p. 370). In the research, formative evaluations were carried out in order to guarantee the usability of the exercises, eliminating errors in design, content and didactics. The research highlights the importance of guidelines for connecting theories of learning and instruction to the practical challenge of designing digital learning materials (Diederen et al., 2003, p. 370). The second and final paper published in CERP, involving digital exercises, explored the practical possibilities of digital learning objects for food chemistry, offering a comprehensive overview of the opportunities available. By following practical guidelines established in the research, the authors point out that "it is possible to create effective digital resources that promote learning in this specific area" (Gruppen, p. 368), since digital learning objects can enrich the students' experience by providing interactive, visually appealing and easy-to-understand information, thus enhancing the learning process in food chemistry. Along the same lines, Maksimenko et al. (2021) point out that experiences involving visualization can be seen as a useful tool for enhancing students’ understanding of chemical concepts, and it is essential for a better perception of abstract notions that cannot be otherwise visualized in full detail.

Regarding computers, this technology made its first appearance at CERP in 2004 when it investigated computer-assisted education. The research carried out an intensive course using the internet which, according to Arda (2004, p. 107), resulted in a "significant increase in students' environmental awareness (20%) and in their knowledge of environmental issues (10-12%)". The work reveals that there has been an improvement in awareness of environmental pollution and computer-assisted teaching has contributed to increasing students' knowledge (Arda, 2004). For the authors, these findings indicated the relationship between environmental knowledge and attitudes, highlighting the effectiveness of using digital technology in education to promote students' environmental awareness and knowledge (Arda, 2004). As for the last work involving this type of technology (Computer), published in 2017, which analyzed computer models and types of formative assessments in the teaching and learning of Chemistry regards students' understanding of the nature of computer models. This study investigated the use of computer models and formative assessments in chemistry teaching, focusing on students' understanding of the nature of models (Park et al., 2017). According to Park et al. (2017), frequent exposure to computer models during experimental lessons resulted in a better understanding of the nature of models, as this highlights the importance of involving students in the use of these models to enhance their conceptual understanding. For (Park et al., 2017, p. 107), "a better understanding of scientific models is expected to facilitate students' understanding of scientific concepts".

“Multimedia” technology was first highlighted in CERP in an article published in 2007 in which the DVD was presented as an effective tool for teaching Physical Chemistry, providing positive gains in the learning of the students involved in this research (Jennings et al., 2007). According to the research, the DVD enabled the addressing of concepts and applications that are not commonly included in the traditional curriculum (Jennings et al., 2007), in which " Students showed positive learning gains for the information contained in the DVD module" (Jennings et al., 2007, p. 322). The authors conclude that, although long-term studies are needed to assess retention of information, the DVD showed promise as a curriculum supplement, allowing for the inclusion of additional topics and experiences" (Jennings et al., 2007). The latest work involving "multimedia" technology was published in 2019. Among the main findings of the research, it stands out that the "study tested whether the addition of a video review to the self-assessment intervention could improve the identification of deficits and strengths in practical chemistry skills" (Lau, 2019, p. 8). The results showed that participants who watched the video performed better in critiquing lab demonstrations and were more critical of performance standards. However, overall performance on the self-assessment did not differ significantly between the groups (Lau, 2019). The authors conclude that "video revision can be a useful tool for structuring self-assessment, but its integration with the learning process must be more careful to guide students more effectively" (Lau, 2019, p. 10).

Regarding software technology, the first article published in CERP was in 2001, in which the study highlighted that in-service training on chemical models had a positive impact on teacher perception and student learning (Barnea & Dory, 2000). The main finding of the research was that students in the experimental group, whose teachers received the training, scored better on the model perception questionnaire compared to the control group, indicating that the training was effective in improving high school students' understanding of chemical models (Barnea & Dory, 2000). The last CERP paper involving software was published in 2021 (Herrington et al. 2022). The research revealed that the use of simulators in higher education chemistry, especially in the topic of chemical equilibrium, brought significant benefits to student learning. Thus, simulators allow students to visualize and explore different equilibrium scenarios, promoting a deeper conceptual understanding (Herrington et al., 2022). In addition, the simulators offered the opportunity for students to carry out virtual experiments and develop critical thinking skills. However, according to Herrington et al. (2022), it is important to complement the use of simulators with practical activities and classroom discussions for a complete understanding of the subject, since simulators do not replace real laboratory experience, but can be a valuable tool for reinforcing theoretical concepts and broadening the exploration of chemical equilibrium. In this context, Silva Júnior et al. (2014) say that software is a resource that helps educators in teaching and contributes to improving the teaching and learning process. According to Lehtola and Karttunen (2022), software for computational chemistry is of great relevance to education (calculations, images, molecular interactions).

When it comes to "cell phone" technology, the first work published in CERP was in 2014 in which videos were created on cell phones by students and integrated into the general chemistry laboratory curriculum as an alternative form of assessment. The results showed that the students were able to create and edit the videos with ease on the mobile device. In addition, according to Erdmann and Mark (2014), the videos were effective in improving students' ability to correctly report laboratory techniques, especially with regard to the proper use of significant figures. These findings indicate that the inclusion of video laboratory reports can be a valuable strategy to improve learning and retention of practical laboratory skills. For Lok and Hamzah (2021), the use of mobile devices, such as smartphones and tablets, has currently been used as an emerging teaching and learning tool to transform traditional chemistry teaching and learning methods into a more sustainable 21st century teaching and learning approach.

The last article involving "mobile" technology was published in 2020 and discussed the use of apps involving acids and bases in the subject of Chemistry, in higher education, through an interactive and engaging approach for students (Petterson et al., 2020). According to Petterson et al. (2020), these apps promoted in-depth understanding of acid-base concepts through simulations, virtual experiments and interactive exercises. In addition, apps provide flexibility, autonomy and better student engagement, which according to the authors results in more effective learning, preparing them for the challenges of chemistry. It should be noted that one of the characteristics of mobile devices, in which the cell phone is included, is the possibility of using multiple digital resources, such as apps, videos, audio, etc.

Finally, two articles dealt with the combined use of digital resources (multimedia/software and site/software). In the first case, according to Tzougraki et al. (2000), the research examined a master's program that covers chemistry, education and educational technologies. Students take courses in these fields and run research projects, even involving the development of educational software. The library offers resources such as books and software, while experts lead the courses. The infrastructure includes equipped rooms, and a specific website can be used to provide detailed information about the program and the software projects created by the students. As for the website and software, the case study conducted shows that adopting a hybrid instructional model for undergraduate chemistry courses, such as Molecular Symmetry and Group Theory, is beneficial for students (Antonoglou et al. 2011). According to Antonoglou et al. (2011), the hybrid model improves student engagement throughout the semester by offering online study flexibility outside of class. Besides that, the integration of websites and molecular visualization software helps students to better understand the concepts and become more engaged with the content.

IV. CONCLUSIONS

The systematic literature review presented in this research revealed a careful and comprehensive analysis of the use of digital technologies in chemistry teaching based on the articles published in the journal Chemistry Education Research and Practice from 2000 to 2022, allowing us to observe the evolution and scope of research in this field over the last two decades

The results point to the growing relevance of digital technologies in chemistry teaching, with a total of 704 articles on the subject found in the journal. Of these, 45 papers met the established criteria (papers involving chemistry teaching), demonstrating the specificity of the research and the delimitation of the approach. When splitting these results according to time spans, there is a noticeable variation in the number of articles found in each period. However, the distribution of papers is not uniform over the years.

By means of illustration, Bellou et al. (2018) carried out a systematic review in the period 2002-2016 (15 years) in different databases and journals, including CERP articles, and found 43 articles that met the research criteria (use of digital technologies in primary and secondary Chemistry Education). In our study, the impact of CERP on research involving digital technologies in chemistry teaching is noticeable, since CERP alone published 45 papers that met the established criteria in the period 2000-2022 (23 years).

It is interesting to note the diversity of technologies explored in the articles, with software and simulations being the most used tools. This suggests a search for interactive and practical methods for teaching chemistry, potentially enriching the students' learning experience. In addition, the identification of chemistry content addressed with the help of digital technologies highlights the versatility of these approaches, which apply to a wide range of topics, from experimental chemistry to cross-cutting issues such as chemical education and new technologies. Our review also highlights some important findings from the teachers' perspective. In general, teachers hold a positive attitude towards the pedagogical use of digital technologies. Although, chemical education is constantly undergoing changes with advances in digital technology, even after two decades of works on different aspects of the use of technologies in chemistry education, it seems that we are still at an early stage and this is due to the rapid evolution of tools and resources available.

The study also highlights the importance of understanding not only the use of technologies per se, but also their specific application to chemical content. This enables a more contextualized and targeted analysis, contributing to an understanding of the possible influences of technologies on the process of teaching and learning chemistry.

In this review, what we have observed is that the research carried out at CERP presents numerous opportunities for teachers to teach chemical concepts using digital technologies and that students can build knowledge using different digital teaching resources. However, it is important to point out that the growing use of DICTs also presents challenges, such as digital exclusion, cyber security, data privacy (poorly explored in the papers) and the training of teachers who are prepared to use the technologies in their teaching practices.

Although this study achieved its objectives, the exclusion of articles published in scientific conference proceedings, other journals, books and book chapters cannot be considered a limitation, since we looked exclusively at articles published in the CERP journal. It was observed in papers of CERP that digital technologies on Chemistry education has great potential to enhance student and teacher learning.

In summary, the systematic review highlights the growing importance of digital technologies in chemistry teaching, highlighting the evolution of CERP research over time. The approach to the different technologies used, as well as the chemical content covered, enriches the understanding of how these tools can be used effectively to promote chemical education. The scenario described in this research demonstrates a constantly evolving field, full of possibilities for the advancement of chemistry teaching through the integration of technological resources and didactic strategies, such as those described in the articles analyzed.

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