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Digital Technology Approach in Chemistry Education: A Systematic Literature Review

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ABSTRACT
This study systematically reviews empirical studies on digital learning technologies and related instructional techniques for chemistry education from 2020 to 2022. Using the PRISMA criteria, the relevant article's history was followed using the Web of Science, Scopus, and ERIC databases. In this digital era, studies on pedagogical innovations mixed with new technologies are proliferating as a result of technological progress and the emergence of Artificial Intelligence (AI) technology. A growing corpus of empirical research indicates the potential for incorporating digital technology in diverse educational settings. Various new technologies, including robotics, learning analytics, virtual reality (VR), and augmented reality (AR), have found extensive use and have bright futures in the field of chemistry education. According to the current study, VR and digital learning apps were the most completely examined among the recognized technologies employed in chemistry education. The main areas of interest in the classroom were visualization, engagement with chemical structures, and hands-on activities. The findings of this study, which examined impact, advantages, disadvantages, and challenges of online technology in the process of chemistry education, lends insight on the rapidly evolving disciplines of chemistry education research and technologically enhanced instruction.

Keywords: *digital, chemistry, education, technology, virtual.*

INTRODUCTION

There is increasing research on pedagogical innovations that use cutting-edge digital technologies. Digitization advancements have made it possible to support learning processes in a variety of ways. It is also becoming more and more expected that educators and teachers acquire the skills necessary to develop, pick, and implement effective digital multimedia in their future instruction (Langner et al., 2022). Thus, through enhancing their attitude, subjective norm, and self-efficacy, a university course should assist students and teachers in developing their intention and conduct for the future use of digital media in teaching. Understanding how students view and interact with digital tools is essential when using them for teaching and learning (Wong et al., 2021).

The potential advantages of integrating digital technology such as Artificial Intelligence (AI) in educational environments such as K–12 schooling have been supported by an accumulating body of empirical research. Many developing technologies have found widespread uses in the field of chemical education, including robotics, Virtual and Augmented Reality (VR and AR, respectively), and learning analytics (Finkenstaedt-Quinn et al., 2020). Schools now heavily rely on digital media to educate their students as a result of recent world events and educational changes. Without access to real laboratories, science classes in particular stand to lose significant learning possibilities. Teachers play a key role in integrating information and communication technology (ICT) in the classroom. Their abilities and attitudes define the possibilities for improving learning quality through the use of computer technology (De Souza et al., 2021).

In chemistry education, it is crucial to foster spatial abilities. However, if learning is restricted to the memorizing of Newman projections or 3D molecular kits, the process of learning these skills might become tedious. The use of visualizing tools for learning now available requires physical models, which confines learning activities to the classroom (Marzluff et al., 2011). Students can examine actual compounds in a 3D environment using augmented reality (AR), examine compounds from various angles, and regulate compound interactions in real time from any place. Understanding the spatial relationships between molecules is made easier as a result. In order to apply and evaluate an AR application for teaching chemistry to associate degree science students, we devised a methodology. Students could see and rotate the depicted compounds to understand the complexity of a 3D compound structure using figures of small organic molecules and personalized AR cards. (Wong et al. ,2021).

An updated conceptualization is needed for the new educational technique of mobile learning in order to produce successful pedagogical strategies that could improve the teaching-learning process. In chemistry education, it is crucial to foster spatial abilities. However, if learning is restricted to the memorizing of Newman projections or 3D molecular kits, the process of learning these skills might become tedious. The use of visualizing tools for learning now available requires physical models, which confines learning activities to the classroom. Students can examine genuine compounds in a 3D environment, examine compounds from various angles, and manipulate the interaction of compounds in real-time anywhere using augmented reality (AR) in chemistry instruction.

The COVID-19 pandemic altered chemistry education practices all over the world by necessitating the shift to the digital environment and forcing many courses online. The practical, or wet lab, component of the chemistry curriculum benefited the most. It would be foolish to think that computer-based teaching laboratories would have an easy transition. This is untrue, however, as there are a number of unrecognized distinctions between physically giving computer-based training and doing so virtually, such as issues with software, classroom management, and technology. There aren't many "hands-on" computational chemistry training laboratories available online as a result (Kobayashi et al., 2021).

Because of the COVID-19 pandemic, the educational system has undergone adjustments. As e-learning has spread across the globe, it has become more challenging for both students and teachers to adapt to digital technologies and the experiences of the new mode of learning. In addition to COVID-19, many students were embarking on their first foray into the mysterious world of organic chemistry. Undoubtedly a difficult subject, organic chemistry may also be the subject of some students' preconceptions. Furthermore, teaching organic chemistry remotely might be challenging. It is extremely intellectual and abstract in character, and the instructor regularly uses various chemical models to describe molecules in three dimensions. Nevertheless, difficulties offer a chance to use fresh approaches to raise pupils' attention, drive, and comprehension. However, most educators had a matter of days to incorporate their lesson plans from an in-person class to an online platform. In this study, we assessed how these modifications affected first-year undergraduate organic chemistry teaching and learning. With the development of digital technology, there is a chance to provide students with the necessary skill sets to become "Scientists of the Future" who can make use of information at the intersection of multiple fields.

VR and AR have the potential to completely change STEM education. However, the majority of user-friendly tools only support static visualizations, which restricts the amount of comprehensible content. In contrast, more interactive and dynamic alternatives need expensive technology, which prevents widespread adoption and the evaluation of educational benefits. Here, they present https://MoleculARweb.epfl.ch, a free, open-source website with interactive augmented reality (AR) webpage-based apps that function right out of the box in laptops, tablets, and smartphones. Here, students and teachers can naturally manipulate virtual objects to explore molecular structure, reactivity, dynamics, and interactions, covering topics from inorganic, organic, and biological chemistry. Otherwise, in chemical studies, digital sensors allow for the collection of a significant amount of data. We demonstrate how infrared thermography could be harnessed to build digital versions of experiments to assist science teaching on the cloud in a visual and interactive way. These digital versions, or "twins", can be used in conjunction with movies that display the chemical events in question in audiovisual format.

Digitization advancements have made it possible to support learning processes in a variety of ways. Pre-service teachers are now expected to learn how to create, select, and apply acceptable digital multimedia in their future classrooms. Thus, through enhancing their attitude, subjective norm, and self-efficacy, a university course should assist student instructors in developing their intention and conduct for the future use of digital media in teaching. Understanding how students view and interact with digital tools is essential when using them for teaching and learning. Eye-tracking technologies can be used to evaluate perceptual processes in multimedia learning in order to assist student teachers in assessing the perceptions and cognitive processes of their students. This could spark an insightful discussion about multimedia design and have a favorable impact on the behavioral intentions of student teachers for future digital media use in chemistry education. With a group of advanced chemistry instructors, a novel course design was deployed and tested. Participants (a) developed learning materials that adhered to multimedia design principles, (b) conducted a small-scale empirical eye-tracking study to examine how these materials affected learning processes, and (c) produced scientific posters that reflected on the deliberate design of teaching materials.

The fundamental elements of chemistry education include participating in laboratory practical activities, learning laboratory practical skills, and, to some extent, even donning protective gear like safety coats and goggles. Institutions are increasingly investing in expansive chemistry teaching labs, outfitting them with state-of-the-art equipment, chemicals, and digital learning resources in addition to lab furniture. It is now increasingly typical for educators to design and implement thoughtful, research-based ways to teaching and learning in the lab. During the onset of the COVID-19 global pandemic, universities were forced to quickly adapt, mainly through shifting classes online. This sudden and drastic change compelled chemistry educators to reevaluate their pedagogy to adapt to the new paradigm, but also presented an opportunity to examine technological pedagogical content knowledge (TPACK) and its implementation in uncertain times.

Radiochemistry is a branch of chemistry that has high experimental risks, has high research costs, and is subject to certain prejudices. However, it has an extremely important influence on the development of human life. It is particularly important to emphasize the general education of nuclear chemistry and radiochemistry without compromising the quality of the teaching. The introduction of the general education mode into nuclear chemistry and radiochemistry overcomes the shortcomings of narrow audiences. Furthermore, single theoretical courses are limited to a slide- based lecture. Although the audience for general education is wide, it is difficult to carry out related experiments because of safety responsibility and teaching funds. In addition, nuclear chemistry and radiochemistry is a branch of chemistry that has high experimental risks, has high research costs, and is subject to certain prejudices. However, it has an extremely important influence on the development of human life. It is particularly important to emphasize the general education of nuclear chemistry and radiochemistry without compromising the quality of the teaching.

The COVID-19 pandemic forced a move to online means of education. This has had some success in teaching theoretical concepts in conventional manners, but was not sufficient for practical work, which is a major component in Chemistry education. Though virtual experiments can be utilized for such purposes, few instructors are aware of these opportunities. Chemistry education games are helpful tools in chemistry classes, although their design and production are challenging. It is acknowledged that the number of chemical equations is enormous and varied, so it is rather difficult for beginners to memorize equations within a limited time. In a sense, beginners' interest in exploring chemistry is hindered intensively by traditional rote-learning methods.

The aim of this research study is to provide a comprehensive understanding of the use of digital technologies in the context of chemistry education. The study seeks to address three main research questions, which focus on identifying the types of digital technologies used, the most common applications of these technologies, and the effects, advantages, challenges, and problems associated with their use.

METHODOLOGY

The following are the main research questions (RQs) that the current study attempts to answer: (1)RQ1: What kinds of contemporary digital technologies have been created or implemented in chemistry education?; (2)RQ2: According to the analysis of the included papers in this study, what are the most digital technology application focuses in chemistry education?; (3)RQ3: In light of these findings and conclusions found in the current literature review, what are the effects, advantages, challenges, and problems with technology use in chemistry education?

Identification

The systematic review process that we used to select papers for this review consisted of three phases. The first phase was keyword recognition of phrases from existing literature. Once relevant keywords were ascertained, search strings on databases such as Scopus, Web of Science and ERIC (Table 2) were created. 7434 papers were retrieved in this manner.

Table 2: Search string

Scopus	TITLE-ABS-KEY (digital AND technology AND chemistry AND (education OR learning OR teaching OR study))
WOS	digital AND technology AND chemistry AND (education OR learning OR teaching OR study)
ERIC	digital technology in chemistry education

Screening

The second phase was screening. 120 articles were selected by this process. The articles' titles and content were reviewed to ensure all exclusion requirements were met and the articles were relevant to this study. 109 articles passed this review, and irrelevant or duplicate reviews were discarded.

Eligibility

For the third step, known as eligibility, a total of 109 articles have been prepared. All articles' titles and key content were thoroughly reviewed at this stage to ensure that the inclusion requirements were fulfilled and fit into the present study with the current research aims.

Therefore, two reports were omitted because they were not pure science articles based on empirical evidence. Finally, 30 articles are available for review (see Table 2).

Table 3. The selection criterion is searching

Criterion	Inclusion	Exclusion
Language	English	Non-English
Timeline	2020-2022	< 2020
Literature type	Journal (only research articles)	(book chapter, conference proceeding)
Publication Stage	Final	In Press
Subject Area	Chemistry	Non-Social Science, Education, Computing

Data Abstraction and Analysis

The PRISMA flow diagram for the current study selection process is illustrated in Figure 1. The search strategy described were identified 7434 articles through the corresponding searches in the three database systems, and 11 duplicated records were removed. After initial screening, 7314 articles were excluded, and 109 records were retrieved for full-text screening based on the inclusion and exclusion criteria described in Figure 1. Finally, 30 articles were included in this review. Full-text analysis of the 42 included studies was conducted. The results are presented in the major categories of author and publication year, types of technology and outcomes or major findings.

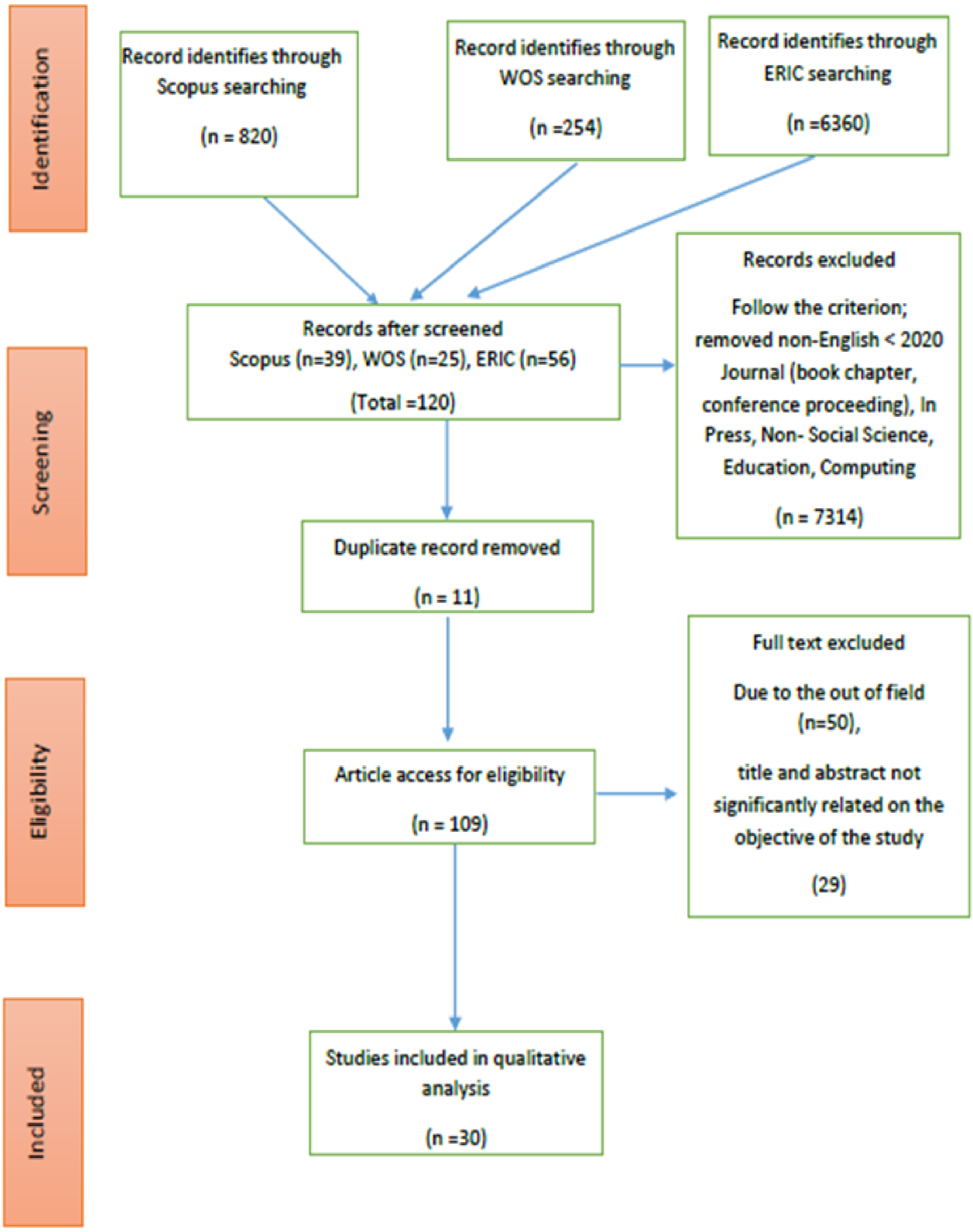

Figure 1. Flow diagram of the proposed searching study (Moher D, Liberati A, Tetzlaff J, 2009)

RESULT AND DISCUSSION

Based on the searching technique, 30 articles were extracted and analyzed. All articles were categorized based on three main themes, which are effect of digital technology (11 articles), Advantage of digital Technology (10 articles), and challenge and problem (9 articles). To answer the three objectives, all the findings were analyzed and synthesized. Table 4 (Appendix 1) shows the summary of the included articles based on name of researcher, year of publication and findings.

The findings were sorted into major categories: AR, VR (including Virtual Lab and visual aids), digital literacy and learning, videos, eye tracking software, smartphones, simulators and chatbots, 3D printed technologies, interactive board games, interactive apps, and other software or web resources. Among 30 included studies, 6 (20%) involved VR of some sort; 4 studies each

(13%) evaluated the adoption of digital learning techniques and software, web and computational usage in chemical education; 3 studies each (10%) involved the use of AR, videos, simulators or chatbots; two studies each (7%) applied smartphone and 3D printing; 1 study each involved eye tracking software, interactive board games and interactive apps. (Figure 2).

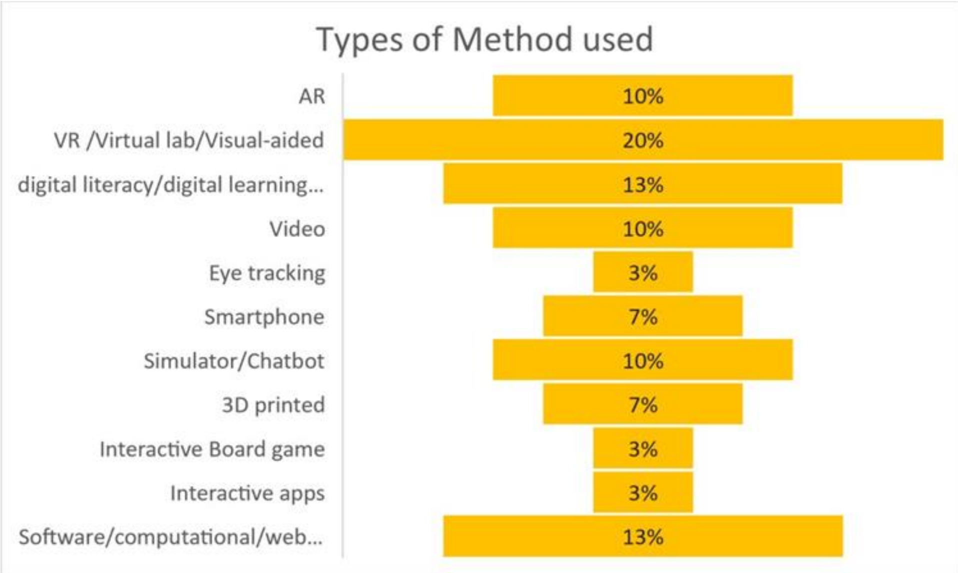

Figure 2: Types of Method used on digital Technology in Chemistry education

Effect of digital technology in Chemistry Education

The findings suggest that AR technology should be widely used as a digital tool to encourage active learning in chemistry courses. Students responded positively to the AR educational software and the AR materials utilized in 87 percent of quantitative questionnaire responses, indicating that using AR technology for chemistry subjects was an effective teaching strategy that boosted their learning (Wong et al., 2021). With the advancement of digital technology, students can be equipped with applicable skill sets as "Future Scientists" who can apply knowledge at the intersection of multiple fields (Crucho, 2020). A considerable portion of laboratory activities such as observation, analysis, and conversation can be offered on a broad scale via digital twins. The technology has the potential to increase involvement in experimental chemistry. It also serves as an example of how the open scientific movement may be aided by technology to increase its impact on chemistry education (Xie, 2021).

Teachers and science communicators can use web apps to create interactive material for their lessons and hands-on activities for their students and target audience, both in person and online, as we demonstrate. Teachers and science communicators can create interactive material for their courses and hands-on activities using these online apps. They can target the general population in person or online, as they have demonstrated. Thousands of visits to molecularweb attest to its ease of use, and teacher feedback attests to its usefulness in pandemic education. From Wet Labs to WebLabs, Chemistry in the Cloud (Rodrique, 2021). The entire course design, evaluation outcomes, and impact on student instructors' attitudes, subjective norms, and self-efficacy expectations regarding using digital media in teaching are all examined. There are also implications for using multimedia learning with eye-tracking in a student teacher course (Langner, 2022), The views of the chemistry instructors are offered as vignettes that demonstrate the process by which these educators modeled digital technology use to aid TPACKs. They also make suggestions for other chemistry educators thinking about their TPACKs (Carpendale, 2020). A seminar on educational technology appears to correlate to an increase in participant TPACK, including TPACK self-efficacy and attitude. Based on this finding, they suggest that the seminar should be allocated in direct link with an internship (Zimmermann, 2021).

Anyone, regardless of whether or not they have a psychiatric mental disorder, can experience sensory issues for a variety of reasons. Sensory issues were once thought to be associated with psychiatric mental disorders like Schizophrenia and Attention Deficit Hyperactivity Disorder. This article explores the literature on sensory overload and how this may affect chemistry laboratory education (Flaherty, 2022)

Advantages of Digital Technology in Chemistry Education

With the advancement of digital technology, students can be equipped with applicable skill sets as "Future Scientists" who can apply knowledge at the intersection of multiple fields. This report uses an open-source programming language to automate a popular laboratory experiment carried out by Chemistry and Chemical Engineering students (Tan, 2020). Due to different factors that influence the transfer from conventional laboratories to virtual laboratories, the adaptability and accessibility of virtual laboratories is important. This research is based on student input from their first virtual laboratory experience and after they have completed an academic year. Finally, the students believe that virtual laboratory experiments should be included in the laboratory curriculum to help them learn more effectively (Abigail, 2022). The design and implementation of remote alternatives may give meaningful alternatives when in person laboratory learning is not possible. The benefit of in- person experiential laboratory learning, according to the students, was connected to their capacity to learn and practice technical skills while putting theory learned in class into practical context and application (Accettone, 2022).

This work may bring enlightenment to the popularization of nuclear chemistry through new media technology. This work may bring enlightenment to the popularization of nuclear chemistry and radiochemistry through new media technology. The research results showed that not only did the VR platform effectively improve students' learning confidence, but also the effect of teacher-student interaction and the usability of VR equipment were recognized (Wang,2022). Manta is a virtual reality-based immersive molecular simulation tool that allows students to explore "actual" molecule structures and chemical processes on-the-fly. Manta can be used as a virtual classroom and even a playground for chemistry education, with students interacting with molecular structures (Zhao, 2022).

"CHEMTrans" is a chemistry learning game that includes a variety of chemical reactions. It helps pupils grasp chemical equations and cultivate their collaborative abilities by using Aeroplane Chess concepts. The players must write chemical reactions in various conditions in a short amount of time in order to meet their objectives (Li jun ,2022). This computational study was tailored for upper-division undergraduates and first-year graduate students. Students were challenged to execute theoretical computation on a home PC during the pandemic lockdown. They were able to model PAH molecules in the same way that graphene quantum dots are modelled, as well as learn how to use open-source tools such as Avogadro, ORCA, visual molecular dynamics (VMD), and nanoHUB.org (Melia, 2022).

The basic building blocks of numerous elements, such as carbon, hydrogen, other elements, and associated organic and inorganic compounds, are available for free as part of an open-source repository of 3D printable model design files. Because one of the primary ways visually impaired persons perceive physical entities is by touch (tactile), these models have a lock and key design, similar to jigsaw puzzle parts, as well as Braille and print notation, making learning more interactive, engaging, productive, and effective. The concept of hybridization is also discussed in order to increase learning. A 3D printed model was conceived and constructed to provide effective solutions for youngsters with special needs (Singhai, 2022). This technology report outlines the production and testing of an Ag/AgCl reference electrode, a platinum (Pt) counter electrode, and a carbon paste working electrode. The lab-made electrodes were tested using cyclic voltammetry (CV) using orange juice and ruthenium hexamine as analytes. These electrodes were created with 3D printing technology, which is becoming more widely available in educational settings. These customizable designs can be made rapidly and at a fraction of the cost of commercially available electrodes thanks to 3D printers (Schmidt, 2022).

The movies were judged to be effective in illustrating crucial components of each experiment based on student feedback. Some students said that they felt as if they were actually completing the experiments themselves. The kitchen-based experiments, on the other hand, provided students with hands-on experience and allowed them to observe and relate to concepts discussed in the lecture portion of the course (such as classifying matter, taking physical measurements, using units and significant figures, preparing solutions, calculating moles and molarity, and using separation techniques) (Mojica, 2022).

In this communication, we describe five at-home experiments and demonstrations that can complement an analytical chemistry curriculum for one semester. During the COVID-19 epidemic, distant undergraduate students, enrolled in a hybrid course on analytical chemistry, successfully carried out the experiments. Students performed spectrophotometric studies on their mobile smartphones. All other materials required for the research were constructed in a $265 (1,170 Malaysian Ringgit) DIY laboratory kit, with the potential for additional cost savings.

Challenges and Problems of Digital Technology

The global pandemic made it difficult to learn chemistry and, more significantly, to get ready for tests. The lack of professors' attention is one issue that students encounter, and using remote learning technologies like a chatbot could be a potential solution. To assist Russian students in getting ready for their final chemistry exam, the Chemist Bot was developed. It offers a range of activities, including the ability to study theory, the chance to perform tasks from actual exams, and educational games. The Chemist Bot is now engaged in the training of new participants—students who will pass the exam in the summer of 2022 (Korsakova, 2022).

30 students in grade 12 participated in this practical experiment, which lasted two hours, and instructed them to use a smartphone app to measure the amount of Fe3+in a sample of water. A diagnostic conceptual test was used to gauge the pupils' grasp of the concepts of oxidation- reduction and iron determination. After taking part in the experiment, it was discovered that the students' comprehension of both ideas had greatly improved (Meelapsom, 2022). A hybrid technology called augmented reality (AR) overlays three-dimensional (3D) digital data on a representation of reality. Users using this technology can visualize and manipulate three-dimensional chemical formations. Despite its potential, these tools aren't often used in chemistry.

The use of AR in early education has the potential to improve the knowledge and visualization of chemical structures, even though the standard 2D screen is still preferred when teaching chemistry. There should be a new chance for teaching and learning methodologies as a result of the AR technology's expanding connectedness to web platforms and scientific networks (Fombona, 2022).

In some chemistry experiments, the main phenomena happen too quickly to be observed. One might slow down the procedure and make the important observations apparent and understandable for the students by using everyday digital cameras or mobile phones with high-speed options. This article discusses the SloMoChem research project and demonstrates the advantages of employing digital technology to comprehend combustion considerably more effectively (Sieve, 2021). Animations, interactive simulations, and video recordings were mentioned as benefits by students because they facilitated processing of information, provided different ways to present the information, allowed for a variety of response, navigation, and flexibility options, and allowed for self-evaluation of their progress. These findings imply that regardless of the specific situations in which students' study, their learning can be supported and further enhanced by incorporating the UDL framework's principles into the instructional design of an online environment in first-year chemistry courses (Reyes, 2021)

CONCLUSION

As a conclusion, the use of digital technologies in chemistry teaching was thoroughly reviewed in this article. In the framework of technological applications in chemistry education research, a literature evaluation and search of the available sources were conducted. Thirty articles were extracted and analyzed in accordance with the search methodology. The effect of digital technology (11 articles), the advantage of digital technology (ten articles), and the challenge and difficulty (seven pieces) were the three main themes used to categorize all of the articles (9 articles). All the results were analyzed and synthesized to address the three objectives.

The applications for virtual reality and digital learning attracted the most interest among these three categories. The research was broken down into a variety of different categories, including augmented reality (AR), virtual reality (VR), visual aids, digital literacy, chatbots, and 3D printing, interactive board games, interactive apps, and the web. Of the 30 studies included, six (20%) examined the use of virtual reality (VR) or virtual labs, four (13%) examined the use of digital learning tools and software, the web, and computation in chemical education, and three (10%) examined the use of augmented reality (AR), video, simulators, or chatbots. Two studies (seven percent) used a smartphone and 3D printing, whereas only one study used eye tracking, an interactive board game, and interactive apps in their research.

Digital Technology in teaching and learning have high impact to the Chemistry education field. The AR instructional software and materials received favorable feedback from students. A successful teaching method that increased learning was the use of AR technology in chemistry classes. Digital twins can provide a significant percentage of laboratory operations like observation, analysis, and discourse on a large scale. Technology may lead to a rise in interest in experimental chemistry. It was long believed that sensory difficulties were connected to psychiatric mental illnesses including schizophrenia and attention deficit hyperactivity disorder. This article investigates the research on sensory overload and how it might impact chemistry lab instruction. As vignettes, the opinions of chemistry professors are provided to demonstrate how these teacher educators modelled the use of digital technology in teaching.

Some of the advantages of digital technology is in Chemistry education are ORCA students can be equipped with applicable skill sets as "Future Scientists" who can apply knowledge at the intersection of multiple fields. This report uses an open-source programming language to automate a popular laboratory experiment performed by Chemistry and Chemical Engineering students. The adaptability and accessibility of virtual laboratories is important, according to the ORCA students. The basic building blocks of numerous elements, such as carbon, hydrogen, and other elements, are available for free as part of an open-source repository of 3D printable model design files. These models have a lock and key design, similar to jigsaw puzzle parts, as well as Braille and print notation, to make learning more interactive, engaging and productive.

Otherwise, there are a challenges and problem discussed in this study to apply digital technology in teaching Chemistry. For example, The Chemist Bot was developed to assist

Russian students in getting ready for their final chemistry exam. It offers a range of activities, including the ability to study theory and perform tasks from actual exams. The bot is now engaged in the training of new participants who will pass the exam in the summer of 2022. This article discusses the SloMoChem research project and demonstrates the advantages of employing digital technology to comprehend combustion considerably more effectively. Animations, interactive simulations, and video recordings were mentioned as benefits by students because they facilitated processing of information. Despite its potential, these tools aren't often used in chemistry.

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