*IOSR Journal Of Humanities and Social Science (IOSR-JHSS)*
*Volume 30, Issue 10, Series 7 (October, 2025) 74-81*
*e-ISSN: 2279-0837, p-ISSN: 2279-0845.*
*www.iosrjournals.org*

# Contributions Of Digital Resources To Motivation And Engagement In The Teaching And Learning Process In Chemistry

Cristhian Brito Bezerra Da Silva[1], Allycia Mayra Viegas Pereira[2], Danielly Christinne Ferreira E Ferreira[3], Thiago De Jesus Corrêa[4], Micael Caio Da Silva Figueiredo[5], Lara Asevedo De Arouche[6], Lyzandra Da Silva[7], Adriana Silva Caldas[8]; Luiz Carlos Rocha Junior[9], Ricardo Henrique Nascimento Frazão[10]; Arlan Silva Freitas[11]

[1,2,3,4,5] *(Chemistry Licentiate Student, Federal Institute Of Education, Science And Technology Of Maranhão, São Luís-Monte Castelo Campus, São Luís, Maranhão, Brazil)*
[6,7] *(Chemical Process Technology Student, Federal Institute Of Education, Science And Technology Of Maranhão, São Luís-Monte Castelo Campus, São Luís, Maranhão, Brazil)*
[8,9,10,11] *(Professor, Departament Of Chemistry, Federal Institute Of Education, Science And Technology Of Maranhão, Brazil)*

***Abstract:***
***Background****: The article aims to systematize and discuss the contributions of digital resources to student motivation and engagement in Chemistry teaching, based on a systematic literature review conducted according to the PRISMA protocol.*
***Materials and Methods****: The study performed searches in the databases Google Scholar, SciELO, Web of Science, and CAPES Journals, considering publications between 2018 and August 2025, and selected 15 articles that met the inclusion criteria.*
***Results****: The results indicate that tools such as PhET, Wordwall, Chemsketch, and Avogadro foster conceptual understanding and stimulate students' autonomy and participation. However, the study identifies recurring challenges, such as the lack of technological infrastructure, unequal access to digital devices, and the need for continuous teacher training for the pedagogical use of ICTs.*
***Conclusion:*** *It is concluded that the planned and critical integration of digital resources in Chemistry teaching enhances engagement, strengthens the connection between theory and practice, and promotes more dynamic, collaborative, and inclusive learning environments. The creation of consistent evaluation models and the implementation of continuous teacher training programs are essential to ensure the effectiveness, quality, and sustainability of pedagogical practices based on digital resources.*
***Key Word****: Pedagogical innovation; Educational technologies; Meaningful learning; Active methodologies; Teacher training.*

Date of Submission: 20-10-2025 Date of Acceptance: 30-10-2025

## I. Introduction

The teaching of Chemistry, due to its complex conceptual nature, requires students to navigate between the macroscopic, submicroscopic, and symbolic levels of representation in order to achieve a comprehensive understanding of the phenomena studied (Rahmawati et al., 2022). This complexity, however, often leads to learning difficulties, especially in more abstract topics such as the study of acids and bases in high school, as pointed out by Xavier et al. (2018). These challenges may result in misconceptions and hinder the connection between scientific knowledge and students' everyday experiences, reinforcing the need for more innovative pedagogical approaches (Rahmawati et al., 2022; Xavier et al., 2018).

In this context, the integration of Information and Communication Technologies (ICTs) into Chemistry teaching has proven to be a promising alternative, offering new perspectives to enhance the teaching–learning process (Akpomiemie, 2025). Among these technologies, the use of educational software stands out as one of the most effective ways to incorporate digital resources with pedagogical purposes, overcoming the view that technology is merely a modern accessory (Chroustová et al., 2022). With recent technological advances, there has been a remarkable expansion of educational applications available on digital platforms, which, according to

Chroustová et al. (2022) and Oliveira and Leite (2024), reinforces the potential of these tools as important aids to teaching practice.

The attractiveness and interactivity of digital resources, such as apps and gamification-based platforms, have proven to be key factors in increasing students' interest and engagement (Nenohai et al., 2022). The use of apps in Chemistry teaching is widely recognized by students as an efficient didactic resource (Oliveira et al., 2020), capable of intensifying participation in class. One example is the use of Wordwall, a game-based platform applied to the teaching of chemical kinetics, which has proven to be a viable and engaging tool (Nenohai et al., 2022). Similarly, the AciBase app, designed for the study of acids and bases, has shown to be a playful and motivating resource, making learning more dynamic and interesting (Oliveira et al., 2020; Xavier et al., 2018).

In addition to fostering motivation, digital tools significantly contribute to the construction and deepening of conceptual understanding in Chemistry (Oliveira; Leite, 2024). Through interactive visualization and manipulation of concepts, Rahmawati et al. (2022) highlight that simulations, such as those offered by PhET, facilitate the learning of complex topics like chemical equilibrium. Likewise, Nsabayezu et al. (2023) observed that tools such as interactive periodic tables (Ptable) enhance the understanding of periodic trends, helping students connect the different representational levels of Chemistry. This ability to visualize microscopic processes is an undeniable pedagogical advantage (Nsabayezu et al., 2023; Oliveira; Leite, 2024).

The use of these resources is closely linked to active learning methodologies, in which the student plays a central role in the learning process, while the teacher acts as a mediator, guiding the pedagogical use of technology (Oliveira et al., 2020). Studies such as that of Marpaung et al. (2021), which analyzed the use of Chemsketch software in the teaching of hydrocarbons, show that these tools make lessons more dynamic and arouse greater student interest. The results indicate that the use of interactive technologies significantly increases students' motivation, especially when accompanied by effective teacher mediation (Marpaung et al., 2021; Oliveira et al., 2020).

However, the full and effective adoption of ICTs in Chemistry education still faces significant challenges that limit the realization of their pedagogical benefits (Chroustová et al., 2022). Among the most recurring obstacles, Akpomiemie (2025) highlights the lack of adequate infrastructure in schools, limited access to equipment, and unstable internet connections. Moreover, the acceptance and use of educational software vary according to teachers' profiles, as indicated by Chroustová et al. (2022). Resistance to innovation and the absence of continuous technological training programs hinder the effective integration of these resources into teaching practices (Akpomiemie, 2025; Chroustová et al., 2022).

Although there is a growing number of studies on the development and application of digital resources in specific content areas (Xavier et al., 2018; Nenohai et al., 2022), there remains a gap in the systematic evaluation of these materials, both in their practical and theoretical aspects. Therefore, it becomes essential to create robust evaluation models that consider both technical and pedagogical dimensions (Rahmawati et al., 2022). Thus, given the great pedagogical potential of these resources, as evidenced in case studies (Marpaung et al., 2021), and the persistent challenges in their implementation and acceptance, a synthesis of current knowledge is necessary to support new practices and the development of future educational tools (Oliveira; Leite, 2024).

This article aims to systematize and discuss the contributions of digital resources to student motivation and engagement in Chemistry education, based on a literature review grounded in databases such as Google Scholar, SciELO, Web of Science, and CAPES Journals. The originality of the research lies in the critical integration of empirical and theoretical evidence, providing support for improving teaching practices and for the development of future educational tools that enhance meaningful learning in Chemistry.

## II. Material And Methods

This study was developed in accordance with the recommendations of the PRISMA protocol (Preferred Reporting Items for Systematic Reviews and Meta-Analyses), ensuring methodological rigor, transparency, and reproducibility throughout the processes of search, screening, and selection of studies.

### Search Strategy

The systematic search was conducted in the databases Google Scholar, SciELO, Web of Science, and CAPES Journals. Descriptors in Portuguese and English were used, combined with Boolean operators, such as "ensino de Química" ("teaching Chemistry"), "tecnologias digitais" ("digital technologies"), "gamificação" ("gamification"), "realidade aumentada" ("augmented reality"), "laboratórios virtuais" ("virtual laboratories"), "softwares educacionais" ("educational software"), and "aplicativos didáticos" ("teaching applications"). The time frame included only articles published between 2018 and August 2025, in order to cover recent works aligned with the contemporary context of digital technology use in Chemistry education.

### Eligibility Criteria

The following criteria were defined:

- **Inclusion:** original or review articles published in indexed journals between 2018 and August 2025 that addressed digital resources, software, applications, gamification, or virtual laboratories applied to Chemistry teaching.
- **Exclusion:** monographs, dissertations, theses, extended abstracts, conference papers, and articles lacking relevant information related to the topic.

**Selection Process**

The initial search yielded 348 studies. After screening titles and abstracts, 305 articles were excluded for not meeting the inclusion criteria. A total of 43 articles were considered potentially eligible. Full-text reading allowed for the exclusion of publications that did not meet the objectives of the review, resulting in 15 final articles for analysis, all containing relevant and compatible information with the purpose of the study.

**Data Extraction and Analysis**

The included articles underwent qualitative analysis, considering their objectives, methodologies, digital resources explored, impacts on the teaching–learning process, and reported limitations. The synthesis of findings made it possible to identify recent trends, potentialities, and challenges in the use of digital technologies in Chemistry teaching.

## III. Result

**Procedure methodology**

The use of digital resources in Chemistry teaching has become a fertile field of investigation, aimed at understanding how software, applications, and simulators contribute not only to reducing conceptual abstraction but also to enhancing student engagement and autonomy. The studies selected for this research encompass different educational levels and methodological approaches, ranging from virtual laboratories and interactive simulators to applications focused on molecular visualization and educational games, highlighting the diversity of pedagogical possibilities.

Despite contextual variations, the results converge in indicating that Information and Communication Technologies (ICTs) foster more meaningful, interactive, and contextualized learning experiences. However, the studies also point out recurring challenges, such as dependence on technological infrastructure, inequality of access, and the need for continuous teacher training. Table 1 summarizes these studies, highlighting their objectives, main results, and conclusions, which serve as the foundation for the critical discussion presented in this article.

**Table 1:** Summary of selected articles on the use of digital resources in Chemistry teaching

| Author(s) and Year | Article Title | Objective of the Study | Main Findings | Conclusion |
|---|---|---|---|---|
| Marpaung et al. (2021) | *Analysis of Student Motivation using Chemsketch on Hydrocarbon Topic in SMA Negeri 2 Merauke* | To analyze student motivation when using Chemsketch in the teaching of hydrocarbons. | Students showed greater motivation and active participation when using Chemsketch. | Chemsketch is an effective tool to enhance motivation and understanding of hydrocarbons. |
| Nenohai et al. (2022) | *Development of Gamification-Based Wordwall Game Platform on Reaction Rate Materials* | To develop and validate a Wordwall-based game platform for chemical kinetics. | Wordwall received positive expert validation and increased student engagement. | Gamification through Wordwall contributes to active learning in Chemistry. |
| Siedler (2022) | *MoleculAR - um aplicativo baseado em realidade aumentada destinado ao ensino de ligações químicas (MoleculAR – an augmented reality application for teaching chemical bonding)* | To present and evaluate an augmented reality app for teaching chemical bonding. | MoleculAR was highly rated for its interactivity and ability to facilitate visualization of bonds. | Augmented reality is a promising resource for teaching abstract concepts. |
| Gomes et al. (2024) | *O uso do material didático software RasMol no ensino de Química através do design instrucional (The use of the educational software RasMol in Chemistry teaching through instructional design)* | To investigate the use of RasMol software as an instructional design-based teaching resource. | RasMol proved effective for molecular visualization, with positive pedagogical contributions. | RasMol enhances structural learning of molecules by integrating technology and pedagogy. |

| | | | | |
|---|---|---|---|---|
| Oliveira et al. (2021) | *QUILEGAL - um recurso para o ensino de Ciências Naturais (QUILEGAL – a resource for teaching Natural Sciences)* | To present QUILEGAL as a digital educational resource for Natural Sciences. | QUILEGAL was validated as an accessible and efficient tool for basic education students. | QUILEGAL promotes investigative and interactive learning in Natural Sciences. |
| Silva, Loja & Pires (2020) | *Quiz Molecular - aplicativo lúdico didático para o ensino de Química Orgânica (Molecular Quiz – an educational game app for teaching Organic Chemistry)* | To develop and apply a game-based app to support Organic Chemistry teaching. | Molecular Quiz increased participation, interest, and performance in Organic Chemistry topics. | Educational apps like Molecular Quiz are strategic tools to engage students in Chemistry. |
| Pongkendek (2021) | *The use of Chemsketch to increase student learning outcomes and motivation in learning hydrocarbons* | To assess the influence of Chemsketch on motivation and learning outcomes in hydrocarbons. | Chemsketch significantly improved students' learning outcomes and motivation. | The use of Chemsketch directly contributes to student motivation and academic achievement. |
| Lampe et al. (2019) | *XENUBI - aspectos técnicos e pedagógicos de um aplicativo para o ensino de Química (XENUBI – technical and pedagogical aspects of an app for Chemistry teaching)* | To discuss technical and pedagogical aspects of the Xenubi app for teaching the Periodic Table. | Xenubi was validated in terms of design and usability, standing out as a pedagogical tool. | Xenubi combines technical and pedagogical aspects, proving useful for teaching the Periodic Table. |
| Rodrigues (2024) | *Educational software in the monitoring of Inorganic Chemistry II* | To evaluate the effectiveness of PhET and MolView software in teaching Inorganic Chemistry II within a tutoring program. | There was a significant improvement in student success rates, with reports of better understanding and application of content in other subjects. | The use of ICT proved effective in facilitating learning and increasing student engagement in abstract content. |
| Santos & Cirino (2019) | *Ensino de Geometria Molecular com app de simulação digital (Teaching Molecular Geometry with a digital simulation app)* | To investigate the contributions of the PhET® simulator to the teaching of Molecular Geometry in high school. | Students performed better in diagnostic assessments, indicating meaningful subordinate and superordinate learning. | The use of digital simulators enhanced meaningful learning, especially when students already had prior knowledge. |
| Salame & Makki (2021) | *Examining the Use of PhET Simulations on Students' Attitudes and Learning in General Chemistry II* | To evaluate the impact of PhET simulations on learning and attitudes of General Chemistry II students. | Simulations promoted conceptual understanding, motivation, and positive attitudes toward learning. | PhET simulations are transformative tools in Chemistry education, promoting experiences that go beyond the traditional laboratory. |
| Wanzeler et al. (2023) | *Programa Avogadro na educação: aperfeiçoando a compreensão de geometria e polaridade molecular dos estudantes (Avogadro program in education: improving students' understanding of molecular geometry and polarity)* | To examine how Avogadro software can enhance understanding of molecular geometry and polarity concepts. | There was a significant increase in evaluated skills, especially in recognizing molecular polarity (from 23.5% to 70.6%). | Avogadro proved feasible and effective in teaching sequences, facilitating 3D visualization and conceptual understanding. |
| Nabiça & Souza (2021) | *Software Cidade do Átomo como instrumento didático no ensino de Química (Atom City software as a didactic tool in Chemistry teaching)* | To report the use of Atom City software in teaching radioactivity through problem-solving. | Students showed positive engagement, using the computer as a mediator for contextualization and understanding. | The software promoted contextualized and interdisciplinary learning, bridging theory and practice. |
| Paes & Yamaguchi (2024) | *O uso do aplicativo Molecular Geometry no ensino de Química (The use of the Molecular Geometry app in Chemistry teaching)* | To evaluate the contributions of the Molecular Geometry app to learning Molecular Geometry. | Over 90% of students (1st and 3rd years) recognized that the app contributed positively to their learning. | The app was considered efficient as a didactic tool, assisting in the identification and understanding of molecules in a virtual environment. |
| Xavier et al. (2018) | *Química e Tecnologia: um aplicativo para a* | To develop and apply the AciBase app to | The educational game increased students' | AciBase is a playful and motivating tool, useful |

| | | | | |
|---|---|---|---|---|
| | *abordagem dos conteúdos de ácidos e bases no Ensino Médio (Chemistry and Technology: an app for teaching acids and bases in high school)* | facilitate the learning of acids and bases. | interest, improved understanding, and linked theory to practice. | as a didactic aid for teaching acids and bases. |

Source: The authors (2025).

The literature reviewed demonstrates that digital resources applied to Chemistry education have increasingly become fundamental elements of pedagogical innovation. They contribute not only to students' cognitive and conceptual development but also to enhancing their motivation and engagement in classroom activities. The selected studies span various educational levels and methodological approaches, encompassing the use of mobile applications and digital games, as well as tools based on augmented reality and virtual simulations. The following sections present the main results and discussions, organized into thematic axes that reflect the key trends and evidence identified in the reviewed research.

**Digital Simulations and Virtual Learning Environments**

Digital simulations have proven to be effective tools for overcoming the abstraction challenges typical of Chemistry learning, particularly in topics requiring the visualization of microscopic processes. Nsabayezu et al. (2023) observed that using *Ptable*—an online interactive periodic table connected to Wikipedia—enhanced students' performance and knowledge retention on periodic properties, while also fostering greater motivation through interactivity and autonomy. Similarly, Salame and Makki (2021) reported significant learning gains and positive attitudes resulting from the use of *PhET* simulations, reinforcing the role of these technologies as cognitive mediators in Chemistry instruction.

Santos and Cirino (2019) demonstrated that the *PhET Molecular Geometry* simulator enabled students to visualize molecules in three dimensions, improving their understanding of spatial relationships and atomic bonding. This use of simulations facilitated learning processes characterized by progressive differentiation and integrative reconciliation, consistent with Ausubel's Theory of Meaningful Learning, thus confirming that digital simulations are powerful cognitive mediation tools for complex concepts.

Wanzeler et al. (2023) also verified the effectiveness of the *Avogadro* program, showing that 3D molecular visualization promoted better comprehension of molecular geometry and polarity. Students' accuracy rates improved substantially, indicating that the manipulation and construction of molecular models help overcome the abstraction difficulties commonly found in Chemistry education.

These findings align with those of Paes and Yamaguchi (2024), who, through the use of the *Molecular Geometry* app, reported acceptance rates above 90% among students, reinforcing the contribution of Information and Communication Technologies (ICTs) to active and participatory learning. Digital simulations have therefore become interactive, accessible environments capable of integrating theory and practice, making the visualization of chemical phenomena more concrete and engaging.

Rodrigues (2024) further demonstrated that incorporating *PhET* and *MolView* software in academic tutoring programs led to substantial improvements in student success rates and conceptual understanding, confirming the relevance of digital simulations in consolidating meaningful learning. These results are consistent with those of Chroustová et al. (2022), who identified teacher acceptance as a decisive factor in the adoption of such tools, highlighting that educators' attitudes and behavioral intentions are crucial for the successful integration of ICTs into educational contexts.

**Educational Applications and Gamification**

The use of digital applications and gamified platforms has proven to be a highly effective strategy for fostering student interest and engagement. Sales et al. (2022), in their study of the *Wordwall* platform for teaching chemical kinetics, demonstrated that gamification can transform the learning environment, making it more interactive and collaborative while facilitating the assimilation of complex concepts. These findings confirm that well-designed gamified experiences can significantly enhance student motivation and interaction. Nenohai et al. (2022) similarly highlighted the positive impact of gamification on student motivation in Chemistry topics such as reaction rates.

Silva, Loja, and Pires (2020) presented *Molecular Quiz*, an educational game designed to support the teaching of organic functions, which yielded positive results in both learning outcomes and student perceptions. The balance between educational content and playful interaction created a dynamic environment that facilitated content retention and peer learning.

Comparable findings were reported by Xavier et al. (2018) through the *AciBase* app, developed for teaching acids and bases. The game, based on hypermedia methodologies, stimulated students' curiosity and engagement, making lessons more interactive and accessible. Both *AciBase* and *Molecular Quiz* confirm that gamification, when aligned with pedagogical objectives, serves as an effective mediator in the construction of chemical knowledge.

The *QuiLegAl* app (Oliveira et al., 2021) also stood out for integrating interactive features aimed at teaching chemical bonding and equations. It promoted learner autonomy and improved understanding of symbolic and molecular representations. The app's intuitive interface and exploratory approach illustrate the potential of mobile applications as tools for active learning—bridging the gap between scientific concepts and students' everyday experiences while adapting to diverse educational contexts.

Oliveira et al. (2020) found that the use of educational apps in Organic Chemistry enhanced classroom dynamism and stimulated scientific curiosity. Students reported that these tools allowed clearer visualization of molecular structures and reaction mechanisms. Building on this, Oliveira and Leite (2024) proposed the *Educational Applications Evaluation Model (EAEM)*, combining technical and pedagogical criteria to assess Chemistry apps available on Google Play. According to the authors, systematic evaluation is essential to ensure alignment between digital resources and educational objectives.

Assunção et al. (2023) further emphasized that smartphone-based applications are flexible and accessible pedagogical tools that can be adapted to the technological realities of diverse educational settings. The portability and familiarity of mobile devices contribute to continuous learning, both within and beyond the classroom. Overall, these studies suggest that the combination of playful design, interactivity, and accessibility is key to enhancing Chemistry teaching through digital technologies.

**Augmented Reality and Three-Dimensional Visualization**

The integration of Augmented Reality (AR) into Chemistry education has enabled students to visualize molecular structures in three dimensions, strengthening their spatial and cognitive abilities. Silva and Correia (2023) demonstrated that using concept maps enhanced with AR in the teaching of molecular geometry led to better performance and greater engagement during experimental activities. Students using AR achieved significantly higher results in constructing physical molecular models, confirming the technology's effectiveness in promoting both conceptual understanding and emotional involvement.

Studies on 3D modeling tools (Pongkendek, 2021; Marpaung et al., 2021) have also reported motivational and performance gains when using programs such as *Chemsketch* and *Avogadro* in structured instructional sequences. These tools expand representational and inferential skills and are particularly valuable for subjects that require spatial reasoning.

The *MoleculAR* app, developed by Siedler (2022), exemplifies this trend by allowing students to visualize and manipulate atomic and molecular representations in a virtual environment. The study highlighted that teacher participation in the app's design process was critical to ensuring pedagogical coherence and classroom applicability—showing that AR, when combined with participatory design, enhances engagement and conceptual comprehension.

Similarly, Gomes et al. (2024) showed that 3D molecular visualization using *RasMol*, supported by instructional design principles, promoted meaningful learning and student engagement. The instructional approach effectively integrated learning objectives with digital tools, creating interactive and immersive learning experiences.

Wanzeler et al. (2023) further reinforced the importance of 3D visualization for overcoming abstraction barriers, demonstrating that tools such as *Avogadro* and *MoleculAR* improve students' ability to mentally construct molecular models and relationships. Collectively, AR and 3D modeling tools represent significant advances in the visualization and understanding of chemical phenomena.

Earlier studies, such as Lampe et al. (2019), also confirmed this potential. Their analysis of the *Xenubi* app highlighted its design alignment with Cognitive Load Theory and its intuitive usability as core strengths, making it an efficient resource for teaching the Periodic Table. Moreover, *Xenubi*'s availability in both digital and analog formats broadens its pedagogical reach, benefiting schools with limited infrastructure. These findings underscore that AR and responsive design represent important didactic innovations that integrate interactivity and visual cognition to foster meaningful learning.

**Implementation Challenges and Teacher Acceptance**

Despite the growing evidence of ICTs' positive impact on Chemistry teaching, several studies highlight persistent structural and pedagogical barriers that limit their effective integration. Akpomiemie (2025) identified a lack of technological infrastructure, unstable internet connections, and insufficient continuous training as critical obstacles to effective ICT implementation in schools. These limitations not only hinder access but also influence teachers' perceptions of the feasibility of digital tools.

Similarly, Akpomiemie (2023) found that although teachers recognize the benefits of ICTs for student performance, the availability of equipment and Chemistry-specific software remains scarce. Chroustová et al. (2022) added that technology acceptance varies according to teachers' experience and profile, influenced by performance expectations, facilitation conditions, and personal innovativeness. Resistance to innovation, combined with limited institutional support, highlights the need for continuous professional development programs that prepare teachers to use digital technologies critically and creatively.

Studies by Oliveira et al. (2021) and Siedler (2022) indicate that teacher adoption depends on factors such as technological familiarity, curricular alignment, and institutional backing. Many educators report difficulties in integrating digital tools into their teaching practices due to inadequate infrastructure, limited planning time, and insufficient training.

In the case of *MoleculAR*, Siedler (2022) emphasized that teacher involvement during app development was essential to ensure alignment between technological features and educational goals, though gaps in teachers' technological competence were also evident. This underscores the urgent need for targeted teacher training programs that promote critical and creative engagement with digital tools.

Gomes et al. (2024) further observed that the effectiveness of *RasMol* depends on well-structured instructional planning, requiring teachers to understand both the potential and the limitations of the software. Collectively, these findings suggest that successful technological integration requires not only access to digital tools but also the development of robust pedagogical and digital competencies.

**Pedagogical Integration and Future Perspectives**

The collective findings indicate that the effectiveness of digital resources depends on their intentional and pedagogically grounded integration into the curriculum, supported by active learning methodologies and effective teacher mediation. Oliveira and Leite (2024) argue that adopting clear pedagogical criteria is crucial for ensuring that applications serve as instruments for meaningful learning rather than as mere illustrative supplements. Nsabayezu et al. (2023) and Silva and Correia (2023) likewise emphasize that students' active participation is essential to the success of digital learning experiences, requiring activities that promote interaction, exploration, and reflection.

Applications such as *Molecular Geometry*, *QuiLegAl*, *AciBase*, and *Molecular Quiz* demonstrate that learning becomes more meaningful when students actively engage with dynamic representations and cognitive challenges. This integration fosters autonomy, scientific curiosity, and critical reasoning, contributing to a more contextualized and participatory learning environment.

Studies by Siedler (2022) and Gomes et al. (2024) reaffirm that instructional design and teacher involvement are decisive factors for the success of digital practices, ensuring coherence between content and technological functionality. Likewise, tools such as *Avogadro* and *PhET* (Santos & Cirino, 2019; Wanzeler et al., 2023) illustrate the growing potential of hybrid and interactive learning environments that integrate visualization, experimentation, and reflection.

Overall, the findings suggest that Chemistry teaching mediated by digital technologies contributes to the development of cognitive, representational, and technological competencies, while fostering greater student autonomy and inquiry-based learning. The converging evidence points toward the consolidation of a new educational paradigm-one in which technological and pedagogical innovation are deeply interconnected, promoting learning environments that are more inclusive, dynamic, and contextually relevant. In this emerging paradigm, technology ceases to function merely as a supplementary resource and becomes a constitutive element of the pedagogical process. The future of Chemistry education mediated by digital technologies lies in this synergy between technological advancement and didactic innovation, leading to more meaningful, collaborative, and inclusive learning experiences.

## IV. Conclusion

The analysis of the studies included in this systematic review underscores that the integration of digital resources into Chemistry education represents a robust pedagogical strategy, capable of addressing the inherent abstractness of the discipline while simultaneously enhancing student motivation and engagement. Evidence indicates that Information and Communication Technologies (ICTs) function as critical mediators in fostering more meaningful, interactive, and visually supported learning experiences.

Nevertheless, the literature highlights several challenges in implementing these tools effectively. These include the need for comprehensive teacher training, reliance on adequate technological infrastructure (such as internet connectivity and devices), and the necessity of aligning digital resources with both pedagogical objectives and the specific educational context.

The development of digital educational resources has increasingly benefited from agile and participatory design methodologies, engaging educators and students from the early stages of tool creation. Such an approach ensures that the resources address genuine educational needs and are grounded in well-established pedagogical principles.

Furthermore, the motivational and engagement-enhancing effects of digital resources extend beyond their gamified or playful elements, encompassing the development of learner autonomy, self-regulation, and active learning, in alignment with constructivist frameworks.

Overall, the findings suggest that the strategic and intentional integration of digital resources can mitigate the abstract nature of Chemistry, facilitate the visualization of microscopic phenomena, and promote deeper and more durable learning outcomes. Nevertheless, continued research is warranted to assess the impact of these tools across diverse educational contexts and at larger scales, thereby ensuring effective, sustainable, and evidence-based implementation.

## References


[1]. Akpomiemie, V. L. Challenges Of Integration Of Information And Communication Technology (Ict) In Chemistry Teaching In Secondary Schools In Bayelsa State. Fuo-Journal Of Educational Research, [S. L.], V. 4, N. 2, 2025. Doi: 10.5281/Zenodo.14885888.

[2]. Akpomiemie, V. L. Et Al. Assessment Of Information And Communication Technology Tools On Chemistry Teaching And Learning Among Secondary School Teachers In Ogbia, Bayelsa State. Zamfara International Journal Of Education, Gusau, V. 3, N. 6, Dez. 2023.

[3]. Assunção, W. C.; Martins, J. L.; Andrade, L. D. De. O Uso De Aplicativos De Smartphone Como Estratégia De Ensino Em Ciências. Revista Communitas, [S. L.], V. 7, N. 15, 2023. Doi: 10.29327/268346.7.15-12.

[4]. Chroustová, K. Et Al. Differences In Chemistry Teachers' Acceptance Of Educational Software According To Their User Type: An Application Of Extended Utaut Model. Journal Of Baltic Science Education, [S. L.], V. 21, N. 5, P. 762–787, 2022. Doi: 10.33225/Jbse/22.21.762.

[5]. Gomes, L. F. Et Al. O Uso Do Material Didático Software Rasmol No Ensino De Química Através Do Design Instrucional. Revista Ilustração, Cruz Alta, V. 5, N. 7, P. 129–138, 2024.

[6]. Hitlal, D. Virtual Chemistry Laboratories In The Caribbean: A Qualitative Study. Journal Of Chemical Education, V. 100, P. 2847–2859, 2023.

[7]. Lampe, L. Et Al. Xenubi: Aspectos Técnicos E Pedagógicos De Um Aplicativo Para O Ensino De Química. In: Seminário Internacional De Educação, Tecnologia E Sociedade: Ensino Híbrido, 24., 2019. [S. L.]: Núcleo De Educação On-Line Faccat, 2019.

[8]. Marpaung, D. N. Et Al. Analysis Of Student Motivation Using Chemsketch On Hydrocarbon Topic In Sma Negeri 2 Merauke. Journal Of Applied Science, Engineering, Technology, And Education (Asci), V. 3, N. 1, 2021. Doi: 10.35877/454rlasci105.

[9]. Nabiça, M. G.; Souza, J. R. T. Software Cidade Do Átomo Como Instrumento Didático No Ensino De Química. Química Nova Na Escola, São Paulo, 2021. Doi: 10.21577/0104-8899.20160256.

[10]. Nenohai, J. A. Et Al. Development Of Gamification-Based Wordwall Game Platform On Reaction Rate Materials. Orbital: Electronic Journal Of Chemistry, V. 14, N. 2, P. 116–122, 2022. Doi: 10.17807/Orbital.V14i2.16206.

[11]. Nsabayezu, E. Et Al. Online Periodic Table Of Elements To Support Students' Learning Of Trends In Properties Of Chemical Elements. Education And Information Technologies, V. 28, P. 11793–11817, 2023. Doi: 10.1007/S10639-023-11650-7.

[12]. Oliveira, F. C. De; Milani Júnior, J.; Carvalho, J. W. P. Uso De Aplicativos No Ensino De Química Orgânica Na Percepção De Discentes. Revista Educação E Cultura Contemporânea, Rio De Janeiro, V. 17, N. 49, 2020. Doi: 10.5935/2238-1279.20200054.

[13]. Oliveira, F. C. De Et Al. Quilegal: Um Recurso Para O Ensino De Ciências Naturais. South American Journal Of Basic Education, Technical And Technological, V. 8, N. 2, 2021.

[14]. Oliveira, V. S. De; Leite, B. S. Modelo De Avaliação De Aplicativos Educacionais: Avaliando Aplicativos De Química Orgânica Da Google Play. Química Nova, São Paulo, V. 47, N. 8, P. 1–8, 2024. Doi: 10.21577/0100-4042.20240032.

[15]. Paes, A. P. S. G.; Yamaguchi, K. K. De L. O Uso Do Aplicativo Molecular Geometry No Ensino De Química. Revista Edapeci, São Cristóvão (Se), V. 24, N. 2, P. 137–151, Maio/Ago. 2024. Doi: 10.29276/Redapeci.2024.24.220374.137-151.

[16]. Pongkendek, J. J. Et Al. The Use Of Chemsketch To Increase Student Learning Outcomes And Motivation In Learning Hydrocarbons. J-Pek (Jurnal Pembelajaran Kimia), V. 6, N. 1, P. 9–18, Jun. 2021.

[17]. Rahmawati, Y. Et Al. Students' Conceptual Understanding In Chemistry Learning Using Phet Interactive Simulations. Journal Of Technology And Science Education, [S. L.], V. 12, N. 2, P. 303–326, 2022. Doi: 10.3926/Jotse.1597.

[18]. Rodrigues, A. R. S. P. Software Educativo En La Supervisión De La Química Inorgánica Ii. Educación Química, 2024.

[19]. Salame, I. I.; Makki, J. Examining The Use Of Phet Simulations On Students' Attitudes And Learning In General Chemistry Ii. Interdisciplinary Journal Of Environmental And Science Education, V. 17, N. 4, E2247, 2021. Doi: 10.21601/Ijese/10966.

[20]. Sales, D. O. Et Al. O Uso Da Plataforma Wordwall Como Estratégias No Ensino De Química. Brazilian Journal Of Development, Curitiba, V. 8, N. 3, P. 16959, 2022. Doi: 10.34117/Bjdv8n3-097.

[21]. Santos, A. C. Da L. Dos; Cirino, M. M. Ensino De Geometria Molecular Com App De Simulação Digital: Possíveis Contribuições Para Uma Aprendizagem Significativa. Ensino & Multidisciplinaridade, V. 5, N. 2, P. 36–52, Jul./Dez. 2019.

[22]. Siedler, M. S. Et Al. Molecular: Um Aplicativo Baseado Em Realidade Aumentada Destinado Ao Ensino De Ligações Químicas. Educitec – Revista De Estudos E Pesquisas Sobre Ensino Tecnológico, Manaus (Am), V. 8, E200622, 2022. Doi: 10.31417/Educitec.V8.2006.

[23]. Silva, E. S.; Loja, L. F. B.; Pires, D. A. T. Quiz Molecular: Aplicativo Lúdico Didático Para O Ensino De Química Orgânica. Revista Prática Docente (Rpd), V. 5, N. 1, P. 172–192, 2020. Doi: 10.23926/Rpd.2526-2149.2020.V5.N1.P172-192.Id550.

[24]. Silva, K. S. Da; Correia, P. R. M. Aprimorando A Percepção Espacial Em Geometria Molecular Através Do Estudo Com Mapas Conceituais E Tecnologia De Realidade Aumentada. Alexandria: Revista De Educação Em Ciência E Tecnologia, Florianópolis, V. 16, N. 2, P. 335–353, Nov. 2023. Doi: 10.5007/1982-5153.2023.E91971.

[25]. Trindade, Í. T. M. Et Al. Laboratório Virtual De Química: Uma Alternativa Didática Para O Ensino De Química Orgânica. Research, Society And Development, V. 11, N. 10, E426111032888, 2022. Doi: 10.33448/Rsd-V11i10.32888.

[26]. Wanzeller, H. P. Et Al. Programa Avogadro Na Educação: Aperfeiçoando A Compreensão De Geometria E Polaridade Molecular Dos Estudantes. Educere – Revista Da Educação Da Unipar, Umuarama, V. 23, N. 1, P. 19–32, 2023. Doi: 10.25110/Educere.V23i1.20239108.

[27]. Xavier, J. L. Et Al. Química E Tecnologia: Um Aplicativo Para A Abordagem Dos Conteúdos De Ácidos E Bases No Ensino Médio. Educitec – Revista De Estudos E Pesquisas Sobre Ensino Tecnológico, Manaus, V. 4, N. 8, P. 666–687, Nov. 2018.