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ABED

ORIGINAL ARTICLE

USE OF VIRTUAL LEARNING ENVIRONMENTS, ARTIFICIAL INTELLIGENCE AND INNOVATIVE ENTREPRENEURIAL THEMES IN CHEMISTRY TEACHING

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ABSTRACT

This article investigates the contributions of the use of Virtual Learning Environments (VLEs), Artificial Intelligence (AI) resources and Innovative Entrepreneurial Themes (IETs) in chemistry teaching, with a focus on promoting student protagonism and meaningful learning. The research, with a qualitative approach, was developed based on pedagogical practices carried out in high school, face-to-face and with elements of hybrid education, through the use of VLEs and the application of entrepreneurial projects aimed at innovation and the creation of solutions based on scientific knowledge. The data was collected through participant observations during the courses and analyzed using the content analysis technique proposed by Bardin. The theoretical foundation is based on Moran and Vygotsky's conceptions of mediation, development, the use of digital technologies and Ausubel's theory of meaningful learning, as well as contemporary authors who discuss Education 4.0, entrepreneurial education (EE) and the use of digital technologies in education. The results reveal the potential of these approaches to contribute to teaching-learning processes in a dynamic, contextualized way that is aligned with 21st century skills

Keywords: Education 4.0, Chemistry Teaching, Artificial Intelligence, Entrepreneurial Education, Virtual Learning Environments.

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USO DE AMBIENTES VIRTUAIS DE APRENDIZAGEM, INTELIGÊNCIAS ARTIFICIAIS E TEMÁTICAS EMPREENDEDORAS INOVADORAS NO ENSINO DE QUÍMICA

RESUMO

O presente artigo investiga as contribuições do uso de Ambientes Virtuais de Aprendizagem (AVAs), recursos de Inteligência Artificial (IA) e Temáticas Empreendedoras Inovadoras (TEIs) no ensino de Química, com foco na promoção do protagonismo estudantil e da aprendizagem significativa. A pesquisa, de abordagem qualitativa, foi desenvolvida a partir de práticas pedagógicas realizadas no ensino médio, presenciais e com elementos da educação hibrida, por meio do uso de AVAs e da aplicação de projetos empreendedores voltados à inovação e à criação de soluções baseadas em conhecimentos científicos. Os dados foram coletados por meio de observações participantes realizadas no decorrer das disciplinas e analisados com base na técnica de análise de conteúdo proposta por Bardin. A fundamentação teórica apoia-se nas concepções de Moran e Vygotsky sobre mediação, desenvolvimento, uso de tecnologias digitais e na teoria de aprendizagem significativa de Ausubel, bem como em autores contemporâneos que discutem Educação 4.0, educação empreendedora (EE) e o uso de tecnologias digitais na educação. Os resultados revelam o potencial dessas abordagens para contribuições nos processos de ensino aprendizagem de modo dinâmico, contextualizado e alinhados às competências do século XXI.

Palavras-chave: Educação 4.0, Ensino de Química, Inteligência Artificial, Educação Empreendedora, Ambientes Virtuais de Aprendizagem.

USO DE ENTORNOS VIRTUALES DE APRENDIZAJE, INTELIGENCIA ARTIFICIAL Y TEMAS EMPRESARIALES INNOVADORES EN LA ENSEÑANZA DE LA QUÍMICA

RESUMEN

Este artículo investiga las contribuciones del uso de Entornos Virtuales de Aprendizaje (EVAs), recursos de Inteligencia Artificial (IA) y Temas Emprendedores Innovadores (TIEs) en la enseñanza de la Química, con un enfoque en la promoción del protagonismo de los estudiantes y el aprendizaje significativo. La investigación, con enfoque cualitativo, se desarrolló a partir de prácticas pedagógicas realizadas en el bachillerato, tanto presenciales como con elementos de educación híbrida, mediante el uso de VLEs y la aplicación de proyectos emprendedores orientados a la innovación y la creación de soluciones basadas en el conocimiento científico. Los datos se recogieron a través de observaciones participantes durante los cursos y se analizaron mediante la técnica de análisis de contenido propuesta por Bardin.

La fundamentación teórica se basa en las concepciones de Moran y Vygotsky sobre la mediación, el desarrollo, el uso de las tecnologías digitales y la teoría del aprendizaje significativo de Ausubel, así como en autores contemporáneos que discuten la Educación 4.0, la educación emprendedora (EE) y el uso de las tecnologías digitales en la educación. Los resultados revelan el potencial de estos enfoques para contribuir a los procesos de enseñanza y aprendizaje de forma dinámica, contextualizada y alineada con las competencias del siglo XXI.

Palabras clave: Educación 4.0, Enseñanza de la Química, Inteligencia Artificial, Educación Emprendedora, Entornos Virtuales de Aprendizaje.

1. INTRODUCTION

Contemporary education has been challenged by rapid technological, social, and cultural transformations that require new ways of teaching and learning. In this context, the so-called Education 4.0 emerges as a response to the demands of the 21st century, proposing an integrated, dynamic, and student-centered approach, with the intensive use of digital technologies, active methodologies, and the promotion of student agency (Bacich and Moran, 2018). Education 4.0 requires not only the incorporation of new technologies but also a profound shift in mindset, transforming schools into environments for the development of life competencies, with a focus on creativity, collaboration, and critical thinking (Felcher and Folmer, 2021). In the same sense, Allan (2019) emphasizes that Education 4.0 requires teachers to act as curators and facilitators of pedagogical experiences that foster students' interest and autonomy, using digital resources as allies in the construction of contextualized and innovative knowledge.

Chemistry teaching, traditionally associated with memorization of formulas and abstract concepts, can benefit from innovations, especially when integrated with resources such as Virtual Learning Environments (VLEs), Artificial Intelligence (AI) tools, and pedagogical practices inspired by Entrepreneurial Education (EE). Such approaches not only promote meaningful learning but also foster essential competencies for the contemporary world, such as autonomy, creativity, problem-solving, and teamwork.

The National Common Curricular Base (Base Nacional Comum Curricular – BNCC), in the area of Natural Sciences and its Technologies, highlights necessary aspects for the theoretical articulation of content and themes with practical approaches in the classroom, guiding an education that encourages student agency within the context of digital culture. The document states that learning goes beyond conceptual content, emphasizing the social, cultural, environmental, and historical contextualization of knowledge. It also addresses processes of creation, meaning-making, reflection, and contextualization enabled by the integration of diverse teaching methodologies and digital technologies (MEC, 2018; Santos and Costa, 2025). In this sense, scientific advances and the rapid expansion of the use of digital technologies across different spaces, times, and contexts have generated social changes and new educational demands (Bacich and Moran, 2018; Santos and Costa, 2025).

Based on the in-person teaching experience with elements of "hybrid education" at the Federal Institute of Goiás – Formosa Campus, especially integrated into the context of the Business and Innovation Incubator Center, it is observed that the articulation between Chemistry teaching, digital technologies, and innovative entrepreneurial themes (IETs) can generate positive impacts on student engagement and development. The use of VLEs, AI-based platforms, and entrepreneurship-oriented projects enabled discussions aimed at building active and contextualized learning.

In light of this context, the present article aims to investigate how the integration of educational technologies, VLEs, AIs, and IETs in Chemistry teaching can foster student agency, meaningful learning, and the development of critical and innovative individuals. To this end, a qualitative approach will be employed, grounded in the contributions of Vygotsky, as well as in contemporary authors who discuss Education 4.0, Entrepreneurial Education (EE), and the use of technologies in the classroom.

2. THEORETICAL FRAMEWORK

2. 1. Education 4.0 and its implications for teaching

Education 4.0 is an emerging concept that reflects the digital revolution and its implications for the school environment. Schwab (2016) argues that Education 4.0 is closely linked to the Fourth Industrial Revolution, which demands a reconfiguration of pedagogical practices to include innovative technological tools, active methodologies, and the promotion of the development of competencies oriented toward the 21st century. This new educational model moves away from a traditional view of teaching and seeks to prepare students for unforeseen challenges, focusing on autonomy, creativity, and, above all, student agency. According to Bacich and Moran (2018), Education 4.0 is based on three main concepts: (1) personalization of learning, (2) active learning, and (3) the use of digital technologies, with these concepts being intrinsically interconnected at the core of the analyses of this study involving VLEs, AIs, and IETs.

In this sense, Allan (2019) complements this view by stating that the teacher's role in Education 4.0 is transformed: the teacher is no longer the center of the teaching-learning process and instead becomes a mediator and facilitator. Thus, each student learns at their own pace and according to their own needs, working with others in groups and projects under the supervision of guiding teachers (Freire et al., 2025; Moran, 2015). Rather than simply transmitting content, the teacher creates learning environments that foster collaboration, critical thinking, and student autonomy. With the introduction of technologies such as VLEs and AIs, students assume an active role in their knowledge construction process.

2. 2. Digital Student Agency in Chemistry Teaching

The concept of "student agency," grounded in Vygotsky (1987), highlights the importance of social mediation in the learning process. For Vygotsky, interaction with others—whether the teacher or peers—is essential for cognitive development. Learning is not an isolated act, but rather a dynamic and collaborative process. Applying this perspective to Chemistry teaching means creating conditions for students to feel like active participants in the process, becoming co-responsible for their own learning and engagement.

In the context of the current digital culture in which we live, the integration of digital resources supports the development of educational challenges, enabling new forms of organizing pedagogical and curricular activities. It provides resources that can be applied in the classroom to enrich students' learning experiences and support the teaching of scientific concepts that are difficult to understand and visualize (Santos and Costa, 2025), as is the case with chemical knowledge.

In this way, within the context of Chemistry teaching, especially in an innovative setting, the implementation of VLEs can significantly contribute to "digital student agency." VLEs enable students to access instructional resources autonomously, participate in discussions, simulations, and problem-solving activities that broaden their understanding of chemical concepts.

2. 3. Artificial Intelligence in Chemistry Teaching

Artificial Intelligence (AI), as discussed by various authors and contemporary references on digital education, has been gaining significant ground in education. AI-based tools can analyze student performance in real time, provide personalized feedback, and suggest adaptive learning strategies (Azambuja and Silva, 2024; Costa Junior et al., 2023). These technologies are especially valuable in Chemistry teaching, a discipline that often requires the assimilation of complex concepts, the performance of calculations, multi-step procedures, and the application of theories to real-world practical situations.

In this sense, AIs can be powerful tools in the construction of interactive and personalized learning environments, helping to identify students' difficulties and offering immediate solutions (Dillenbourg, 2018). In Chemistry teaching, combined with "digital student agency," this can be translated into the creation of simulators that allow virtual experimentation, as well as the methodological organization of calculations, reasoning processes, procedures, and multi-step reactions.

With AIs analyzing and progressively adjusting activities according to generative responses, this tool can provide effective, ethical, academic learning oriented toward students' individual needs, under the guidance of teachers engaged in the use of technological tools applied to education.

2. 4. Entrepreneurial Education and Its Impact on the Development of Critical and Innovative Individuals

Entrepreneurial Education (EE) plays a central role in the formation of critical and innovative citizens. Authors such as Kourilsky (2015) and Torrens (2017) emphasize that EE is not limited to business creation, but also involves the development of competencies such as creativity, problem-solving, and strategic thinking. The integration of these themes into Chemistry teaching can contribute to students not only engaging with the content, but also applying knowledge in creative ways, whether through projects, experiments, innovative solutions, or the development of business and entrepreneurial initiatives.

In the context of Chemistry teaching, entrepreneurial approaches can be implemented through projects that involve the creation of innovative solutions to everyday problems, such as the development of new materials, sustainability-related solutions, or applications in the chemical industry, as well as entrepreneurial pathways grounded in innovation and chemical knowledge aimed at addressing contemporary societal challenges. These projects not only highlight chemical concepts but also prepare students to think innovatively, solve real-world challenges, and promote student agency.

3. METHODOLOGY

A qualitative research approach in education was adopted in this study in order to understand how the use of VLEs, AIs, and IETs may influence digital student agency and meaningful learning in Chemistry teaching. According to Ausubel (2003), "meaningful learning" occurs when new information is substantially integrated into the learner's existing cognitive structure, being particularly enhanced by methodologies that involve problematization, contextualization, and autonomy (Freire et al., 2025).

The research tools and data collection strategies were based on participant observation and reflective field diaries throughout the educational process, across different subjects and concurrent interdisciplinary extracurricular projects carried out within the Business and Innovation Incubator Center, with a focus on entrepreneurship and innovation.

Qualitative research, according to Ludke and André (1986), seeks to understand educational phenomena from the participants' perspective, valuing context, lived experiences, and the meanings attributed by the individuals involved in the educational process. This approach is not focused on numerical data, but rather on the richness of interactions, practices, and transformations that occur within the studied environment.

Within this perspective, the "participant observation" technique was employed, as described by Triviños (1987), which consists of the researcher's direct involvement in the field of study, allowing them to experience educational practices and seek to understand how behaviors, relationships, and meanings are constructed in everyday school life. This methodological choice was essential for a sensitive and critical analysis of pedagogical practices involving VLEs, AIs, and IETs in Chemistry teaching, integrating theory and practice through active listening and a commitment to the students' context.

Participant observation took place during in-person classes with elements of "Hybrid Education," in classes from Integrated High School (IHS) within Vocational and Technological Education (VTE) and from the undergraduate degree program in Biology Teacher Education, involving chemical and technological knowledge, as shown in Table 1. Throughout the activities, the teacher-researcher directly followed students' interactions and performance in tasks involving the use of VLEs, AIs, and Entrepreneurial Pedagogical Proposals (EPPs), such as the final project focused on chemical concepts and innovative entrepreneurship.

Thus, we understand "Hybrid Education" as the "combination and integration of pedagogical activities through in-person education in the physical school space and non-in-person education, supported by digital information and communication technologies and online environments, aimed at innovation and the expansion of time and space in the educational process, with curricular organization and planning that are compatible" (Lima, 2024, p. 14), which is intrinsically aligned with the axes and resources used in the methodology of this study.

Regarding "Hybrid Education" in its strict sense, we understand it as an "ecosystem that prioritizes the careful combination of in-person pedagogical activities within the educational institution and other activities outside it (in a relational and continuous way), mediated by teaching planning and the use of ICTs" (Brazil, 2025, p. 40), with a focus on the expansion of time and space and on student agency (Costa and Lima, 2025).

Table 1. Classes/subjects, courses, academic term, workload, digital educational resources, and pedagogical methodologies.

Classes/subjects	Courses	Academic term	Workload	Digital educational resources and pedagogical methodologies
1st year IHS Chemistry I	Integrated Technical High School in Sanitation	2024	54h	VLE (labels, forums, chats, lecture slide pages, readings, assignment submissions, questionnaires, URL links, software, image galleries, file folders, infographics, and mind maps) AIs (studies, research, explanations and content summaries, organization and comprehension of exercise list calculations, entrepreneurial advertising prompts, suggestions of names and business areas for fictional companies) Final entrepreneurial project (EPP) using AIs and the CANVA platform (creation of a fictional company, including name and logo, financial spreadsheets, product pricing, estimated costs and profits over a 1-year period, in a specific area chosen by groups of 3 to 4 students, with each member assigned a specific role within the company)
1st year IHS Chemistry I	Integrated Technical High School in Biotechnology	2024	54h	
2nd year IHS Water and Effluent Analysis	Integrated Technical High School in Sanitation	2024	108h	
3rd year IHS Methods of Extraction, Separation and Purification of Bioproducts	Integrated Technical High School in Biotechnology	2024	54h	
1st semester General Chemistry	Undergraduate Degree in Biological Sciences Teacher Education	2024/1	54h	

Source: Prepared by the authors.

The observations were recorded in "reflective field diaries" through the institutional system SUAP, documenting aspects such as student engagement, autonomy in activities, use of digital tools, and the mobilization of chemical concepts to solve real-world challenges. These records were analyzed in light of content analysis according to Bardin (2011), allowing the identification of categories and patterns that reveal aspects of student agency and meaningful learning.

The "reflective field diaries," used as an instrument of data recording in this research, are aligned with Dewey's (1959) conception of reflection in action, for whom reflective thinking is an active, persistent, and careful process of examining beliefs and practices in light of their foundations and consequences. Thus, the records were not limited to factual descriptions of classes, but involved a critical, continuous, and dynamic analysis of lived experiences, enabling the researcher to reinterpret the educational process based on observation and attentive listening to students.

Content analysis, according to Bardin (2011), consists of a set of systematic and objective procedures for description and interpretation that allow for the organization and categorization of qualitative data, with the aim of identifying meanings, patterns, and inferences relevant to the research problem under investigation. The processes involving the application of this methodology and participant observation took place in person throughout the entire 2024 academic year, as well as during the completion of final projects involving the creation of fictional companies based on chemical knowledge studied throughout the courses.

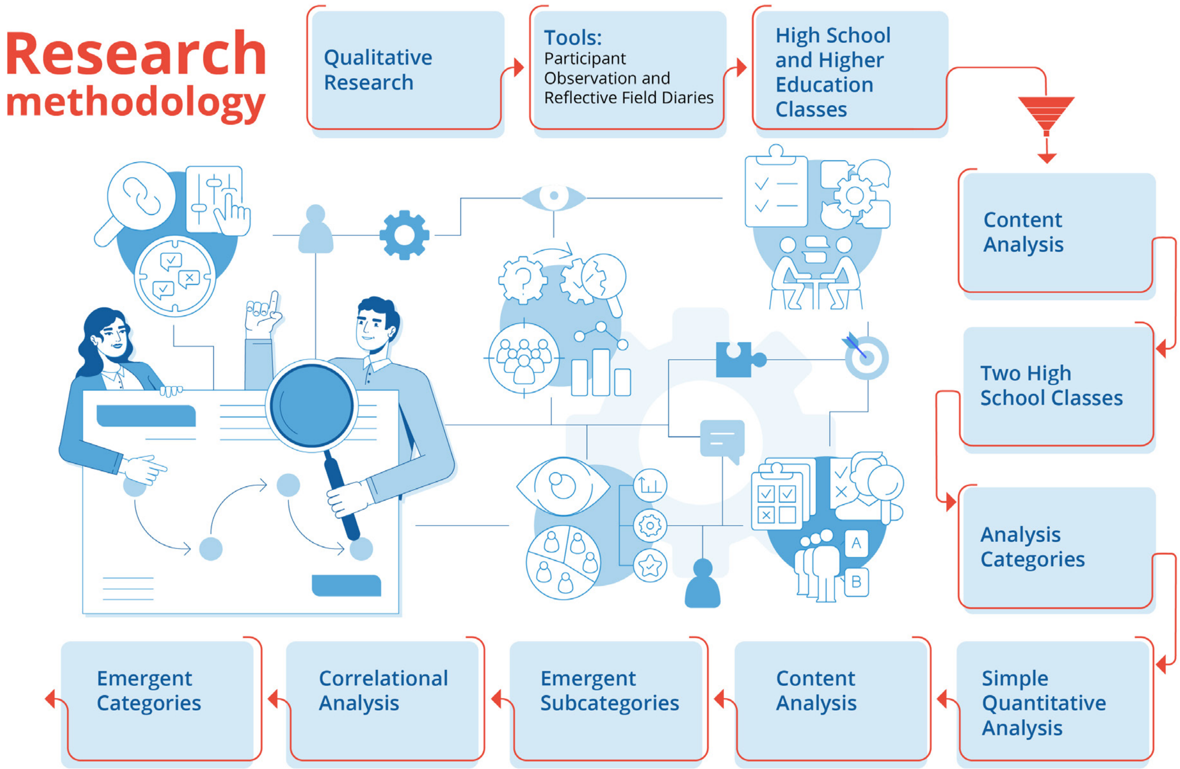
Through this follow-up, observed perceptions, and data processing, it was possible to capture students' perceptions regarding the methodologies used, the use of educational technologies, as well as the impact of entrepreneurial approaches on their learning processes.

3.1. Analysis Categories

The initially proposed analysis categories sought to identify and address topics such as: (i) the effectiveness of VLEs in the learning process, (ii) the contribution of AI tools to the understanding of chemical concepts and entrepreneurial suggestions, (iii) the impact of entrepreneurial activities on the development of critical and creative skills, and (iv) the level of engagement and autonomy perceived during the activities.

The categories and observed data were processed through a simple quantitative analysis, with the generation and interpretation of graphs, charts, and descriptive tables, allowing an overall visualization of student engagement and receptiveness toward the innovative methodologies applied. After the processing of this data, the interpretations were subjected to Bardin's (2011) content analysis in order to identify subcategories and emergent categories related to student agency, understanding of chemical content, creativity, and critical thinking. Figure 1 summarizes the methodological flowchart adopted in this research.

Figure 1. Flowchart of the research methodological framework.



Source: Prepared by the authors.

4. RESULTS AND DISCUSSION

The extracurricular interdisciplinary extension project transversal to this study, entitled "Interdisciplinary Socio-Entrepreneurial Actions for Awareness, Prospecting, and Regional Pre-Incubation of the Incubator Center of the Formosa Campus"[1], together with entrepreneurial concepts addressed in parallel with chemical concepts in the classroom, served as guiding elements for the discussions throughout this research process.

In this study, we define and conceptualize Innovative Entrepreneurial Themes (IETs) as diverse entrepreneurial topics that, in a transversal and integrated manner with scientific knowledge, foster discussions and reflections on entrepreneurial concepts and methodologies, encouraging innovative solutions to contemporary situations and social challenges, while simultaneously promoting student agency through the development of specific competencies and skills for critical and proactive action. In Table 2, the IETs addressed in the extension project can be identified, along with the concepts that were also discussed in an integrated manner throughout the courses.

[1]Call for Proposals 04/2023/PROEX/IFG – Extension Actions – Tier 2 (link).

These discussions with the participants of the interdisciplinary extracurricular extension project, which took place on a biweekly basis and were also addressed transversally during the courses, were of significant importance for the final entrepreneurial project, as an EPP, at the end of each curricular component. This final project integrated chemical concepts, the use of AIs for problem-solving and entrepreneurial suggestions, as well as the use of the CANVA platform for the preparation of creative advertisements, logos, and presentations. A file with an example of the guidelines provided for the final projects in one of the mentioned groups, containing students' production and the chosen entrepreneurial areas, is available in a shared document on Google Docs via the link.

In this sense, we define Entrepreneurial Pedagogical Proposals (EPPs) as pedagogical actions that, mediated by scientific knowledge, foster the development of competencies and skills such as creativity, problem-solving, and strategic thinking, as well as the practice of applying scientific knowledge in a creative, proactive, and agentic manner—whether in projects, experiments, innovative solutions, or the proposal of business and innovative entrepreneurial ventures.

Table 2. Innovative Entrepreneurial Themes (IETs) addressed in the extension project and in classroom activities in a transversal manner.

IET	Objective
Entrepreneurship and Business Incubator	To discuss classical concepts and forms of entrepreneurship, as well as the functioning of a Business Incubator.
Innovative Entrepreneurship	To differentiate concepts and present forms of innovative entrepreneurship.
Innovation	To understand the concept of innovation in products and processes.
Business Plan	To understand what a business plan is.
Practical Business Plan	To reflect on and propose a practical business plan.
Business Model (CANVAS)	To understand what the CANVAS business model is and how to develop it.
Design Thinking	To identify the concept of Design Thinking and its various forms of application, such as prototype ideation and business organization.
SWOT Matrix	To define the elements that compose the matrix and practice its development in different areas.
Physical and Digital Marketing	To understand mechanisms for creating promotional materials and dissemination in physical and digital media.
Online Business Opportunities	To explore various online business possibilities, as well as strategies for reaching a target audience.
How to Start a Business	To identify how to start a business, including the necessary bureaucratic requirements.

Source: Prepared by the authors.

4.1. Virtual Learning Environments in Hybrid Education

The scope of this research was based on observations and interpretations related to two first-year Integrated High School classes at IFG – Formosa Campus, totaling 60 students (29 students from the Biotechnology Technical program and 31 students from the Sanitation Technical program). As illustrated in Graph 1, it is possible to observe, through the VLE (Moodle) used institutionally at IFG since 2003 (IFG, 2025), the distribution of 66 digital teaching-learning resources used in the applied methodology.

It is considered that the use of VLEs, such as Moodle, contributes to the integration of multimedia tools available within the platform, such as forums, videos, and others, as well as web-based resources (Barquero et al., 2019; Maranhão et al., 2025).

The Moodle platform, according to Silva et al. (2025a), is the most widely used within Brazilian Federal Institutes, being adopted by 38 institutions, representing 89.47% of the surveyed institutions. This prevalence can be attributed to several factors, such as being open-source and free of charge, offering extensive configuration possibilities, and allowing the inclusion of plugins that can be adapted to specific needs and to the customization of courses and students. Its user-friendly interface is designed to facilitate efficient use, reducing the learning curve for both administrators and instructional designers as well as end users.

Another relevant factor is the large global community of Moodle users and developers, who contribute with updates, support, and additional resources, strengthening institutional confidence in the choice of this platform. These aspects, combined with its ability to integrate with other educational tools, make Moodle a robust and reliable choice for managing a wide range of courses (Silva et al., 2025a).

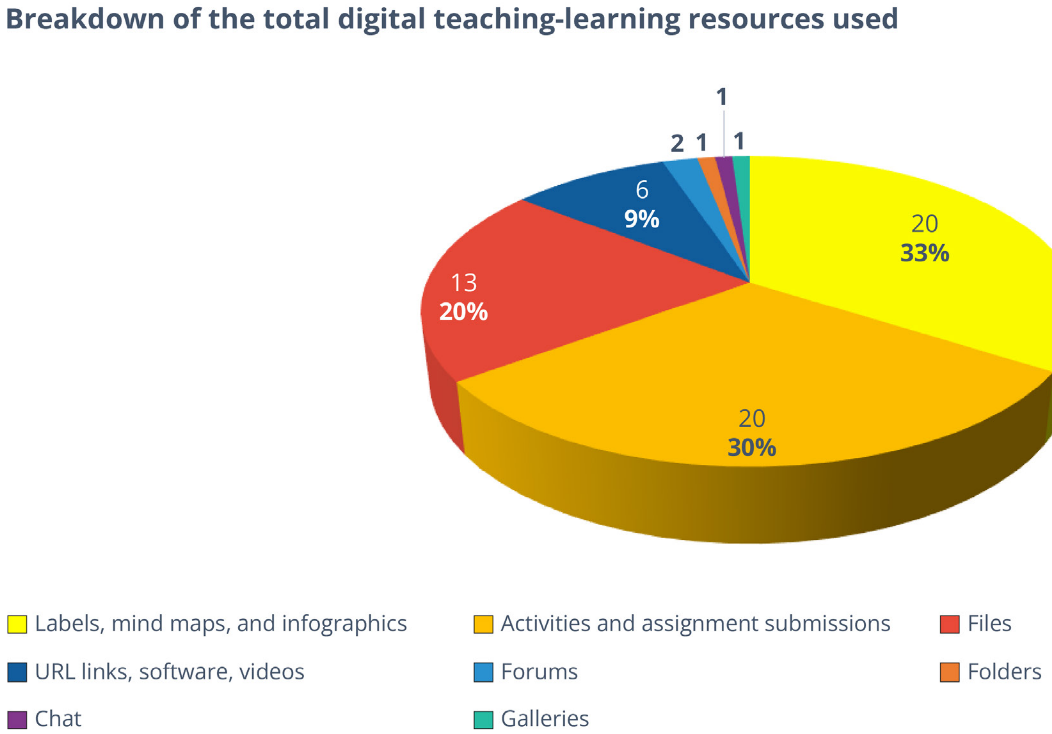
This platform allows teachers to use it as a tool for organizing content and activities with flexibility, using resources such as quizzes, forums, and progress-tracking tools, which contribute to a more dynamic teaching process centered on students' needs (Silva et al., 2025b).

According to Filatro (2018), VLEs, such as Moodle, are platforms that facilitate interaction between students and educators by providing access to instructional materials and assessment tools. Playing a vital role as a mediating tool between educator and student, VLEs offer a diversification of educational formats and strategies, being essential to address different learning preferences and styles, while promoting student interactivity and autonomy. These platforms are essential for overcoming physical and temporal barriers, providing a dynamic and interactive educational experience (Silva et al., 2025a).

The personalization of teaching is a significant advantage of VLEs, as it allows the adaptation of the learning pathway to the individual needs and preferences of students. Analytics and reporting tools help teachers identify specific difficulties and provide targeted support, facilitating assessment and immediate feedback—essential actions for students to quickly identify areas for improvement and for educators to continuously monitor their progress (Filatro, 2018; Silva et al., 2025a).

In this context, in dialogue with Lima's (2024) concept, the use of VLEs in "Hybrid Education" becomes highly beneficial for the combination and integration of pedagogical activities supported by digital information and communication technologies, aiming at innovation and the expansion of time and space in the educational process. The flexibility and personalization of teaching effectively contribute to each student progressing at their own pace, exploring areas of interest and developing essential skills.

Graph 1. Breakdown of the total digital teaching-learning resources used in the applied methodology (66 resources = 100%).



Source: Prepared by the authors.

4.2. Supporting and Protagonist Digital Teaching-Learning Resources

Based on the theoretical discussions, observations, and data analysis of this research, in light of Vygotsky and Moran, we define "digital student agency" as a dynamic, collaborative, and proactive attitudinal process, characterized by social and digital interaction, mediated by digital technologies that enable the personalization of active and meaningful learning, fostering individuals' critical engagement with scientific knowledge and the technologies available in a given socio-historical context.

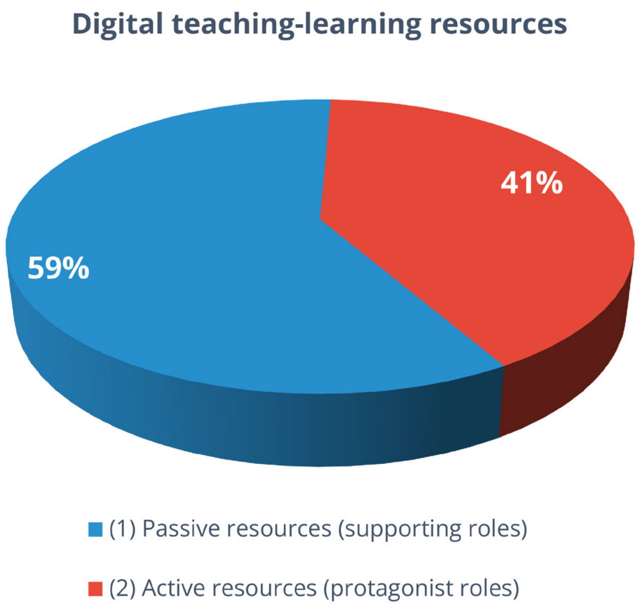
Under this understanding of digital student agency, we propose and divide two emergent subcategories derived from the digital teaching-learning resources used: (1) passive resources with supporting roles and (2) active resources with protagonist roles. Thus, the total digital teaching-learning resources used in Table 1 were reorganized, as well as the distribution of their percentages presented in Graph 2.

Table 1. Division of digital teaching-learning resources into two emergent subcategories: (1) passive resources with supporting roles and (2) active resources with protagonist roles.

Digital teaching-learning resources	Description	Quantity
(1) Passive resources (supporting roles)	Labels, mind maps, infographics, folders, files, and galleries.	39
(2) Active resources (protagonist roles)	Activities, assignment submissions, software, videos, pages, URL links, forums, and chats.	27
Total		**66**

Source: Prepared by the authors.

Graph 2. Total digital teaching-learning resources used from the Moodle VLE: (1) passive resources with supporting roles and (2) active resources with protagonist roles.



Source: Prepared by the authors.

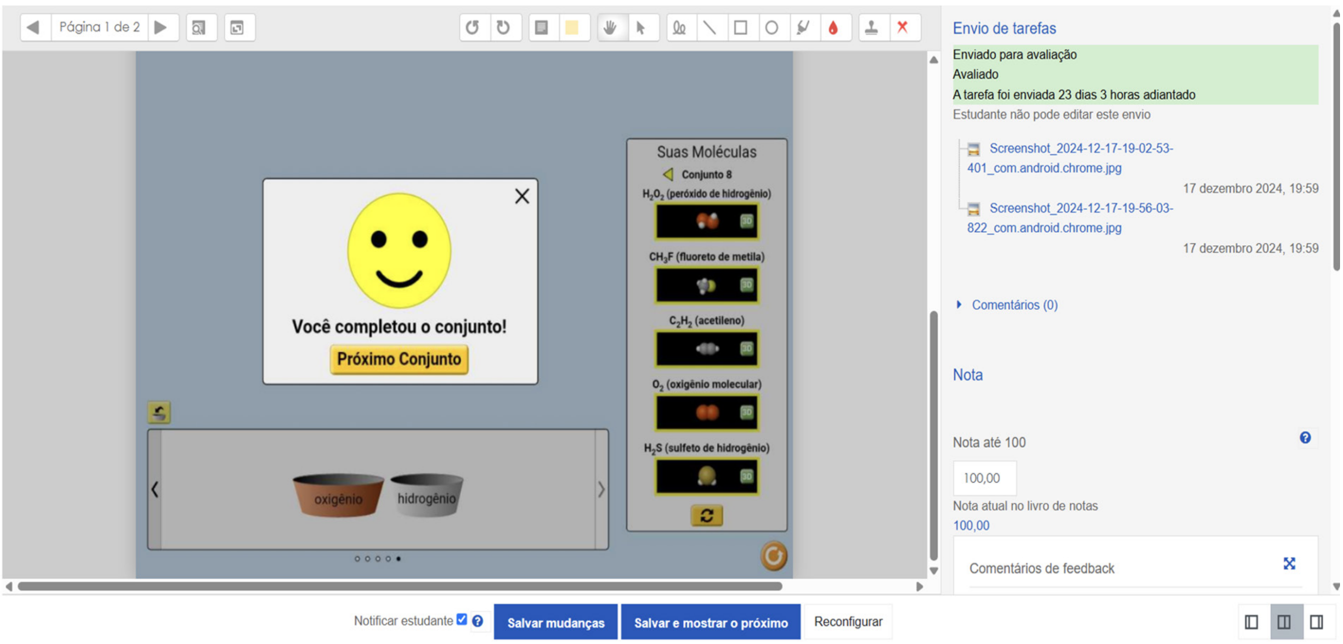
In this sense, we define "passive resources with supporting roles" as a set of activities within VLEs that require skills of reading and interpreting texts, figures, graphs, tables, web pages, files, lesson materials, mind and/or concept maps, labels, infographics, among others. These resources are of fundamental importance for the knowledge, understanding, and application of scientific concepts within a dynamic teaching-learning process in an autonomous and atemporal manner, mediated by the use of virtual classrooms.

Among the various passive resources with supporting roles, we highlight the use and construction of concept maps in teaching and recognize their importance for establishing connections between concepts, reducing simple memorization and reproduction of content, definitions, or algorithms for problem solving, thereby promoting students' conscious reasoning for articulating concepts with one another. In this way, the creation and use of concept maps presents itself as a new perspective for an active and conscious learning process (Freire et al., 2025).

On the other hand, "active resources with protagonist roles" are defined as a set of activities within a VLE that require skills such as visualizing, reflecting, watching, practicing, creating solutions, problem-solving, writing, producing texts, comments, answers, debates, assessments, and syntheses, as well as the ability to express oneself orally by socially sharing knowledge. Thus, these include activities such as assignment submissions, questionnaires, use of software and apps, videos, web pages, URL links, forums, chats, video recordings, visual creations, dissemination on social networks, as well as presentations of ideas and academic work.

It is also worth highlighting in this study, within the active resources with protagonist roles, the use of free online software[2] for structural drawing, involving studies of molecular compounds and chemical bonding (Figures 2 and 3), made available and addressed within the Moodle VLE.

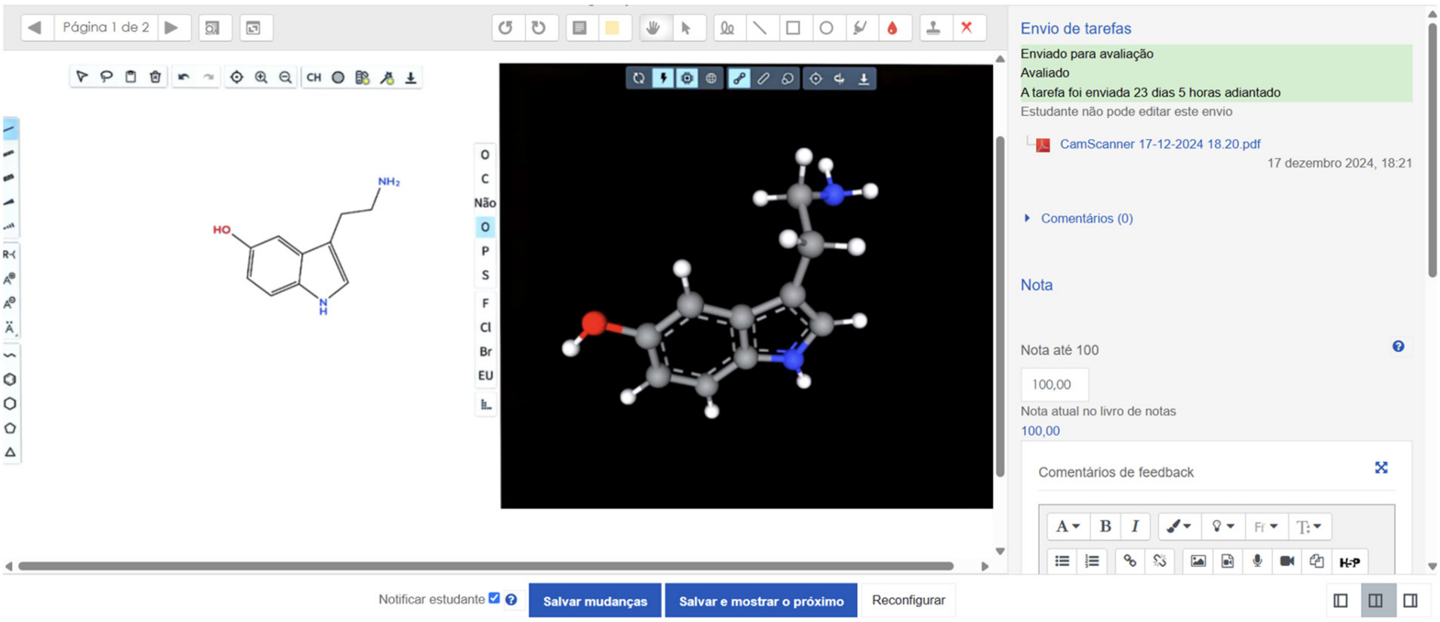
Figure 2. Figure 2. Use of the PhET online software for structural drawing involving studies of molecular compounds in chemical bonding (example of student production and submission of answers from 1st-year Integrated High School students).



Source: Prepared by the authors.

[2] PhET (link) e MolView (link).

Figure 3. Use of the MolView online software for structural drawing involving studies of molecular compounds in chemical bonding (example of student production and submission of answers from 1st-year Integrated High School students).

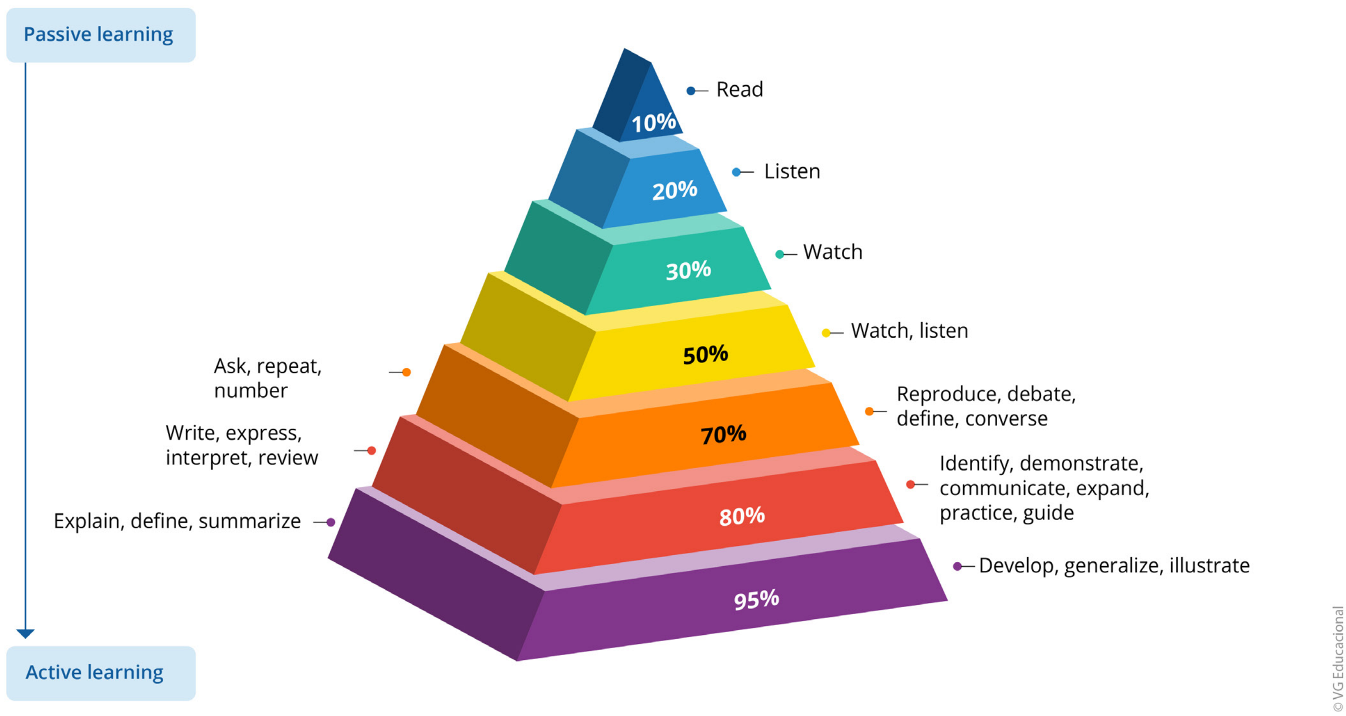


Source: Prepared by the authors.

We distinguish the two emergent subcategories based on theoretical frameworks that value the complexity and depth of the learning process. The distinction between passive and active resources (supporting and protagonist roles) directly aligns with the cognitive levels proposed in Bloom's Taxonomy (Anderson and Krathwohl, 2001; Bloom, 1956), in which the former are associated with stages such as remembering, understanding, and applying, while the latter relate to higher-order levels such as analyzing, evaluating, and creating. Furthermore, this division is also inspired by the Learning Pyramid developed based on the studies of William Glasser (1993), which highlights that students learn more when they actively do, teach, and engage in the learning process, as illustrated in Figure 4.

Thus, the categories defined in this study seek to evidence how different types of digital resources, when well structured and contextualized, can stimulate varying levels of student agency and deepen meaningful learning in Chemistry teaching mediated by educational technologies.

Figure 4. “Learning Pyramid” developed based on the studies of William Glasser (GLASSER, 1993). Source: TUTOR MUNDI (2021), image prepared by the authors.



Source: Prepared by the authors.

4.3. Artificial Intelligence and Innovative Entrepreneurial Themes in Chemistry Teaching

In this study, we considered the main AIs used at the time of the research, such as ChatGPT, Gemini, and Copilot, which were initially introduced to students in order to identify similarities and their familiarity with the available tools.

In this way, the use of AIs, IETs, and creative design platforms such as CANVA, in a transversal manner within Chemistry teaching, can be considered entirely as active resources with protagonist roles. This was evidenced by the development of students’ skills and competencies related to visualizing, reflecting, practicing, creating solutions, writing, producing texts, comments, answers, debates, evaluations, and syntheses, as well as the ability to express themselves orally by socially sharing knowledge, as occurred during the presentation of the final projects involving chemical concepts and IETs.

During the implementation of this study, several elements were identified and analyzed through participant observation, such as the statement of Student A from the 1st year of Integrated High School in the Biotechnology technical program: “Wow, professor, I thought it was wrong or forbidden to use AI to study, solve exercises, and complete assignments.” In our analysis and reflection regarding the specific use of AIs, we understand that, in a transversal manner, this pedagogical practice can identify and enhance digital student agency, in addition to contributing significantly to the internalization and socialization of scientific knowledge.

We advocate for the ethical and social use of AIs in teaching and learning processes, as we believe that when individuals write, ask questions, interpret, practice, produce texts, review, and create solutions and concise syntheses in their autonomous individual study or in groups, they engage in both social and digital reflection. In this process, students write and analyze AI-generated responses in relation to the prompts they submit, as well as critically interpret these responses, requiring a solid foundation in prior scientific knowledge discussed socially with the teacher and the class throughout the teaching and learning process.

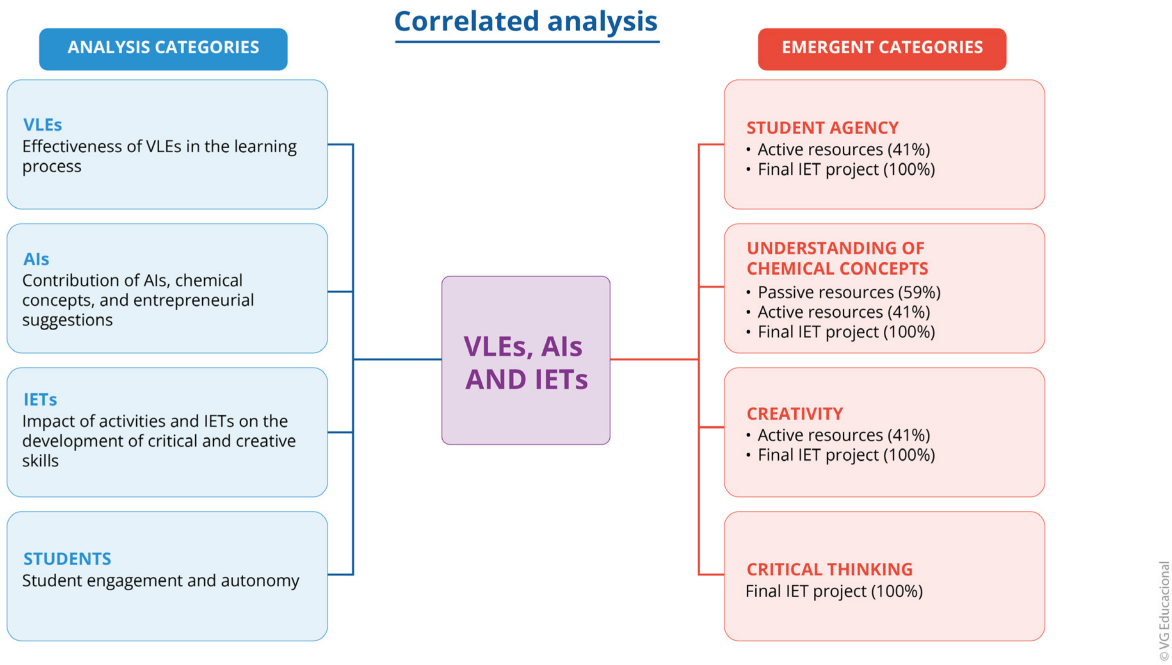
It is important to emphasize, with care in methodologies involving AIs, that ethical use, adequate theoretical knowledge, and mediated, supervised, and teacher-guided social interaction in an academic manner are essential initial phenomena in teaching and learning processes involving transversal elements and new digital tools in education. Thus, we understand that the integrated use of VLEs, AIs, and IETs can significantly contribute to Chemistry teaching and to other disciplines in general.

Regarding the IETs used, these stand out as entirely protagonist-oriented, since the individuals involved demonstrated full creativity, proactivity, sociability, teamwork, oral expression, and structuring skills, as they reflected on, discussed, and developed their innovative entrepreneurial proposals during the execution and presentation of their final projects.

4.4. Correlations between analysis categories, emergent subcategories, and emergent categories

Based on the entire discussion presented, involving the integrated use of VLEs, AIs, and IETs in Chemistry teaching, we identified the emergence of four categories: (i) student agency, (ii) understanding of chemical concepts, (iii) creativity, and (iv) critical thinking. Finally, in a comprehensive and correlated analysis between resources, analysis categories, emergent subcategories, and emergent categories, we can interpret and corroborate the overall findings of this study through the infographic shown in Figure 5.

Figure 5. Correlated analysis between resources, analysis categories, and emergent categories.



Source: Prepared by the authors.

We emphasize that the final projects involving IETs, even with initial guidance, were carried out in a fully autonomous and agentic manner by the students, where a high level of engagement, interest, and autonomy was observed among the classes studied, through appropriate teacher reflection based on field diary records. In light of this comprehensive analysis involving all variables, observed data, resources, methodologies, analysis categories, emergent categories, and their correlations, it was possible to infer that the use of VLEs, AIs, and IETs can contribute to student agency and to the promotion of meaningful learning in Chemistry teaching.

It is identified in the integrated learning of these tools that the student presents themselves as an active and technologically engaged subject, a protagonist in the educational process, developing autonomous skills in relation to socially and historically available new technologies. In this way, the teaching-learning process, intrinsically dynamic and requiring ethics, critical thinking, and civic, environmental, and proactive attitudes, as well as soft and hard skills, must be aligned with “technologies” and their innovations available in a given socio-historical context.

We emphasize, in the analysis of data identified in the field diaries, the reflection on the importance of the teacher’s role as a mediator and guide of scientific knowledge, which is currently “easily” available through various digital resources, sources, and technologies. The teacher, in their role as a representative of scientific culture, holds a central role and responsibility in promoting critical social discussion and inquiry into these digital sources.

In this regard, the teacher planned, organized, and implemented not only theoretical chemistry content during classes, but also activities in computer labs and extracurricular sessions through the Moodle VLE, aimed at supervised guidance on the use and application of AIs and IETs throughout the educational process of this study.

Furthermore, according to Costa and Teixeira (2025), the role of digital technologies as mediators extends beyond learning itself and also involves the transformation of the educational environment. By providing spaces in which students collaborate in real time and externalize their thinking, digital tools demonstrate the potential to reduce dependence on the traditional teaching format, which still prevails in many educational contexts.

According to these authors, another still underexplored element is the capacity of hybrid methodologies to create a culture of collective learning, in which collective intelligence develops in a self-sustaining way. It is observed that, in this sense, students not only engage with the use of digital tools but also begin to value and promote group learning, integrating themselves more actively into the process of knowledge construction (Costa and Teixeira, 2025).

Such development goes beyond conventional pedagogical goals and suggests that the continuous use of practices based on distributed cognition may shape a new generation of learners prepared to deal with collaborative, interconnected, and complex environments (Costa and Teixeira, 2025).

Thus, teaching models with hybrid elements may present a transformative potential that meets the profile of increasingly digital and connected students. The exploration of these technologies, when properly integrated into the curriculum, can create more resilient, collaborative, and future-oriented educational environments, prepared to address the demands of a constantly changing world (Costa and Teixeira, 2025).

5. CONCLUSION

Through the overall reflection on the work conducted, several challenging issues were identified, such as the availability of digital devices for carrying out activities, the scarcity of scheduled time in computer laboratories, and students' difficulties with software and VLEs, as well as with handling technologies and file conversion. However, given the challenges encountered throughout this process and their appropriate addressing, the objectives proposed in this study are considered to have been achieved.

Through the applied methodology, it was possible to promote innovative discussions and contribute to more dynamic and participatory teaching-learning processes related to the practical use of technologies. The integration of VLEs, AIs, and IETs allows for the observation of the development of autonomous and agentic skills in relation to socially and historically available new technologies, as well as student interest and engagement with the range of resources used throughout the educational trajectory.

In this context, the teaching-learning process tends to present itself in a dynamic and interactive way, stimulating both "digital student agency" and the Vygotskian concept of "student agency" as a whole. This finding is corroborated in this study, where a high degree of autonomy, proactivity, interest, and engagement among students can be observed in the use of technology-mediated educational resources.

It is also identified in this study, beyond participant observations, a significant proportion of active resources with protagonist roles involving didactic-pedagogical activities and practices, using VLEs, AIs, and IETs in an integrated and transversal manner in Chemistry teaching, with the students' final project being proposed and guided by the teacher and considered fully autonomous, creative, and agentic.

Thus, based on the elements and data emerging from the research, it was possible to infer that the use of VLEs, AIs, and IETs can contribute to student agency as a whole and to the promotion of meaningful learning in Chemistry teaching, since students become active participants in teaching-learning processes, using digital resources and entrepreneurial proposals.

In light of the results obtained and the reflections presented, this study shows that the integration of VLEs, AIs, and IETs in Chemistry teaching promotes not only the appropriation of chemical and entrepreneurial concepts, but also the development of autonomous, creative, and agentic skills in students. It was observed that, even in the face of challenges such as the availability of digital devices, limited laboratory scheduling, and initial difficulties in handling software and technologies, students were able to engage actively, demonstrating student agency in all its forms, both traditional and digital, by carrying out activities, developing final projects, and interacting critically and collaboratively in learning processes.

Active resources, when properly structured and applied, proved essential in fostering higher levels of understanding, analysis, and creativity, corroborating the theoretical frameworks used, such as Bloom's Taxonomy and Glasser's Learning Pyramid, as well as Vygotsky's principles of student agency. Thus, it can be stated that the applied methodology effectively contributed to meaningful, integrated, and interdisciplinary learning, strengthening the competencies and skills required for students' academic, social, and contemporary development, thereby reinforcing the relevance of the transversal and integrated use of technologies, innovative methodologies, and entrepreneurial themes in the educational context of the twenty-first century.

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