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Development of digital and science, technology, engineering, and mathematics skills in chemistry teacher training

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Citizens of the twenty-first century use specific skills to solve real-life problem situations, propose interdisciplinary solutions, and sustainably solve their communities' socio-scientific and technological problems, locally and globally. Science, technology, engineering, and mathematics (STEM) education is an integrated and interdisciplinary teaching-learning space. STEM careers are subject to gender gaps in terms of access to higher education, and only a quarter of female students follow a STEM career. Moreover, later in their professional careers, women often obtain lower salaries and income in the STEM professions. STEM education seeks to actively engage students by incorporating technologies into teaching-learning processes since, favoring searching, analysis, solution, and simulation of socio-scientific problems. The latter has become highly visible during the pandemic caused by COVID-19, particularly in emergency remote education measures. Information and communication technologies (ICT) plays a role in online education, either *via* the knowledge involved in school curricula or an understanding of how the pandemic has evolved. This is a triple task for professors since they must have the right skills to train citizens of the twenty-first century, build new stimulating learning spaces for their highly technologized students, and develop these skills in their students. This article reviews the concepts associated with digital and STEM skills by analyzing a case study, exploring the perception of students in terms of their development of these competencies, and the commitments required in the study plans made by a Professor of Chemistry in a Chilean state university. A mixed investigation was undertaken, considering three phases with different methodologies. The first phase consisted of a bibliographic study, comparing both the digital and STEM skills of several organizations in Chilean education (UNESCO, MINEDUC, and ISTE). ISTE was used as the basis of the applied questionnaire to establish coherence in the dimensions coming from different reference frames. A second phase refers to the analysis of the study plan programs associated with STEM, ICT, and chemistry teaching, through an Analysis Matrix of Aprioristic Categories. In a third phase, the development of digital skills in undergraduate Chemistry students and professors were evaluated through the Digital Competence Questionnaire of Higher Education Students. Based on UNESCO information, the STEM competencies address both the content and its application to problems related to STEM careers in a manner consistent with the training model for science and chemistry teachers. In the case of digital skills, UNESCO integrates international reference frameworks respecting each country's laws, enabling them to adapt them. In Chile, MINEDUC focuses on teachers' use of digital tools to improve the teaching-learning processes of students; and ISTE is focused on the skills of higher education. The analysis of the study programs shows that students' digital skills do not meet the requirements of the Chilean Ministry of Education (MINEDUC). However, the programs enhance more complex cognitive levels when the curricula advance, promoting STEM skills. The digital competence questionnaire for higher education students (CDAES) survey showed a development proportional to the curricular pursuit of the students where, in the first year of the degree, the students declare positive answers in 60.5% of the items consulted. This trend increases in the second and third years (90.7% of positive answers) and the fourth and fifth years (93.0 and 95.4% of positive answers). It remains a challenge to develop skills to design, create or modify technological educational media that promote the use of digital and STEM skills. In conclusion, this research proposes digital and STEM skills for teacher training, discussing the relevance of their integration in STEM teaching and learning. The teacher training curriculum does not have an explicit association with digital and STEM skills, although it addresses the skills required by national and international benchmarks. However, the students indicate positive attitudes toward the digital skills developed progressively during their training as teachers. As future Chemistry teachers, they value the development of digital teaching skills that allow them to address the challenges that arise in the classroom and thus promote the appreciation of STEM careers, which helps form citizens with more sustainable intentions.

KEYWORDS

STEM-digital-skills, stem, teacher education, chemistry teachers, STEM-education

Introduction

In Chile, there was an explosion in social awareness and demands for change at the end of 2019 in response to the long-term social inequalities (Paúl, 2019) that had previously hindered educational processes. However, with the arrival of the COVID-19 health crisis, normal school operations were disrupted, resulting in school closures and the wide-scale confinement of people to their homes for nearly 2 years, as reflected in many other countries during this time.

The health crisis highlighted inequalities at the local and global levels: billionaires increased their incomes whilst poverty increased (Chiodi, 2021; Ferreira, 2021). The digital divide deepened, affecting people with lower incomes and education levels, evidenced by a lack of adequate electronic devices or knowledge of their use (Ferrer, 2021), meaning not all students had the same opportunities, tools, or access to online classes, and resulting in an interruption and decline in education for many (Griffiths et al., 2021; Human Right Watch, 2021).

The hurried transition from face-to-face classes with limited access and use of digital resources, to classes based almost entirely on these media, was mediated by information and communication technologies (ICT) (Li and Lalani, 2020), forcing students to modify their methods of learning and teachers to modify their teaching strategies (Ruz-Fuenzalida,

2021) by adopting an emergency education (Mateus et al., 2022), which is still present today in a hybrid form.

In this scenario, teachers have enabled the educational system to be resilient, with an emphasis on teaching-learning processes for their students mediated by ICT. In the context of the pandemic, ICTs have generated learning opportunities through a constant effort by teachers and students to adapt to virtualized education (Amaya et al., 2020).

In Chile, the educational system is broken down as follows. Mandatory education, is composed of pre-school education and Primary education (grades one to eight), which is called "Basic," and Secondary education (grades ninth to twelve), which is called "Median." Higher education includes professional technical education (tertiary education of 2 years or more) and University education (degree and post-degree, 4 years or more).

In the case of the State University participating in this study, the initial training of science teachers is a bachelor's degree in education science in an undergraduate format. In this phase, teachers develop curricular activities for 10 semesters, which include internships. In the case of chemistry pedagogy, these internships are carried out at the end of the first, second, fourth, and fifth years of the course. In the last semester, a professional internship is carried out, which qualifies them as competent teachers to address the challenges of educating citizens in the twenty-first century.

The first priority of this research was to review the concept of digital skills and science, technology, engineering, and mathematics (STEM) for the training of science teachers who address interdisciplinary problems with sustainable solutions. Then, we aimed to determine the perception of their STEM and digital skills through a case study and the use of technologies by students in a chemistry teacher training program at a Chilean state university, as well as to analyze the training programs associated with these skills.

Research conceptual framework

Integration of technology in education: Science, technology, engineering, and mathematics education

The resilience of the educational community in emergency contexts is an example of a triumph for quality education that allows students to address the problems of societies in crisis, requiring a sustainable way out of the current situation of crisis and inequality. In this scenario, STEM education has emerged and seen its potential is recognized in strengthening the learning processes of students by addressing problematic situations in real life and solving them through interdisciplinarity, inherent values, and ethics. Its contribution to addressing various socio-scientific problems that arise at a local and global level—many with more catastrophic consequences than the pandemic, such as global warming and its consequences, water crises, and ocean acidification—are recognized as situations that can only be faced if we as a society have skilled and innovative professionals who have developed in the context of STEM disciplines for the twenty-first century.

STEM education was promoted at the beginning of the 1990s by the National Science Foundation, addressing the requirement to strengthen interest in natural sciences, engineering, and mathematics in the context of strengthening human capital in view of new socio-technological challenges (Baxter and Stolow, 2013); establishing itself as an emerging interdisciplinary movement with diverse conceptions that vary based on the context that defines it (**Table 1**), STEM education allowed its application at all educational levels and successfully complements itself with various methodological approaches (Domènech, 2019; Ross et al., 2022).

From its inception to the present, approaches to the concept of STEM have been constantly evolving, making it difficult to achieve a consensus (Martín-Páez et al., 2019). Within the great variety of conceptions of STEM education, there are some that highlight one or two disciplines above the others, such as the definition given by Shaughnessy (2013), who defined STEM education as the resolution of science and mathematics problems, incorporating technology and engineering. According to some authors, STEM education is a type of interdisciplinary learning based on real-life problems, where different disciplines are approached in a cohesive and fluid manner (Bybee, 2013; Mayes and Rittschof, 2021) and "is a pedagogical approach aimed at supporting the understanding of systems and connections" (York et al., 2019; Pernaa, 2022, p. 1,190).

Holmund et al. (2018) explored various STEM concepts among specialized and non-specialized teachers involved in the integration of these disciplines. Although the concept was not clearly demonstrated, common elements such as interdisciplinarity, the importance of instructional practices, and the resolution of real-world problems, were identified (Hu and Guo, 2021). Despite this lack of consensus, teachers have managed to improve their teaching practices using various approaches and methodologies when designing learning experiences for STEM subjects at the school education level. Through project-based learning and extracurricular activities, they have managed to foster application skills in real contexts, collaborative work, scientific literacy, creative and critical thinking, attitudes toward science and technology, and contextualization of professional development in STEM areas (Pramujiyanti et al., 2021; Hallinen, 2022; Pernaa, 2022).

When children and adolescents do not have equal access to quality STEM education as their peers because of gender, a gap is created that limits the development of skills that are strengthened by its application, such as critical thinking, creative thinking, problem-solving, and digital skills. This limitation not only reduces women's presence in the workforce of professions

TABLE 1 Review of STEM skills and STEM education.

	STEM skills refer to. . .	Definition	References
UNESCO	STEM skills allow contribution to economic growth, productivity, and meeting the demands of the future.	An individual's ability to apply STEM knowledge, skills, and attitudes appropriately in their day-to-day, work, or educational context. It contemplates know-what and know-how, considering the ethics and values to act appropriately and effectively in a given context.	Soo, 2019
America	They contribute to making informed decisions about their personal health, nutrition, training, transportation, cybersecurity, financial, and parenting skills, conduct analyses and solve problems, propose innovative solutions and face technological advances, being better prepared to participate in society as jurors, voters, and consumers, and have a better quality of life.	United States: Ability to identify questions, understand and engage with STEM issues as a concerned and thoughtful citizen. It presents 5 categories: problem-solving, social communication skills, technology and engineering skills, system skills and time, resource, and knowledge management skills. Mexico and Chile state that STEM Education develops transversal skills (critical thinking, problem-solving, creativity, communication, collaboration, data literacy, digital literacy, and computer science).	Committee on Stem Education, 2018; Tang and Williams, 2018; Bascopé et al., 2020; Gras et al., 2020; Pérez et al., 2020
Europe	It responds to socio-scientific problems; stakeholders from different sectors (education, politics, and business) emphasize the need to identify and improve the key skills and skills for the SXXI.	European Union: Skills that young people require to face the demands of their personal, civic, and labor future, to improve the international competitiveness of STEM-based industries, in a world economy led by innovation. Finland: Refers to a transversal curriculum, where STEM education is implemented through the problem-based learning strategy by means of socio-scientific issues.	European Commission, 2016; Hui et al., 2017; Maass et al., 2019
Asia	To boost the country's economy through promoting STEM education that trains talented and STEM-literate citizens to achieve a competent workforce for the future.	China: Skills for the twenty-first century (critical thinking, creativity, cooperation, and communication with others). South Korea: Does not declare STEM skills, but associates STEM education with the improvement of understanding, interest, and potential toward science and technology.	National Institute of Education Sciences [NIES], 2017; So et al., 2019; Hu and Guo, 2021; Lee et al., 2020; Ma, 2021
Oceania	The training of a workforce with STEM skills through interdisciplinary teaching committed to real world problems and competition in a global economy.	Australia: STEM capabilities are creative thinking, critical analysis, problem solving mathematical, scientific, and technological literacy, collaboration, interdisciplinary thinking, project management, and self-direction. STEM discipline skills and knowledge, collaboration, communication, independent thinking, integrated knowledge and ICT skills, and numeracy.	Fraser et al., 2019; Murphy et al., 2019

associated with STEM areas but also provides adult women with fewer tools to face personal and work problems, limiting their decision-making process and affecting their quality of life (UNICEF, 2020; Ortega-Sánchez et al., 2022).

The importance of STEM education lies in providing the skills that citizens of all genders require to sustainably solve scientific and technological problems both in their communities and globally. To achieve this purpose, it is necessary to implement STEM education without distinguishing between gender, race, ethnicity, or socioeconomic status.

Digital education

The educational context of the twenty-first century is immersed in a society with high consumption of digital media, where students spend between 16 and 21 h on media per day, that is, they spend most of their waking hours using various technologies (Guzmán-Duque et al., 2020). In addition, multimedia is extremely captivating for young people and presents lower infrastructure requirements, transforming them into facilitators of learning processes contextualized in their interests and relating technologies to knowledge (Elías et al., 2021a; Hernández-Ramos et al., 2021). Although the sciences are recognized as eminently experimental and have captivated students for centuries, experimental educational resources are rarely used in public secondary education, primarily owing to the lack of resources and infrastructure (Viera et al., 2017), further enhancing the use of ICT-mediated education. In this manner, the definition of digital education as "the act of teaching and learning through digital technologies" is relieved in the present reality, and even more so in emergency contexts.

Digital education is based on ICT, a type of technological medium, and its role in learning (**Table 2**). For example, the teaching-learning process can be conducted through mobile platforms and the use of different types of devices, such as mobile learning, mobile-Learning, or m-Learning (Bajpai et al., 2019; Espejo et al., 2021).

Migration to digital environments has benefited both students and teachers by optimizing information processing

TABLE 2 Description of different types of educational models based on the learning and ICT associated with them (adapted from Zydney and Warner, 2016; Huang and Hew, 2018; Romero and Quintero, 2018; Bajpai et al., 2019; Guzmán-Duque et al., 2020).

Learning and ICT	Definition	Characteristics
e-Learning—electronic learning—e-learning or online learning	Teaching–learning model that uses the Internet and ICT as communication and interaction tools in a training process. Considered to be the first evolution in distance learning that incorporated the use of ICT, leaving behind communication methods such as correspondence, radio, audio cassettes, and videos.	It allows a greater number of students to use the same application; students can learn at their own pace and reduce training time; allows combining different typologies of auditory, visual, and audiovisual materials; and develops the interaction between teachers and students as well as with the didactic contents.
m-Learning- mobile learning	Learning model that uses mobile devices as tools. It is considered to be the evolution of e-learning, owing to the incorporation of smartphones or tablets.	It is considered the next step in the development of online learning because it emphasizes the concept that you can learn anywhere and at any time, rather than just from a fixed or predetermined place.
b-Learning—blended learning	A literal translation is blended learning. It consists of a combination of virtual and physical environments in the learning process. Consider the use of traditional methodologies and ICT through e-learning and m-learning. It combines pedagogical approaches, and prioritizes the effectiveness and socialization opportunities of the participants, with the technological advances provided by online learning.	Blended learning is considered to benefit students and institutions, enhance learning outcomes, increase the flexibility of access, and develop the best use of resources and didactic content.
Gamification	A strategy that promotes the participation of students through the use of games, motivating them to be actors in their own learning and follow guidelines that improve their school performance.	It uses games to practice, apply knowledge, and improve the appropriation of theoretical aspects; facilitate the development of skills such as team and collaborative work; work in competitive simulated environments that allow them to work under pressure and the development of skills that facilitate decision-making for problem-solving; encourage the creation of collaborative content, allowing satisfaction in the use of virtual and mobile platforms; and adopt technology as a didactic mechanism to guide their courses.

and communication development (Venegas and Proaño, 2021). From this perspective, the challenge in initial teacher training implies creating a change in teaching strategies and pedagogical models of teaching and learning, including the technological devices used by students. Therefore, digital education is enhanced as a support for students who have access to it, as opposed to a classroom and face-to-face teacher, promoting autonomy and collaborative work with their peers online (Singh, 2015).

In this manner, the inclusion of ICT in education has generated new didactics and has enhanced pedagogical ideals formulated by teachers, psychologists, and epistemologists, such as (a) offering learners learning environments rich in materials and experiences that capture their interests; (b) providing greater freedom to explore, observe, analyze, and build knowledge; (c) stimulating imagination, creativity, and critical faculties; (d) providing them with multiple richer and more up-to-date sources of information; (e) providing them with a scientific understanding of social and natural phenomena; and (f) enabling multisensory learning experiences. ICTs become unmatched allies for innovation in education by facilitating: (a) collaboration between people with common interests and complementary skills, regardless of their location; (b) interaction with knowledge repositories; (c) synchronous and asynchronous communication; and (d) understanding of concepts in a transversal and integrated manner. ICTs are not only profoundly transforming the meaning of education, but have also become the best tools to adapt to change (UNESCO, 2021; Venegas and Proaño, 2021, pp. 20–21).

Digital skills in teachers

Understanding that teachers are leaders in the digital transformation processes of learning spaces, a review on the concept of digital competence is presented. This definition began to form with the development of ICT as a transformational entity in society. One of the first to define and use the concept of digital competence was the European Union (Borrell and Enestam, 2006), defining digital competence as "The safe and critical use of information society technologies for the work, leisure, and communication. [sic] It is based on the basic skills of ICT: use of computers to obtain, evaluate, store, produce, present and exchange information, and communicate and participate in collaborative networks through the Internet" (p. 6).

Da Silva and Behar (2019) described digital skills as a set of elements that include knowledge, skills, and attitudes directed toward the use of ICT. In addition, it considers it fundamental for a social context in which the use of possible technologies is constantly explored, where the digitally competent subject can understand enough technological resources to know how to use information critically and thus, communicate using various tools. Similarly, Zhao et al. (2021) suggested that an approach should be taken to the pedagogy involved in digital skills that encourages adaptation or evolution toward both the new connected society and new curricular model. They also stated that teachers and students have a basic or medium level in the development of digital skills, allowing them to communicate and collaborate, but with this approach if they encounter any difficulty, they are stuck.

Digital skills in teachers refer to the development or improvement of pedagogical tasks through digital technologies, for which the concept of digital pedagogical competence considers the constant use of the attitudes, knowledge, and skills required to organize, conduct, evaluate, and revise a continuous method of learning through ICT, based on theory, recent research, and experience that supports possible student learning (From, 2017). However, a component is missing, which is added by Lund and Eriksen (2016) when recognizing that digital skills in teachers present a double challenge: Not only do they have to use different digital tools in their own professional work, but they must also be able to promote the use of ICT in their students in a productive and relevant manner. This represents a greater challenge because it goes beyond the immediate requirements of teachers in training and involves situations in which knowledge is transformed into discipline-specific didactics, class management, and advising students to productively use culturally available resources that have finally been framed based on the education policy of each country (**Table 3**).

In Chile, digital skills are guided by the recommendations of UNESCO (2019), which provides a framework of skills for teachers in ICT matters. This framework is proposed as a guide for effective integration into teacher education programs. That is, the capacity of teachers to integrate ICT is strengthened, so that they structure learning in an innovative manner, combining technology with pedagogy, developing social activity, and promoting cooperation and collaborative learning. The Chilean Ministry of Education (MINEDUC) demands that teachers change their pedagogical practices using ICT to improve the teaching-learning process of students. According to MINEDUC (2011), "Good use of computers and the Internet is one of the skills that should characterize the competent citizen in the twenty-first century. Therefore, by achieving this at the end of their schooling, young people master the basic tools of ICTs, which is an important objective of the curricular plan of any educational institution" (p. 13).

The evaluation of digital skills is framed in its origins in international standards such as those developed by the International Society for Technology in Education (ISTE). These standards have promoted a guide for the effective use of technologies as well as the development of skills to learn, teach, and lead in this developing digital age (ISTE, 2022). **Table 4** shows other reference frameworks that frame teacher training; note that they do not include all the aspects considered in the dimensions of digital competencies proposed by UNESCO (2019), which is particularly concerning in the case of teachers. Chemistry teacher training standards (2022) have just entered into force.

At the national level, two standardized tests have been conducted to address the use of ICT: the international computer and information literacy study (ICILS) and the quality measurement system in education (SIMCE TIC). For its part, the ICILS seeks to assess "an individual's ability to use computers to research, create, and communicate, and thus be able to participate effectively at home, school, workplace, and digital society" (Education Quality Agency, 2019a, p. 4). For 2018, this study showed that the students presented medium and low results; however, 20% were below the minimum level, with no gender difference, but a socioeconomic gap (Education Quality Agency, 2019b). In the case of the SIMCE TIC, the development of ICT skills in students in the fourth year of secondary education (second year of Chilean secondary education) was evaluated, and the last evaluation (2013) showed that 46.9% of the students presented at an initial level, 51.3% at an intermediate level, and only 1.8% at an advanced level (Enlaces, 2014).

For higher education students as well as for chemistry teacher training students, as far as it has been possible to review, no studies were found that accounted for the level of development of digital skills. Although there have been actions such as those taken by Silva et al. (2016), who raised criteria to evaluate digital skills in teachers in training, this measurement has not yet been carried out. Based on the SIMCE results, it was expected that students would not develop digital skills when they enter their degree.

Because of the technological and digital contexts in which STEM is immersed, it is impossible to understand STEM education in the absence of digital skills (or vice versa). The relationship between the field of STEM disciplines and digital skills is symbiotic because when implemented together, they strengthen scientific, mathematical, and technological skills (López et al., 2021).

Another point of convergence between STEM and digital skills occurs when they are analyzed from the perspective of tertiary education and the workforce. STEM professions or occupations require a high level of digital skills that need to be addressed through digital education, both at school and in higher or tertiary education institutions (Economic Commission for Latin America and the Caribbean, 2020). Therefore, developing digital skills in science teacher's initial training, particularly chemistry teachers, is critical when promoting science at school and entry into professional STEM-related degrees.

Materials and methods

The methodological design of the study allowed enabled it to answer the following questions: (a) What is the

TABLE 3 Description of the UNESCO dimensions around the teacher training frameworks and standards that include digital skills.

	Students of higher education (ISTE, 2007)	(MINEDUC, 2011)	(European Commission, 2016)	**Standards pedagogy in chemistry** (MINEDUC, 2022)
UNESCO (2019)	1. Understanding the role of ICT in education policies			
	Digital citizenship: Understanding human, cultural, social affairs, and legal and ethical conduct	Social, ethical, and legal: use and incorporation of ICT, a framework of respect and commitment, oneself, others, and the environment	Not described	Not described
	2. Curriculum and assessment: Promotion of specific objectives and contribution to assessments			
	Pedagogy: Acquisition of ICT competencies improves teaching-learning processes	Professional development and responsibility: use of ICT as a tool and opportunity of improvement	Communication and collaboration	Not described
	3. Pedagogy: Acquisition of ICT competencies improves teaching-learning processes			
	Critical thinking, solution of problems and decision making	Pedagogical: integration of ICT to teaching processes and learning	Digital content creation	Scientific research skills, nature of science, substances, intermolecular interactions, chemical reactions, and thermodynamics
	4. Application of digital competences			
	Organization and administration	Management: Development and/or strengthening of students' learning processes	Information and information literacy	Scientific research skills, and the nature of science
	Communication and collaboration	Technique: use of systems and current and emerging tools	Safety	Nature of science
	5. Professional learning of teachers			
	Research and management of information		Troubleshooting	

reference framework for the development of digital and STEM skills considered in the science teacher's initial training, in particular chemistry teachers?; (b) What is the perception of students regarding the development of their digital and STEM skills during their teacher's initial training?; and (c) Is the development of digital and STEM skills promoted through the programs considered in the Study Programs?

Adaptation of the digital competence questionnaire for higher education students questionnaire

In the first instance, as the basis of the questionnaire used, a review of the dimensions and evaluation criteria presented by the ICT standards for students (ISTE, 2007) was conducted, to later compare the questions and dimensions of the CDAES questionnaire described and validated by Gutierréz-Castillo et al. (2017). The questionnaire included a section on informed consent and characterization of the participating subjects. Each question of the CDAES questionnaire was analyzed for examples and words that were not used in the country and then corrected with words that did not interfere with or modify the meaning of the items (Table 5). A pilot study was conducted with a group of students (n = 10) that asked about their impressions regarding the questionnaire and its observation helped in adapting the questions of the questionnaire to the context of the participating students. The students who participated in the pilot study were not part of this study.

Determination of digital skills in students from initial training of chemistry teachers

To determine digital skills, mixed-type research was conducted with a quasi-experimental methodology (Elías et al., 2021b) and a naturally constituted group of participants (n = 49,

TABLE 4 Relationship between UNESCO and teacher training frameworks in Chile.

UNESCO	Standards for educators (ISTE, 2016)	Common framework for teaching digital skills (INTEF, 2017)	Chemistry teacher standards (MINEDUC, 2022)	Framework for good teaching (MINEDUC, 2021)
1. They understand the relationship of ICTs to national priorities in education.	Not described	Not described	Not described	Not described
2. They understand how ICT promotes specific objectives defined in the curriculum, and how it can help in assessment.	X	X	Not described	X
3. They acquire ICT skills to improve teaching and learning methods.	X	X	X	X
4. They acquire digital tools.	X	X	X	X
5. They manage activities in educational institutions and ensure the protection of people.	Not described	X	X	X
6. Empowerment of teachers with ICT so that they implement professional improvement.	X	X	Not described	X

36.3% of the population total students, cohorts from 2017 to 2021, **Table 6**). The participants were students of the bachelor of education in chemistry and pedagogy in chemistry at the metropolitan university of educational sciences (UMCE). To start the investigation, the signing of an informed consent form was requested (Annex 9.2) to support the ethical aspects described in Law 20,120 (2006).

The digital skills declared by the students in the initial training of chemistry teachers were determined by applying the CDAES questionnaire, which consisted of three sections: (a) obtaining informed consent, (b) characterization of the sample, and (c) the CDAES questionnaire.

The CDAES questionnaire consisted of 43 items (**Table 5**) structured as positive statements and the responses were rated on a 4-point Likert scale, where 1 = strongly disagree, 2 = disagree, 3 = agree, and 4 = strongly agree.

The structured questionnaire was in Spanish and had six previous dimensions based on the ISTE (2007): (D1) technological literacy (items 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, and 12); (D2) information search and treatment (items 13, 14, 15, 16, 17, and 18); (D3) critical thinking, problem solving and decision making (items 19, 20, 21, and 22); (D4) communication and collaboration (items 23, 24, 25, 26, 27, 28, 29, 30, and 31); (D5) digital citizenship (items 32, 33, 34, 35, 36, and 37); and (D6) creativity and innovation (items 38, 39, 40, 41, 42, and 43).

The data were organized, coded, and statistically analyzed using IBM SPSS Statistics 25 software and graphed using Origin 2021 software. The collected data were combined in the same database and descriptive statistics were calculated: medians, modes, frequencies, and variances of the questionnaire items. The reliability of the questionnaire was determined through Cronbach's α Coefficient, based on Gutierréz-Castillo et al. (2017), who validated the CODES questionnaire.

Documentary analysis of the digital skills described in the study plan of initial training of chemistry teacher

The presence of curricular activities associated with the development of digital skills was conducted through an a priori analysis (Díaz et al., 2020) of the programs of the subjects of communication skills (first semester), applied computing (second semester), and the subjects of the didactics line of the old and redesigned curriculum of the chemistry pedagogy career, because both curricular programs are in force. In addition, the skills, evaluation criteria, and standards for the teaching profession (MINEDUC, 2011) and the ICT competency framework for teachers (UNESCO, 2019) were considered.

The study programs were analyzed using a qualitative methodology (Cárcamo, 2005) with an intrinsic case design (Stake, 1998) of a descriptive type and an analysis of documentary content (Valles, 2009). The design was cross-sectional and characterized by the use of documentary sources that were not observational or conversational. For the a priori content analysis, the skills of the selected programs were categorized within the cognitive levels of Marzano and Kendall's (2007) taxonomy. This taxonomy is frequently used in the formulation of learning objectives in terms of observable and measurable behaviors, which is why it is widely used in the design of curricula, evaluations, and standards (Sánchez, 2019).

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TABLE 5 Description of the statements related to digital competence questionnaire for higher education students (CDAES) (adapted from Gutierréz-Castillo et al., 2017).

Dimensions	Item	Statement
D1. technological literacy	1	I am able to use different types of operating systems
	2	I am able to use different mobile devices
	3	I surf the internet with different browsers
	4	I master different tools for information processors, spreadsheets, databases. . .
	5	I investigate and solve problems in systems and applications
	6	I am able to use different digital treatment image, audio or video processing tools
	7	I can communicate with other people using synchronous tools
	8	I know how to design web pages using some informatic program, including texts, audio images, link. . .
	9	I know how to use collaborative work software using online tools such as Groupware
	10	I dominate Web 2.0 tools to share and publish online resources
	11	I use effectively the virtual campus used in my university
	12	I feel competent to use the virtual management of my university
D2. information search and treatment	13	I am able to locate information through different sources and databases available on the internet
	14	I know how to identify relevant information by evaluating different sources and their origin
	15	I am able to organize, analyze and ethically use information from a variety of sources and media
	16	I synthesize the information appropriately selected for the construction and assimilation of the new content, through tables, graphs or diagrams
	17	I use graphic organizers and software to make mind and concept maps, diagrams or schemes to present the relationships between ideas and concepts
	18	I plan information searches to solve problems
D3. critical thinking, problem solving and decision making	19	I am able to identify and define problems and/or research questions using Information and Communication Technologies (ICT)
	20	I use the digital resources and tools to explore current world issues and solve real problems, attending to personal, social, professional, etc. needs.
	21	I know how to analyzed the capabilities and limitations of ICT resources
	22	I configure and solve problems that arise related to hardware, software and network systems, to optimize their use in learning
D4. communication and collaboration	23	I share information of interest with my classmates using a variety of environments and digital media
	24	I effectively communicate information and ideas to multiple audiences, using a variety of media and formats
	25	I am able to develop cultural understanding and global awareness through communication with other students and professionals from other cultures
	26	I know how to use computer programs and technological tools to manage and communicate information with my classmates and other users
	27	I am able to coordinate group activities using tools and means of the internet
	28	I interact with other classmates and users using social media and ICT-based communication channel
	29	I am able to function in professional networks
	30	I am able to design, create or modify a wiki
	31	I know how to use social bookmarking to locate, store and tag internet resources
D5. digital citizenship	32	I assume an ethical commitment in the use of digital information and ICT, including respect for copyright, intellectual property and the proper reference of source
	33	I promote and practice the safe, legal and responsible use of information and ICT
	34	I demonstrate personal responsibility for lifelong learning using ICT
	35	I consider myself competent to make constructive criticism, judging and making contributions to the ICT work developed by my classmates
	36	I exercise leadership for digital citizenship within my group
	37	I exhibit a positive attitude toward the use of ICT to support collaboration, learning and productivity
D6. creativity and innovation	38	I have the ability to conceive original, novel and useful ideas using ICT
	39	I am able to create original works, using traditional and emerging ICT resources
	40	I identify trends anticipating the possibilities of use that ICTs provide me
	41	I use models and simulations to explore complex systems and issues using ICT
	42	I develop materials where I use ICT in a creative way, supporting the construction of my knowledge
	43	I am able to adapt to new situations and technological environments

Competences were discriminated based on verbs/actions (Navarro et al., 2020) such as textual marks, and were classified on the basis of a list of subcategories characteristic of each cognitive level. The analysis matrix contained cognitive levels (categories) and a brief description of each one, the list of verbs/actions (subcategories) for each level, and finally, the column of the skills stipulated in the subject programs.

Results and discussion

Characterization of the research participants

The people who participated in the research were of age 23.1 ± 3.5 y, 42.9% declared themselves men and 55.1% women, with 2.0% of people who preferred not to identify with a specific gender. A hundred percent of the students answered the question about their place of residence and they all live in the Metropolitan Region. Seventy percent of the students live in central districts of the Metropolitan Region and the remaining thirty percent live in peripheral districts.

The majority of the students declared that they belonged to a medium (57.1%), followed by a low socioeconomic level (36.7%), and a minority belonged to a high socioeconomic level (6.1%). The students came from schools with private-subsidized and municipal (public) financing, with 53.1% and 36.7%, respectively. In addition, the vast majority of students followed elective scientific courses (83.7%).

When asked if they had previously studied for another career, 26.5% answered that they had, implying that one out of every four students had previously studied another career. The analysis of the response to how they financed their course revealed that 71.4% of the students had a scholarship, 16.3% were financed with some type of bank credit, and 12.2% paid the tariff of the university in cash or were waiting for a decision on some benefit or scholarship.

The participants were grouped according to their years of study, using the subject of the earliest semester being studied as a classification criterion. In the fifth year, there was more than one cohort because not all students had the same time of graduation or degree from their course. The survey was conducted both online and voluntarily. A representative participation in the course was observed, with the exception of the first and third years, who presented values lower than 30% of the corresponding cohort. The low participation values are a limitation of this study. To balance this situation, three different invitations were made to the students to answer the survey. However, in a pandemic context, with online curricular activities, low participation was achieved. This was consistent with the low commitment shown in all the curricular activities to which they were invited.

Students' perception of their digital and science, technology, engineering, and mathematics skills

The analysis of descriptive statistical parameters such as variance allowed us to observe the dispersion of the results (**Figure 1**). Good coherence was observed in the answers to the CDAES questionnaire, with 80% of variances in the medium [1–0.5] and low [< 0.5] levels, with the exception of those who were in the first year; this group was the one with the greatest dispersion. In contrast, the second-year group showed 100% medium and low variances, with the group showing less dispersion in their responses, and no significant gender difference was observed. The replies to the questionnaire showed good internal consistency with a Cronbach's α of 0.937.

Extreme values of variance were observed in all groups, except in the fourth year, that only presented medium and low variance. For example, in Dimension 1 (D1) of items 2 (I am able to use different mobile devices) and 7 (I can communicate with other people using communication tools through the web) had low variances; showing agreement with the positive responses. On the contrary, item 3 (I surf the internet with different browsers), in the same dimension, presented a high variance in the first, third, and fifth years. In Dimension 2 (D2), it was observed that item 17 (I use graphic organizers and software to make conceptual and mental maps, diagrams, or schemes, to present relationships between ideas and concepts) presented a high variance in all classifications, except for the third and fourth year, where it shows a medium variance. On the contrary, item

TABLE 6 Curricular prosecution of the subjects of the participants of the CDAES survey.

Earliest semester that declared to be studying a subject	Year of course progression	Number of respondents	Cohort participation percentage
1–2	First	4	27.3%
3–4	Second	15	42.9%
5–6	Third	7	25.9%
7–8	Fourth	11	58.3%
9–10	Fifth	12	57.7%

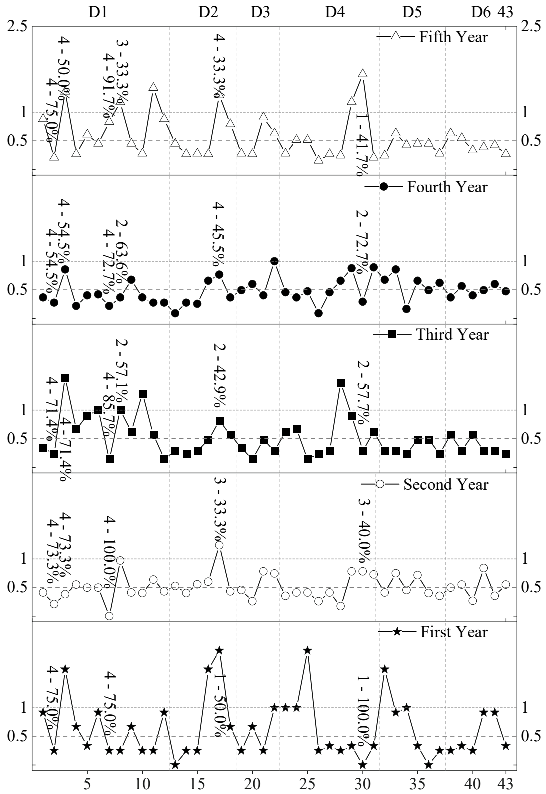

FIGURE 1
Variances obtained from the results of the application of the digital competence questionnaire for higher education students (CDAES) according to the year of career progression of pedagogy in chemistry.

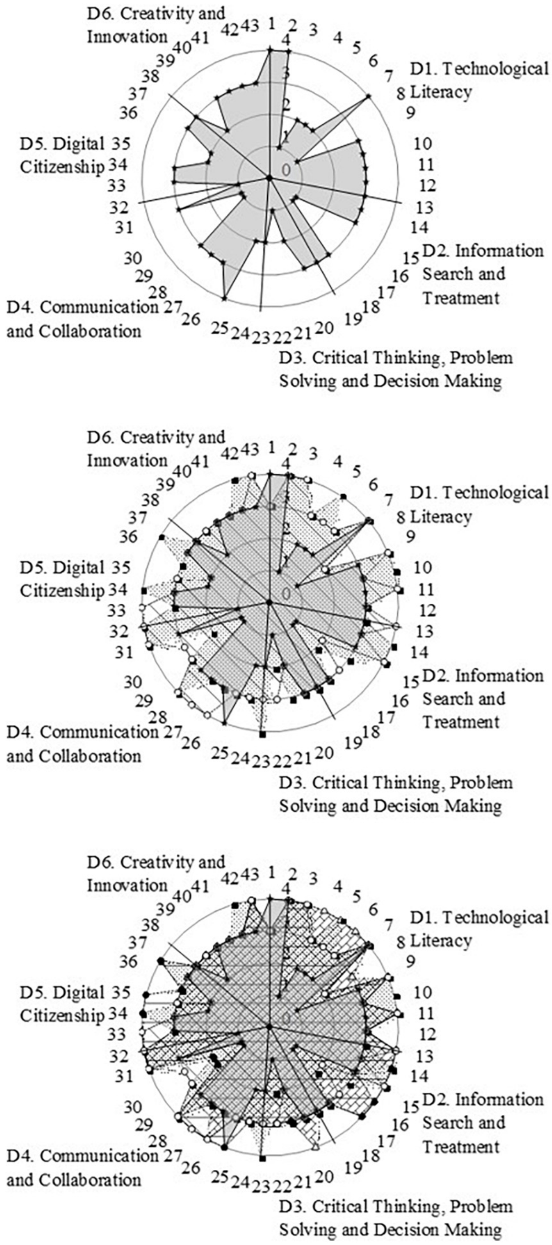

FIGURE 2
Mode of the results of the CDAES applied to students of the pedagogy in chemistry career.

30 (I am capable of designing, creating, or modifying a wiki) presented a medium or low variance in all years, except in the fifth year where it presented a variance above 1. Simultaneously, there were cases where the variance reached the value 0, that is all students presented the same answer, as in the case of the first year with items 13, 30, and 36, and the second year with item 7.

Owing to the low dispersion of the answers, the CDAES results were analyzed using the median and mode descriptive statistics, observing the same trends in both. Figure 2 shows the radial graphs of the discourse of the students in initial training as chemistry teachers, presenting the items as points and dimensions of the survey as "D." In the case of first-year students, 60.5% of the positive responses were observed (agree and strongly agree).

Regarding the items highlighted for their high variance values, such as in the first year in item 3 (I surf the Internet with different browsers), the students who declared that they strongly disagree (value 1 of the Likert scale) comprised 25% of answers. Item 7, which was related to the ability to communicate with communication tools using the web, saw 75% of student responses declared to be very much in agreement. Similarly, for item 13 (I am able to locate information through different sources and databases available on the network), 100% of the students agreed with this statement.

Item 17 (I use graphic organizers and software for the realization of conceptual and mental maps, diagrams, or schemes, to present the relationships between ideas and concepts) presented the highest variance; 50% of students declared they were strongly in disagreement with the affirmation. This was interesting because this item was closely linked to student learning. In relation to item 30 (related to designing, creating, or modifying a wiki), 100% of students declared strong disagreement. Finally, in item 36 (I exercise leadership for digital citizenship within my group), all first year students stated that they disagreed with the statement. In general, it was observed that first-year students did not develop the digital skills evaluated by the CDAES survey. It should be considered that this group had low participation (27.3%), with only four students in this group, which could strongly affect the dispersion of their results.

Second-year students showed growth in the development of digital skills, with 90.7% presenting positive responses and 32.6% of students stating that they strongly agreed with the statements presented. Dimensions 4 and 6 showed an increase in positive responses. In item 2 (I am able to use different mobile devices), 73.3% said that they strongly agreed with the statement; in the case of item 7 (I can communicate with other people using communication tools *via* the web), 100% of students declared that they strongly agreed with the statement. In item 17 (I use graphic organizers and software to make conceptual and mental maps, diagrams, or schemes to present the relationships between ideas and concepts), 33.3% of students declared they agreed with the statement. For item 30 (I am capable of designing, creating, or modifying a wiki), 40.0% of students agreed with the responses. In short, the students demonstrated an increase in the development of digital skills when compared to the first year, and they now had mastery in dimensions 4 and 5, which only presented positive responses.

High values of positive responses (>90%) were maintained from the third to fifth years, reaching 95.4% in the fifth year; of the total responses, 39.5% strongly agreed in the third year, 48.8% in the fourth year, and 41.9% in the fifth year (**Figure 1**). The only dimension that remained to be developed in the fifth year corresponded to dimension 4; all other dimensions were developed upon reaching the fifth year of career pursuit. Regarding the items to be observed in Dimension 1, in item 2 (I am able to use different mobile devices), 75.0% stated that they strongly agreed with the statement; for item 3 (I surf the Internet with different browsers) 50.0% of the students declared to be very much in agreement; and for item 7 (I can communicate with other people using web communication tools), 91.7% of the students declared that they strongly agreed with the statement. From Dimension 2, item 17 (I use graphic organizers and software to make conceptual and mental maps, diagrams, or schemes to present the relationships between ideas and concepts) 33.3% of the students declared that they strongly agreed with the statement. On the contrary, for item 30 (I am capable of designing, creating, or modifying a wiki), 41.7% of the students stated that they strongly disagreed with the statement. A notable increase was observed in item 8 (I know how to design web pages using a computer program, including texts, images, audio, links, etc.), where 33.3% of the students declared that they agreed with the statement.

In summary, the improvement in digital skills development from the first to the second year can be attributed to curricular activities explicitly associated with digital technologies such as applied computing (Elías et al., 2021a). Although the growth in these years is notable, these competencies continue to be developed in the following years, although to a lesser degree, possibly because other curricular activities in the study plan continue to be developed and strengthened, competing for time with digital development.

It is possible to observe that, in a greater number of responses, the students declared that they agreed or strongly agreed that they had the competencies described in the different dimensions of the survey, including Dimension 3, which corresponded to scientific competencies (critical thinking, problem-solving, and decision making), particularly item 20 (I am able to identify and define problems and/or research questions using ICT), where students stated that they strongly agreed. This was one of the most relevant dimensions when relating to STEM, because integrated activities, contextualized in real situations and based on the use of digital tools, strengthen the development of scientific and digital skills that students perceive as underdeveloped.

Regarding gender differences, it was observed that students had positive attitudes regardless of gender differences. In STEM education and related disciplines a significant gap is observed between women's predisposition toward these disciplines and the level of opportunity that favors the entry of women into university courses related to professions in STEM, particularly in Latin America and the Caribbean (Arredondo et al., 2019). This gap produced by stereotypes limits the development of the skills inherent in STEM activities, which not only results in a low presence of women in the labor market but also limits their decision-making process in personal aspects, affecting their quality of life (UNICEF, 2020).

Of all items included in the survey, 74.4% were directly associated with skills required for the development of STEM activities. Considering the importance of research, critical thinking, problem-solving, decision making, communication, collaboration, creativity, and innovation, Dimensions 2, 3, 4, and 6 contained the most relevant items when measuring the development of competencies that are considered essential for integrated STEM activities, representing 53.4% of the entire survey. Some items measured the modeling capacity to explore complex systems (item 41); identify and define research questions using ICT (item 18); and locate, analyze, and synthesize information from various sources (items 13, 15, 16, and 17).

Another item related to STEM was number 10, where the majority of students agreed on mastering Web 2.0, tools for sharing and publishing resources online, without showing a significant difference in terms of gender. Another similar item was number 28, where the students stated that they

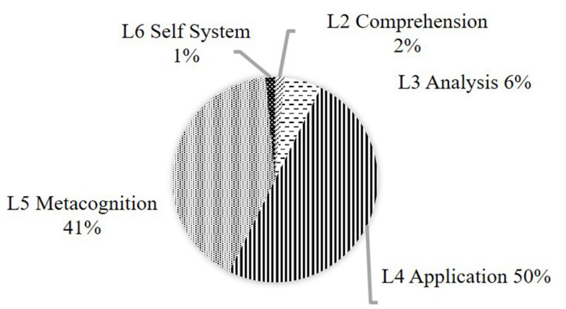

FIGURE 3
Distribution of the cognitive levels of the MINEDUC Standards.

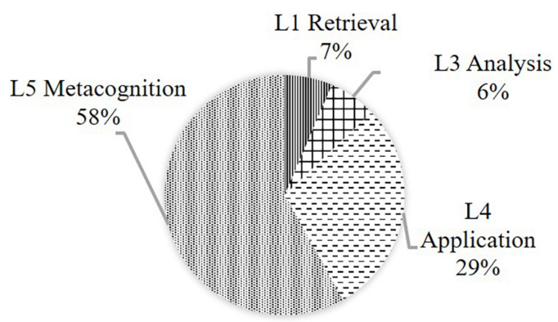

FIGURE 4
Distribution of the cognitive levels of the UNESCO standards.

strongly agreed with the statement "I interacting [sic] with other classmates and users using social networks and ICT-based communication channels," without indicating a gender difference. Although both items corresponded to different dimensions, they pointed toward the conception of the use of ICT associated with communication of actions or information socialization, which is a critical aspect for the development of necessary skills for STEM activities.

When observing Dimension 2 on information search and treatment, it is possible to highlight that 67% of the items were declared as strongly in agreement, without observing a significant difference in terms of gender, which was relevant within the competencies for STEM education, because those associated with research are found, particularly in digital environments, within integrated contextualized problem-solving activities, so these results are considered positive.

Students declared that they had a positive attitude and many of the skills described in the survey, particularly instrumental skills—a situation that was already highlighted in the ICILS of 2018 (Education Quality Agency, 2020); the challenge now is to develop digital skills to evolve into digital skills for the teaching-learning processes.

To address the challenge of training competent teachers, study plans were composed, for which the programs of the first-semester subjects' communication skills and applied computing in their 2016 and 2019 versions were analyzed *a priori*, because both curricula are in use and the didactic course subjects (**Table 7**) were compared with the ICT standards for the teaching profession (MINEDUC) and UNESCO standards (**Figures 3**, **4**).

It has been identified that the MINEDUC standards, such as the UNESCO standards, have the largest number of cognitive levels in the most complex levels, with metacognition and application accounting for more than 80% of the declared competencies, in complete contrast to the identification of the recovery and analysis levels, which fail to exceed 6.5% of the textual evidence that marks the presence of this cognitive level.

The analysis of the study programs revealed that the 2016 applied informatics program included a greater number of skills located at cognitive levels 4 and 5, which are considered more complex within Marzano's taxonomy. This is not the case for the program in its 2019 updated version, where the skills are distributed more homogeneously across the basic and intermediate levels.

The communicative abilities program was designed with the purpose of leveling the skills of the students at the start of their career, which is why it presents more basic cognitive levels, noting that the design applied informatics program (2019) compromises the development of skills associated with the different cognitive levels that allow leveling of the basic and intermediate cognitive levels to advance toward the most complex levels that are associated with the metacognitive system.

The distributions of the different cognitive levels associated with the development of the skills declared in the applied informatics programs of 2016 correspond to what is required by UNESCO. Finally, the analyzed programs move away from the skills declared by MINEDUC, which promote only some upper intermediate levels while failing to ensure the achievement of the simplest levels that are the basis for achieving the most complex ones.

It is important to consider that this study analyzed what is described in the programs of the didactic course because these curricular activities develop tools, strategies, and educational means for future teachers to use in the teaching-learning processes (**Table 7**). Other activities that also required digital and STEM skills, such as the design of a digital teaching portfolio upon graduation, were not included in the analysis.

The declared competencies for metacognition and self-regulation of cognitive levels increased homogeneously for the science didactics programs (third year) and chemistry didactics (fourth year) in their 2013 and 2019 versions. However, in the case of the didactic project program (fourth year), there were fewer records of the recovery level in relation to the 2013 version. These adjustments were consistent with the types of activities that students are expected to perform during the

TABLE 7 A priori content analysis of the study programs through the cognitive domains developed during the initial training of chemistry teachers.

Study programs	Cognitive levels (L)					
	L 1.retrieval	L 2. comprehension	L 3. applying	L 4. analysis	L 5. metacognitive	L 6. self-regulation
Communicative abilities 2019	20%	27%	20%	6%	20%	70%
Applied informatics 2016	10%	11%	7%	38%	33%	1%
Applied informatics 2019	32%	23%	18%	23%	4%	Not described
Science didactics 2013	29%	Not described	Not described	14%	36%	21%
Science didactics 2019	Not described	10%	Not described	10%	60%	20%
Didactics of Chemistry 2013	17%	Not described	Not described	17%	33%	33%
Didactics of chemistry 2019	Not described	8%	8%	15%	46%	23%
Didactic project 2013	12%	25%	No describe	Not described	38%	25%
Didactic project 2019	Not described	22%	Not described	21%	43%	14%

course of the subject, where they must design and plan teaching-learning sequences, develop educational media, and generate various evaluation formats.

The didactic projects developed in a pandemic situation (2021), when the courses were taught online, had an impact on the type of media selected. As a result, student projects developed in 2019, in which the course was dictated in person, were also analyzed. Consistent with online teaching at a global level, it was observed that students diversified their selection, design, and development of STEM educational media, not so much the type of media: 16%–2019 and 2%–2021 for experimental media (laboratory experiences) and 38%–2019 and 55% for innovative media (experiences using simulators and educational software), and slightly declined the selection of traditional media (including blackboard, PowerPoint, and other types of class presentation software) with 46% in 2019 and 43% in 2021.

A sequence of development of these competencies was observed in the analysis of the textual marks in the competencies declared in the programs of the didactic line, ending with the didactic project course, which consistently developed higher cognitive levels, where the students developed, designed, and elaborated didactic projects.

The review of the concepts associated with digital skills and STEM reveals a dialogue with scientific skills to solve problems collaboratively in a sustainable environment, which is consistent with international descriptions (Table 1). From these competencies, STEM education makes sense as a transversal development of critical thinking, problem-solving, creativity, communication, collaboration, and scientific, technological, and digital literacy. In this case study, students in initial chemistry teacher training state that they have sufficient digital and STEM skills as higher education students. However, it is necessary to carry out further studies that allow determining the development of competencies as teachers who transpose scientific and technological knowledge into the classroom through digital tools that will enhance the teaching-learning processes of science, that allow training STEM professionals who solve contextualized problems. Although chemistry teachers do not seem to be directly linked to innovation and economic development, their role is essential in the formation of citizens of the twenty-first century who can progress toward sustainable development.

Conclusion

In search of strengthening scientific, technological, and digital skills on a social level, it is necessary to consider science teachers as agents of change and strengthen their training from the integrated perspective proposed by STEM, so that science teachers will be able to design integrated learning experiences between the various disciplines developed in school education, with a focus on solving real-life problems. It is through interdisciplinarity, collaborative work and contextualization that chemistry teachers can contribute to the formation of citizens with the necessary skills to achieve a sustainable future, capable of contributing to the solution of local and global problems associated with the discipline.

The comparisons of the dimensions presented by the reference frameworks were consistent with each other; however, they did not include all the dimensions associated with the development of digital, scientific, and pedagogical skills. The chemistry teacher training standards do not account for the use of ICT in and for teacher training; they only mention that it is necessary to use ICT to integrate the knowledge of science from the didactic aspect, without providing a guide or detail on how they would expect teachers to develop digital and STEM skills in the teaching-learning processes.

The CDAES application results allowed the determination of an appropriation of digital competencies in students in initial chemistry teacher training at the user level without gender differences, which increased strongly in the second year and then gradually in the subsequent years for the continuation of the course. In particular, it was highlighted that students declared a high level of assessment in the development of their digital competencies required for STEM. However, it was concerning that students placed a lower value on their abilities to use models and analyze or solve problems with networks or hardware, all of which require medium or high levels of understanding, challenging us as teacher educators to address this gap in initial teacher training, with a view to promoting STEM teaching-learning processes.

On the contrary, documentary analysis of the programs of the first year of the career and of the didactic lines managed to establish semantic relationships between the competencies declared in the initial training plans for chemistry teachers, because the programs commit intermediate cognitive levels and at the end of the higher-level career. It is expected that the skills associated with higher cognitive levels will also be addressed transversally in the curricular activities of the upper semesters.

It is expected that more complex skills (metacognitive systems) will be achieved. Although this study promotes a positive discourse regarding digital skills, it is still necessary to evaluate whether these skills are actually developed in later years so that future chemistry teachers can promote STEM careers in their classroom work and allow them to walk the path toward sustainable development.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

Ethics statement

The studies involving human participants were reviewed and approved by Comité de Ética de la Universidad de Santiago de Chile. The patients/participants provided their written informed consent to participate in this study.

Author contributions

ME: postgraduate thesis. JP: undergraduate thesis. MC: researcher team. EC: education researcher. MT: curricular researcher. EZ: head education researcher. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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