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Digital technologies as enablers of universal design for learning: higher education students' perceptions in the context of SDG4

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Received: 19 September 2024 / Accepted: 21 November 2024
Published online: 18 December 2024

Abstract
Digital technologies are essential for transforming educational environments, particularly in higher education. These tools have revolutionized information access and enable flexible approaches within Universal Design for Learning (UDL). This educational model integrates findings from educational practice, research, learning theories, technological advances, and neuroscience to provide concrete proposals for implementing diverse teaching practice that accommodates different learning needs. Building on universal design concepts, UDL is structured around three neurological learning systems (affective, recognition, and strategic) and advocates three corresponding principles: multiple means of engagement, representation, and action/expression. Aligning with current parameters of quality education for all, UDL incorporates diversity as a fundamental premise in instructional planning to ensure equitable learning opportunities for all students. This framework enables teachers to create flexible curriculum designs that enrich learning, reduce barriers, and provide accessible educational opportunities. This research examined how digital technologies can enable UDL implementation by analyzing higher education students' perceptions. Using a quantitative methodology with a descriptive scope, data was collected through a specially designed Likert-scale questionnaire. The instrument demonstrated high reliability (Cronbach's $\alpha = 0.97$). The sample included students from the Mexican public university system ($n = 235$) studying pedagogy and education. Results showed favorable perceptions of technology use in UDL across all three principles: representation (what to learn), action and expression (how to learn), and engagement (why to learn). They suggest that digital technologies can expand learning capacity and enhance skill development among university students in the UDL context. However, it should be noted that they need to be carefully integrated into educational frameworks designed and tested for their effectiveness; without such integration, their application may be ineffective or even counterproductive to learning processes. The findings demonstrate the potential of this design as a practical and theoretical model to, in line with current trends, contribute to the achievement of SDG4, promoting quality in education and learning opportunities for all. This will be helpful for institutions seeking to implement technology-enhanced UDL strategies while having broader implications for the body of research for improving higher education.

Keywords Digital technologies in education · Universal design for learning · Educational technology integration · Neuroscience-based learning · Higher education · Accessible learning · Student perceptions · SDG4 · Learning accessibility · Educational innovation

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1 Introduction

During the last decades, it has been a constant concern of education professionals to pay equitable attention to the student body [44, 108, 143]. Effective pedagogy must create integrated learning opportunities that respect individual learning rhythms, styles, and equity principles [88]. This approach requires incorporating Information and Communication Technologies (ICT) across various educational levels and modalities [92]. This can amplify opportunities for personalized learning and foster collaboration among students, as demonstrated by recent systematic reviews of technology-enhanced learning [47, 156]. These studies have shown that, when properly implemented, digital technologies can support diverse types of learning, adapt to individual student needs, and create more accessible learning environments. It should not be forgotten that pedagogical differentiation is key to ensuring that each student receives the appropriate support for growth [147]. However, ICTs must be integrated within a solid pedagogical framework that promotes the development of critical and creative skills, moving beyond mere information consumption. It should be noted that digital technologies were not created for educational purposes,quite the contrary. These should serve pedagogical purposes, not drive educational decisions [55, 56]. Used well, ICT in education has been recognized as a potential catalyst for achieving these goals, offering new avenues for personalized learning and breaking down traditional barriers to access [11, 135]. This focus on addressing diverse learning needs aligns with global educational objectives, such as Sustainable Development Goal 4 (SDG4), which aims to improve the quality and accessibility of education worldwide [149].

Given the diversity of people and the changing environments that surround them, the Universal Design for Learning (UDL) emerges as a response to this need so that it can reach all students, regardless of whether they have disabilities or not [6, 32], eliminating barriers to learning and changing the use of traditional materials and processes for the use of technological means that attract their attention, stimulating the development of motor, sensory, cognitive, affective and linguistic skills, in addition to encouraging active and meaningful participation [50, 134]. The UDL framework, rooted in cognitive neuroscience and learning sciences, provides a structured approach to designing flexible learning backgrounds that accommodate individual learning differences [91]. By offering numerous means of engagement, representation, action, and expression, UDL seeks to optimize teaching and learning for all people based on scientific insights into how humans learn [120]. UDL philosophy advocates flexible curriculum design regarding methods, materials, and assessment approaches [64].

This research examines ICT as a facilitator of UDL in higher education, embracing an accessible perspective that encompasses all students. It focuses on how learners collaborate through meaningful experiences, participate in decision-making processes, and develop self-acceptance [130]. The present study addresses two critical trends in higher education: increasing digitalization and the growing emphasis on adaptable pedagogy [70]. As student populations become more diverse, understanding how to leverage digital technologies within UDL frameworks becomes essential for universities [59]. The general objective was to examine how digital technologies enable UDL by analyzing higher education students' perceptions. This aim is grounded in the understanding that student perceptions can significantly influence the effectiveness of educational interventions [42]. By examining these perceptions, we aim to contribute to the growing literature on implementing UDL in higher education contexts, particularly about digital technologies.

2 Theoretical framework

2.1 The basics of universal design for learning (UDL)

2.1.1 Brief overview of UD origins

Universal Design (UD) was a concept initially worked in architecture in 1970 by Ron Marce, founder of the Center for Universal Design (CUD) in the United States. Its main objective was to design and construct buildings and public spaces that meet the needs of all people in different aspects, such as Communication, use of services, and displacement, among others. In this way, it sought to take into account people with disabilities from the design phase and avoid the high costs and damages that could occur at the time of making an access adaptation to a construction [85, 119, 146].

The translation of UD principles from architecture to education has been explored in depth by Steinfeld and Maisel [142], who argue that the core tenets of accessibility and usability for all are equally applicable in learning environments. Their work demonstrates how the seven principles of UD can be adapted to create more adaptable and practical

educational spaces, both physical and virtual. In order to transpose the original concept of Universal Design to the educational field, it is pertinent to consider the following precisions: avoid labeling people, certain types of needs need not necessarily be present throughout a person's life, and the conception of excluding environments as opposed to the consideration that people are to blame for these situations [148]. This perspective is echoed in Waitoller and King Thorius [152] work, which proposes a critical approach that considers intersectionality and culturally sustaining pedagogy (CSP). Their research emphasizes the importance of considering how various forms of oppression and privilege intersect in educational settings and how UDL can be leveraged to create more equitable learning environments.

2.1.2 Core principles and neuroscience foundations

With the Universal Design (UD) foundation, the Center for Applied Special Technology (CAST) was established in 1984 to support students with various disabilities in their educational process by facilitating access to curriculum requirements. In 1990, David H. Rose, a developmental neuropsychologist, and Anne Meyer, an expert in education, clinical psychology, and graphic design, developed Universal Design for Learning (UDL) [120]. This approach integrates the latest advances in neuroscience and applies them to learning, educational research, technology, and digital media (Meyer and Gordon, 2014 [24, 94],). The evolution of UDL from its origins in UD to its current form as a comprehensive educational framework has been thoroughly documented by Rappolt-Schlichtmann et al. [117]. Their work traces the theoretical underpinnings of UDL, highlighting how advances in cognitive neuroscience and learning sciences have shaped its development and application in diverse educational contexts. They aimed to create physical environments and tools accessible to many people. Among its key proposals is the renewed perspective of inclusion, which rejects the idea that barriers are intrinsic to the individual, viewing them as external elements that threaten, limit, or impede equitable access to education. Therefore, based on the principles of universal design, this model is organized around three primary neurological learning systems: affective (supporting engagement), recognition (supporting representation), and strategic (supporting action and expression) [121]. As can be seen, the neurological foundations of UDL refer to biological brain networks and learning systems, distinct from artificial neural networks used in computing and artificial intelligence, and any confusion in this regard should be avoided.

This neurological basis has been further elaborated by Immordino-Yang et al. [69], who explore the connections between neuroscience, learning sciences, and educational practice. Their work provides a deeper understanding of how UDL principles align with current knowledge about brain plasticity and cognitive flexibility, offering a scientific rationale for the effectiveness of UDL strategies in diverse learning contexts. Katz [72], in her analysis of UDL implementation, obtained results that demonstrate the effectiveness of these neurological principles from the teachers' point of view. After implementing the model, teachers reported positive outcomes for students regarding reduced challenging behaviors and improved student interactions, engagement, and learning. These findings were later supported by extensive research showing how understanding brain function can inform better educational design. UDL represents an adaptive educational approach, as demonstrated by Delgado [37], who describes the experiences and contributions of students from the Universidad Tecnológica Indoamérica in the Master's Program in Education, recovering its principles to work with students with hearing impairment and autism. The findings confirm that the adaptive education process was adapted to the needs presented by the students. This is consistent with the work of Burgstahler [22], who explored applying UDL principles in an Anglo-Saxon context. His study emphasized the importance of proactive design in creating differentiated learning environments.

2.1.3 Evolution to educational contexts

The UDL, according to Pastor [104], is identified as "a theoretical-practical framework for teaching practice from an inclusive perspective" (p. 64). It starts from diversity from the beginning of didactic planning constituted by a support system (Sánchez, Gómez, and López, 2020) that seeks all students' learning opportunities [43]. This conceptualization aligns with the work of Al-Azawei et al. [4], who conducted an ample review of UDL implementation. Their study aimed to analyze the content of a set of articles, where the UDL framework was applied, published between 2012 and 2015. The findings concluded that UDL may represent a promising solution for designing a flexible learning environment that responds to a broad mix of learner needs, abilities, prior knowledge, educational experiences, and cultural differences.

Vasquez [151] describes UDL as an approach built through the convergence of three essential components: the universal design of architecture, ICTs, and neurosciences. In this context, the universal design of architecture is conceived with the necessary flexibility to adapt to the diverse characteristics of each individual. By designing from general

characteristics, its implementation can benefit universally. The central idea of the UDL model is based on learners managing their learning process (Meyer and Gordon, 2014). In this sense, it is defined as an alternative model in which the preferences and needs of students that reflect an enduring characteristic are considered, not defining needs in terms of what the person is struggling with but how their functioning can be improved. Supports must be the result of a careful assessment of individual needs. They serve a dual function by identifying the discrepancy between the person's abilities and the accommodations needed to facilitate participation. In addition, they focus on enhancing personal achievement by improving human functioning.

Some works that have deepened the importance of UDL are those of Sánchez-Gómez and López [130], who developed a theoretical proposal to understand this design, as well as the evaluation of support needs in a specific way in learning that allows attending from the planning processes to that of the needs. This theoretical approach aligns with the work of Rao and Meo [111], who emphasize the importance of proactive planning in UDL implementation. Their research highlights how UDL can be used to design differentiated curricula that address diverse learner needs from the outset rather than as an afterthought. Segura and Quiros [134] examine the Universal Design for Assessment (UDA) from the perspective of the learning assessment process linked to pedagogical mediation. In this approach, assessment must mean that techniques and instruments are closely integrated. Consequently, educators should encourage the implementation of self-assessment, co-assessment, and hetero-assessment processes to foster an evaluative culture, overcoming the conception of assessment as a process exclusive to teachers. From these perspectives, it can be argued that UDA improves the validity of assessments for diverse learners and promotes metacognitive skills essential for lifelong learning. Thus, when designed with UDL principles in mind, technology-enhanced assessments could provide multiple means of action, thus allowing students to demonstrate their knowledge in ways that best suit their learning profiles.

2.2 Digital technologies as UDL enablers

2.2.1 Role of technology in UDL implementation

Digital media share with traditional media the presentation of information through text, audio, images, or video; however, they differ with them in the possibility that ICTs have to store such information, combine media with each other, and even perform transformations of information from one medium to another [128]. In any educational project, it is necessary to deeply analyze the suitability of the tools, their advantages and disadvantages, and whether they will allow achieving the objectives and with superior quality to other alternative means [54] and [52]. Integrating UDL with Technological Pedagogical Content Knowledge (TPACK) provides a model for leveraging technology to support diverse learners [13].

Institutions implementing UDL through digital technologies should prioritize three key areas: First, ensuring that technological infrastructure supports multiple engagement means, as indicated by student preferences for interactive and personalized learning experiences. On the other hand, developing faculty capacity to leverage digital tools for diverse content representation reflects students' high value on multimedia and interactive resources. At the same time, flexible assessment systems that enable various forms of student expression should be created, addressing the clear student preference for diverse demonstration of learning. UDL can guide the design of technology-enhanced learning environments, supporting diverse learners by providing multiple means of engagement, representation, and action and expression [39, 99] while providing specific guidance for technology integration. ICT has become an essential element in various spheres of daily life, standing out for its benefits in creating innovative pedagogical approaches and methods promoting inclusion in educational environments.

The extraordinary progress of emerging technologies requires studies on their possible application in UDL. Virtual reality or artificial intelligence provides more personalized and immersive learning experiences while raising essential questions about accessibility and digital equity. Proposals such as those of Menke et al. [89] and Coppe et al. [30] in the case of virtual reality, or those of Hyatt and Owenz [68], Morgan [93], and Saborío-Taylor and Rojas-Ramírez [125], about artificial intelligence, are innovative in this regard. However, it should not be forgotten that in education, more than in other fields, what is important is not the medium but the use made of it, even in the most innovative technological tools [53].

2.2.2 Types of digital tools and their alignment with UDL principles

UDL can be enriched with technological tools that offer cognitive learning and assessment support, impacting interactions between students with and without disabilities [40, 60, 112, 114, 150]. Specific technologies, particularly

assistive technologies, can enhance access and engagement for students with learning disabilities within a UDL framework [21, 90]. Digital tools and platforms can be integrated into UDL-based instruction to create more engaging and inclusive learning environments [41, 59, 66]. Assistive technologies can support learners with diverse needs by removing barriers to access and promoting independence for students with reading or writing difficulties [1, 87].

Learning Management Systems (LMS) have evolved to incorporate UDL principles, offering customizable interfaces and multiple formats for content delivery [16]. From these perspectives, it can be argued that UDA improves the validity of assessments for diverse learners and promotes metacognitive skills essential for lifelong learning. Thus, when designed with UDL principles in mind, technology-enhanced assessments could provide multiple means of action, thus allowing students to demonstrate their knowledge in ways that best suit their learning profiles.

As Martínez and Hernández [85] show, ICTs provide different ways to respond to this approach, one of which is gamification. Game-based learning within a UDL framework can enhance student engagement and motivation while providing multiple means of representation, action and expression, and engagement [67, 83]. The integration of executive function support into UDL-based instruction is crucial, with practical strategies supporting students' goal-setting, planning, and self-monitoring skills. UDL can promote self-regulated learning, emphasizing the role of metacognition in developing expert learners [96, 115]. All this, moreover, must take place in a digitized and technological society, where technologies and media have a decisive impact on people, especially children and young people. Critical attitudes must be created in the face of the influence and messages they receive.

2.3 UDL Implementation in higher education

2.3.1 Current practices and evidence

Student's academic performance is enriched by the UDL [33] by creating meaningful learning that favors their access to the system in a more straightforward way [136] through didactic and flexible methodologies that adjust to different learning rhythms and styles [133, 84], which minimizes existing barriers within schools [131]. Its scope is not limited to classroom space and cognitive development but to comprehensive development [95], where autonomy is highlighted as one of the skills students develop [102]. Coppiano-Loor and Corral-Joza [31] designed an educational experience to analyze teachers' knowledge about the UDL and to detect their contributions to educational inclusion and its implementation in the teaching–learning process. Among the main findings, it is identified that teachers claim to know the principles of the UDL,however, it is lacking in the activities they develop in the classroom with the students. This gap between knowledge and practice is also highlighted in the work of Evmenova [45], an exploratory study where 70 educators learned about UDL implementation.

The findings suggest that while many may be familiar with UDL principles, there is often a disconnect between theoretical understanding and practical application. This underscores the need for more comprehensive professional development programs that focus not only on the theory of UDL but also on its practical implementation in various educational contexts. Of course, we should not forget the importance of studying its application in higher education, an educational level of great interest [65, 113]. Mendoza et al. [88] developed research that aims to implement the UDL to strengthen the teaching–learning processes in the university classroom by planning motivating activities and promoting educational principles such as equity, integration, and interculturality.

This research adopts a mixed approach with a descriptive design, using the survey technique and descriptive statistical analysis. The results reveal a limited level of knowledge about this approach in the teaching–learning process and lead us to defend the need for more comprehensive training and institutional support to fully exploit the potential of UDL in various educational contexts. Black et al. [15] extend this understanding by examining how UDL principles can foster the development of learning skills. Their research study, focusing on college students, further demonstrated that universal design principles in higher education can enhance learning for students with disabilities. These findings suggest that while many may be familiar with UDL principles, there is often a disconnect between theoretical understanding and practical application.

2.3.2 Student engagement and outcomes

Alba [5] assures that teachers need to think about the diversity of students that make up their group when designing their activities, so it is necessary to leave behind rigid models when planning the teaching–learning process to enrich

and make the curriculum design more flexible, thus reducing possible barriers and offering learning opportunities for all students and breaking barriers [49], it fulfills the role of a methodological guide due to the implications that its instructional structure carries [14]. The primary function of the UDL is the promotion of personal self-realization, the integral development of the person [19] because it is essential to integrate the student population into the culture of the global society, for which it is required to enhance in the person the construction of knowledge both individually and collaboratively, as well as their skills and values. It is also required from the UDL to educate for the understanding and respect for the cultural, ethnic, and linguistic diversity [134].

This holistic approach to education through UDL is further explored by Boothe et al. (2018), who examine the intersection of UDL with culturally responsive teaching practices in a study focusing on the need for universities to educate students from diverse backgrounds. Their work demonstrates how UDL can be leveraged to create more adaptable learning environments that not only accommodate diverse learning needs but also celebrate and incorporate diverse cultural perspectives. Smith and Lowrey [138] extend this understanding by proposing an innovative action plan for researchers and practitioners to expand their knowledge on implementing the UDL framework that includes people with disabilities. Additionally, Novak and Tucker [98] provide a comprehensive framework for implementing UDL at a systems level, emphasizing how it can transform educational institutions to serve all learners better and prepare them for success in a globalized world.

2.3.3 Institutional considerations

These principles alone do not generate the necessary changes; they are general guidelines for each educational institution where they are applied in an environment conducive to differentiated and quality education [129]. The practical implementation of UDL principles requires systemic application across educational institutions, emphasizing leadership support, professional development, and collaborative planning. A general approach to UDL implementation is present in the work of Bracken and Novak [17], which examines and describes best practices worldwide to provide strategies that strengthen accessibility, participation, and student learning outcomes through the development of flexible learning environments.

The UDL methodology effectively improves the learning process for all students and affects higher levels of motivation, improved reading experiences, the ability to elaborate on questions, improvements in the writing process, greater enjoyment in using technology, and autonomy [23]. These findings are corroborated by the meta-analysis conducted by Ok et al. [99], which examined the efficacy of UDL across various educational contexts. Their research provides empirical support for the positive impacts of UDL on student engagement, academic performance, and self-efficacy. Furthermore, Rao et al. [113] extend this understanding by exploring the long-term effects of UDL implementation, demonstrating how student variability and design are often adequately addressed in the existing literature, while information on implementation and outcomes related to UDL is not as consistently reported.

2.4 The three principles of udl and digital technologies in the scope of SDG4

2.4.1 Multiple means of representation through digital tools

The first principle refers to "What to learn?" and offers different didactic means, techniques, instruments, and pedagogical mediation. The perception of students and their way of learning differ, so it is essential to approach the contents through different channels, such as auditory, visual, and motor [62]. Research has shown that multimodal approaches to presenting information can support understanding across diverse learners [34, 74]. The ICT allows using different formats, such as digital texts that allow enlarging the text, audio, audiovisuals, animations, and other graphic elements to make the information meaningful, using links [85]. Integrating ICT with UDL principles can enhance accessibility and engagement in educational settings. When properly implemented, digital tools can offer multiple means of representation, aligning with core UDL principles [91, 122].

As Zhang et al. [157] have recently argued, there have been many criticisms of UDL for lack of clarity in definition, problems in its authentic implementation, and insufficient evidence of its effectiveness. These criticisms warrant further evaluation of UDL, mainly focusing on the theoretical foundations underpinning its conceptualization and implementation. However, as Gómez-Galán [54] points out, it is essential to use ICTs within a solid pedagogical approach that promotes the development of critical and creative skills beyond the simple consumption of information.

2.4.2 Technology-enhanced action and expression

The second principle answers the question "How to learn?" by providing varied means for action. How a subject expresses himself is different, so it is essential to favor different facilitators to use programs and resources and several options for action with materials that allow all students to interact [62]. This principle of multiple means of action supports the development of executive function skills, with diverse options for engagement and expression helping students develop crucial self-regulation and metacognitive abilities [25].

In responsive classrooms, flexible options for demonstrating knowledge can support learners with diverse abilities and communication needs. Technological support is very appropriate, as it makes it possible to use different social media and interactive web tools to facilitate learning with both digital and analog activities [79, 85]. Various technologies can be leveraged to support UDL implementation across different subject areas and educational contexts, enhancing accessibility and engagement for diverse learners [45]. One of the fundamental characteristics of the UDL proposal is that of accessibility [137],since it aims to address the access barriers imposed by an inflexible curriculum, so practices are sought that are oriented towards expansion, diversity, and flexibility in such a way that unnecessary barriers are eliminated, without removing the necessary aims. Furthermore, Tobin and Behling [145] extend this concept by making universal design "just part of what we do" and presenting intentional design options that proactively address potential barriers to learning.

2.4.3 Digital engagement strategies

The third principle, oriented toward "Why learn?" implies motivated learners who learn faster and with greater satisfaction than those who do not [62, 134]. This principle of multiple means of engagement considers the neurological basis of student engagement and its implications for UDL implementation. Research emphasizes the importance of considering affective networks in learning and provides strategies for addressing student motivation and engagement variability. UDL-based strategies can enhance motivation and self-regulation, particularly for students with emotional and behavioral aims in the search for high levels of interest, feelings of competence, and autonomy [118, 139]. It develops multiple options for executive functions, it is necessary to stimulate the student's effort toward goals, so it is essential to take into account their interests and encourage the development of strategies both towards co-evaluation and self-evaluation that lead to self-reflection [109].

Another feature is the personalized options for accessing the curriculum so that each student can progress and increase his or her performance levels. The ultimate goal of UDL is that education contributes to learning, generating expert learners, i.e., engaged students who master their learning process (Meyer and Gordon, 2014). This concept of developing expert learners through UDL is further elaborated by Ralabate (2016), who provides a comprehensive framework for implementing UDL strategies to foster self-directed learning.

2.4.4 Alignment with SDG4 goals

At present, and especially with the future in mind, the UDL is an essential model for taking on the educational challenges of our society. This aligns with the goals set out in SDG4-Education 2030 as defined by the United Nations [149]. Research has shown that UDL can benefit education in several socioeconomic contexts, including marginalized areas [80, 80, 81, 81]. As UDL research progresses, it explores applications in various educational contexts to enhance learning experiences across different settings. An equity-by-design framework integrates UDL principles with culturally responsive teaching practices, advocating for a holistic approach to inclusive education that considers learner variability and systemic inequities [27, 35]. There is also an essential factor to take into account: digital technologies. In a world increasingly dominated by them, they can, properly and pedagogically used, become fundamental tools for UDL.

Integrating UDL principles with ICT offers promising avenues to promote adaptive education and address broader educational goals [48, 103]. The model's principles can be adapted to meet local needs while focusing on inclusivity and accessibility. Case studies of UDL implementation across different countries showcase both aims and opportunities in translating these principles into diverse educational systems [28, 100, 112, 114]. As the date for the SDGs approaches, UDL's role in shaping flexible, equitable, and quality education globally is likely to become increasingly prominent. UDL is increasingly recognized as a strategy for promoting inclusive education at all levels [2, 126, 127], emphasizing proactive design for learner variability and aligning with addressing systemic educational barriers [18]. However, successful global implementation of UDL requires investment in teacher training, infrastructure development, and policy reform.

Integrating this model into international education policy and practice requires collaborative, cross-cultural research to develop contextually appropriate strategies aligned with SDG4 goals in diverse global settings.

3 Methodology

This research worked from a descriptive quantitative approach without resorting to experimental designs since it is suitable for exploring university students' perceptions about using Information and Communication Technologies as a tool to facilitate the implementation of the UDL. Its main objective is to examine the occurrence of a phenomenon and the conditions under which it manifests itself, following the perspective of Hernández Sampieri, Fernández Collado, and Baptista Lucio [63].

The objective was to analyze the perceptions of university students regarding the use of ICT as a facilitating element of UDL from the analysis and reflection of the three basic principles: 1) principle of representation, "what to learn," focuses on the different modalities of representation, whether of information or content, intending to reflect the wide range of learning options. Because people do not process information uniformly, it is necessary to present it to learners through different media and formats and to consider their different capacities for perception and comprehension. This principle addresses how the contents are presented; 2) principle of action and reflection, "how to learn," is based on the existence of different ways to express what is learned, which is why the teacher must offer multiple opportunities for action and expression, allowing free interaction with the information and that the student can demonstrate their learning according to their preferences and abilities; and 3) principle of commitment, "why to learn," focuses on the motivation and commitment of students. To achieve this, it is suggested that various forms of motivation and stimulation be provided for the students, ensuring their commitment and cooperation.

The research was conducted at a public university in the State of Hidalgo, Mexico, primarily serving the region's undergraduate students. The study included students from pedagogy and education who represented different academic programs. The institution's technological infrastructure includes on-site computers and other digital resources in classrooms and virtual platforms for e-learning or b-learning processes, typical of public universities in the country. The field work was carried out from October to November 2023, with 235 participants (24.7% male, 75.3% female). The age of the students is between 17 and 34 years old, with a mean of 20 years old and a mode of 18 years old; the highest percentage is found in the students who are 18 and 19 years old, with 45% for each age group, and the lowest percentage is found in the age of 26, 27, 28 and 34, where there is only one subject in each of these ages. As can be seen, the sample is very homogeneous. There are only gender differences, where the proportion of women is higher than that of men, as is usually the case in the field of education.

In this descriptive study, all codes of good practice for human subjects research of the ethics committees of the participating universities were adhered to, and the guidelines of the Declaration of Helsinki were followed at all times. The anonymity and confidentiality of all participants was assured. The study was registered and approved by the Ethics Committees of the EduInnovagogy (HUM-971), the Observatory on Mediation and Social Intervention in Organizations (ref. 940102), and the ICT in Education and Training Processes-CENID research groups (with assigned code no. PEM-2023-13c), and the Consolidated Body of Evaluation, Planning and Curricular Development, belonging to the Academic Area of Educational Sciences of the UAEH, following the guidelines and regulations of all of them. It was jointly signed by the research team that conducted the entire research process.

The technique used was the survey, and the collection instrument was the *DUATIC Survey* -original acronym in Spanish, where UDL stands for *Diseño Universal del Aprendizaje*, and TIC for *Tecnologías de la Información y la Comunicación*- designed ad hoc to know the perception of university students about the use of the UDL, supported with ICT as a resource to facilitate their learning, it is composed of 42 items grouped into three blocks that correspond to the principles of the UDL: 1) Principle of representation*, what to learn (*14 items), 2) Principle of action and expression*, how to learn (*14 items), and 3) Principle of commitment*, why to learn (*14 items). The responses were presented on a Likert-type scale with response options from 5 to 1, where 5 corresponds to always and 1 to never. Table 1 presents examples of the DUATIC survey structure and how the items were derived according to the three fundamental principles of the established theoretical framework.

The instrument was subjected to expert validation, with the participation of four judges from different educational institutions that work with university students in the use of ICTs to strengthen the UDL, which allowed adjustments to be made to the wording of the items, as well as eliminating and merging some so that they would be presented more

Table 1 DUATIC Survey Structure and Sample Items. Source: Own elaboration

UDL Principle	Dimension	Sample Items	Scale
Principle of Representation ("What to learn?")	Multimedia Resources	"I find it useful that various multimedia resources (videos, presentations, infographics) are used in classes."	5-point Likert
	Interactive Technologies	"I believe that the use of interactive technologies such as online simulations improves the understanding of concepts."	5-point Likert
	Content Accessibility	"Adapting content for mobile devices makes it easier for me to access information anytime, anywhere."	5-point Likert
Principle of Action and Expression ("How to learn?")	Creative Expression	"I find that designing interactive online presentations enhances my ability to communicate my ideas effectively."	5-point Likert
	Digital Collaboration	"I prefer online collaborative writing using tools such as Google Drive for building group projects."	5-point Likert
	Assessment Tools	"The creation of digital portfolios is an effective way to express my academic and professional achievements."	5-point Likert
Principle of Engagement ("Why learn?")	Motivation	"I feel more engaged when academic activities incorporate elements of gamification or educational games."	5-point Likert
	Personalization	"I believe that using online learning platforms gives me the flexibility to tailor my learning to my interests."	5-point Likert
	Self-Directed Learning	"I find classes that offer options for self-directed online learning to be more motivating for me."	5-point Likert

clearly and would allow the scope of the objective and the identification of the principle. The instrument validation process followed established guidelines for educational measurement tools [38]. The expert validation approach aligns with similar UDL implementation studies (e.g., [46, 113, 139]), emphasizing content validity's importance in educational technology assessment. The four judges were selected based on criteria Lawshe [78] established for content validity ratio determination, including relevant expertise in UDL and educational technology. This methodology has been successfully employed in recent studies examining technology integration in higher education (e.g., [48, 59]). A pilot test was applied to 30 university students with similar characteristics to the sample to identify the understanding of each item, consider the response time, and have a first approach to the topic of study on the use of ICT. After making the adjustments, the survey was applied digitally using a Google Forms questionnaire.

Cronbach's Alpha coefficient was calculated to measure the internal consistency of the questionnaire, which allows us to determine its reliability according to the George and Mallery [51] scale. The Cronbach's Alpha coefficient calculated for the instrument as a whole is 0.966, which places it in the excellent category ($\alpha > 0.9$) according to the scale mentioned above. In this sense, the questionnaire demonstrates a high level of rigor, showing that its items are highly consistent with each other. Its internal consistency is very high, which determines that the items are well correlated, contribute effectively to the overall measure, and reliably measure the underlying construct for which it was designed.

Statistical analyses of the data, being such a homogeneous sample, focused on descriptive statistics. The use of inferential statistics was considered to determine possible differences in perceptions based on demographic variables (in our case, gender and age), considering t-tests or ANOVA, but the only interest would be in gender since, about age, practically all participants were between 18 and 19 years of age. IBM Statistical Package for the Social Sciences (SPSS) version 25 (IBM SPSS Statistics 25.0), Python, and Microsoft Excel were mainly used for the statistical work.

4 Results

The analysis of results reveals how digital technologies extend beyond traditional media capabilities in supporting UDL implementation. While traditional and digital media can present information through various formats—text, audio, images, or video—digital technologies uniquely enable dynamic content manipulation, storage, and transformation [128]. The findings are organized according to the three UDL principles, beginning with the principle of representation, which addresses how students access and process learning content. Table 2 shows the results of the students' perceptions of the *Principle of Representation: What to learn?*, and indicates what to learn through UDL using ICT.

Analysis of student responses demonstrates challenging support for digital technology integration in UDL implementation. Students particularly valued multimedia resources in their learning experiences ($M = 4.74$, $SD = 0.596$), with this highest mean score indicating a strong preference for diverse content presentation modes. This finding was reinforced by similarly high ratings for interactive technologies ($M = 4.43$, $SD = 0.745$) and multimodal online presentations ($M = 4.42$, $SD = 0.766$). These consistently high scores across different digital modalities suggest that students recognize the value of technological tools in supporting diverse learning approaches. These results indicate that participants find interactive and multisensory content particularly effective in facilitating their understanding of concepts. The combination of auditory and visual elements in online presentations seems well-received, possibly because it provides a more immersive and engaging learning experience.

Interestingly, despite positive attitudes toward digital technologies, students expressed measured preferences regarding complete digitalization. The relatively lower score for exclusive online platform use versus traditional materials ($M = 3.86$, $SD = 1.051$, highest SD in the study) suggests a preference for blended learning approaches. This finding indicates that while students value digital tools, they recognize the complementary role of traditional learning materials in their educational experience. The higher standard deviation suggests more diverse opinions than other measured variables. The figures for this item would indicate that study participants prefer a mix of digital and traditional resources rather than a complete shift to digital-only materials. This preference for a blended approach could be due to familiarity with traditional materials, the tactile nature of physical resources, or perhaps a concern about screen fatigue involved in digital-only learning. Lower scores on receiving feedback through online platforms ($M = 3.83$, $SD = 1.095$) and learning through platforms that allow active interaction with content ($M = 3.90$, $SD = 1.039$) suggest areas where implementation of digital tools could be improved. Although students appreciate the availability of digital resources, this data would tell us about limitations in current digital feedback and interactive learning systems. The relatively low score for online feedback could indicate dissatisfaction with the quality or ease of use of current online feedback systems.

Table 2 Principle of representation: What to learn? Source: Own elaboration

Item	Descriptor	Mean (M)	Standard Deviation (SD)	Range (Max–Min)
1	I find it useful that various multimedia resources (videos, presentations, infographics) are used in classes	4.74	0.596	Maximum 5 Minimum 1
2	I believe that the use of interactive technologies such as online simulations improves the understanding of the concepts	4.43	0.745	Maximum 5 Minimum 1
3	I prefer to access information through online platforms and digital resources rather than printed materials	3.86	1.051	Maximum 5 Minimum 1
4	I find that online presentations with visual and auditory elements facilitate my learning	4.42	0.766	Maximum 5 Minimum 1
5	Accessing digital libraries and online databases enhances my ability to explore different perspectives on a topic	4.06	0.965	Maximum 5 Minimum 1
6	I believe that online collaboration tools such as document sharing are conducive to teamwork	4.40	0.796	Maximum 5 Minimum 1
7	I prefer to learn through online platforms that allow me to actively interact with the content	3.90	1.039	Maximum 5 Minimum 1
8	Adapting content for mobile devices makes it easier for me to access information anytime, anywhere	4.40	0.802	Maximum 5 Minimum 1
9	I feel more engaged when interactive multimedia elements are incorporated into the lessons	4.26	0.881	Maximum 5 Minimum 1
10	I find that the use of virtual or augmented reality technologies in lessons enhances my learning experience	4.19	0.897	Maximum 5 Minimum 1
11	I prefer to receive feedback through online platforms that allow me to review and improve my work	3.83	1.095	Maximum 5 Minimum 1
12	The use of educational social networks and online forums facilitates discussion and the exchange of ideas with my peers	4.15	0.938	Maximum 5 Minimum 1
13	I believe that the presentation of information through different online formats is more effective than the traditional presentation	4.12	0.944	Maximum 5 Minimum 1
14	The ability to access online lectures and study materials enhances learning flexibility	4.20	0.868	Maximum 5 Minimum 1

We found equal results for platforms that allow active interaction with content, which could indicate that current interactive learning platforms do not meet students' expectations or needs. This could be due to usability issues, lack of engaging content, or perhaps a mismatch between the type of interaction offered and what students consider most beneficial for their learning. It is worth noting that students rate the adaptation of content to mobile devices very positively (M = 4.40, SD = 0.802), which informs us of a strong preference for flexible and accessible learning resources. This high score suggests that students appreciate the ability to access learning materials anytime, anywhere, which is consistent with the increasingly mobile and flexible nature of modern student life, and the importance of ubiquitous learning. The use of virtual or augmented reality technologies in the classroom was also supported (M = 4.19, SD = 0.897). It could be argued, therefore, that students are open to and appreciate innovative technologies in their learning experiences. This openness to advanced technologies shows a potential for further integration of such tools in educational settings, provided they are applied effectively.

Table 3 reflects the results of the second principle of the UDL *How to learn*. The principle of action and expression focuses on providing multiple means for learners to demonstrate their knowledge and skills. The data reveal several interesting patterns in how students view different digital tools and platforms to express their learning. The highest score in this category relates to the design of interactive online presentations (M = 4.37, SD = 0.730). This strong preference signals that students feel empowered by interactive presentation tools, considering them effective means to articulate their ideas. The high mean score, coupled with a relatively low standard deviation, indicates a consistent appreciation of these tools across the student population. This preference could be attributed to interactive presentations' dynamic and engaging nature, which allows students to demonstrate their knowledge in more varied and creative ways than traditional methods.

This is closely followed by the item on the use of virtual or augmented reality technologies to create hands-on experiences in projects (M = 4.34, SD = 0.796). This high score reveals students' enthusiasm for cutting-edge technologies in their learning process and suggests that they see great potential in immersive technologies to create more engaging, hands-on learning experiences. This openness to emerging technologies indicates a desire for more innovative and experiential approaches to demonstrating knowledge and skills. In this regard, students also highly value the creation of digital portfolios (M = 4.31, SD = 0.774). This preference suggests that students appreciate tools that allow them to showcase their work and accomplishments comprehensively over time. Digital portfolios could be considered a more dynamic and versatile alternative to traditional resumes or transcripts, as they allow for a more holistic representation of a student's capabilities and growth.

It is paradoxical that while students show a high appreciation for these digital tools of expression, it is less so for online participatory activities. The item related to participation in online debates or discussion forums received the lowest score (M = 3.63, SD = 1.138). This data, coupled with the highest standard deviation in the table, suggests a wide range of opinions in this regard and shows that many students are less comfortable or interested in this form of expression. It could indicate a preference for more structured or less public ways of expressing ideas or perhaps concerns about the nature of online discussions. Similarly, participation in videoconferencing also scored relatively low (M = 3.72, SD = 1.061). This suggests that, although students appreciate asynchronous digital tools, they may be less comfortable with real-time, face-to-face digital interactions. This could be due to various factors, such as technical difficulties, social anxiety in digital spaces, or simply a preference for more time to formulate and express ideas. On the other hand, students show a strong preference for creative expression through digital media (M = 4.29, SD = 0.829). This may indicate that they value these digital tools' flexibility and diverse options. The use of online survey tools or electronic voting for quick feedback also received high support (M = 4.28, SD = 0.819 and M = 4.21, SD = 0.879, respectively), indicating that students appreciate efficient and immediate ways to provide and receive feedback in their learning process.

Table 4 shows the information obtained regarding the reasons for learning through the UDL using ICTs. We speak of the third UDL principle of engagement, which focuses on the motivational aspects of learning and keeps students interested and engaged in their educational process. The data reveal several interesting patterns in how students view different digital tools and approaches to enhance their engagement with learning. The highest score in this category relates to the flexibility of online learning platforms to tailor learning to individual interests (M = 4.33, SD = 0.767). This prominent preference suggests that students highly value the ability to personalize their learning experience. The high mean score, coupled with a relatively low standard deviation, indicates a consistent appreciation of this aspect of online learning across the student population. This preference could be attributed to students' diverse needs and interests, who value the opportunity to focus on areas that are most relevant or of interest to them.

This is closely followed by the item on incorporating gamification or educational game elements into academic activities (M = 4.30, SD = 0.799). This high score reveals the participants' enthusiasm for more interactive and playful elements

Table 3 Principle of action and expression: How to learn? Source: Own elaboration

Item	Descriptor	Mean (M)	Standard Deviation (SD)	Range (Max–Min)
15	I feel more comfortable expressing my ideas through online platforms such as blogs or educational social networks	3.83	0.982	Maximum 5 Minimum 1
16	I prefer demonstrating my understanding of the subject through multimedia presentations rather than written reports	4.02	0.931	Maximum 5 Minimum 1
17	I find that using online tools allows me to express creativity in academic projects	4.29	0.829	Maximum 5 Minimum 2
18	I find it helpful to participate in videoconferences where I have the possibility to express my ideas in real-time	3.72	1.061	Maximum 5 Minimum 1
19	I prefer to create interactive online projects, such as websites and infographics, to demonstrate my knowledge	4.26	0.891	Maximum 5 Minimum 1
20	I am interested in participating in online debates or discussion forums to express my opinions on academic topics	3.63	1.138	Maximum 5 Minimum 1
21	Academic social networks allow me to collaborate and express myself effectively with my peers	4.12	0.919	Maximum 5 Minimum 2
22	I prefer online collaborative writing using tools such as Google Drive for building group projects	4.24	0.845	Maximum 5 Minimum 1
23	I find that designing interactive online presentations enhances my ability to communicate my ideas effectively	4.37	0.730	Maximum 5 Minimum 2
24	I like the idea of using virtual or augmented reality technologies to create hands-on experiences in my projects	4.34	0.796	Maximum 5 Minimum 1
25	Using online survey tools or electronic voting allows me to get feedback quickly	4.28	0.819	Maximum 5 Minimum 2
26	The ability to create online surveys or electronic voting allows me to get feedback quickly	4.21	0.879	Maximum 5 Minimum 2
27	The creation of digital portfolios is an effective way to express my academic and professional achievements	4.31	0.774	Maximum 5 Minimum 2
28	I prefer to use online learning platforms for activities	4.18	0.889	Maximum 5 Minimum 1

Table 4 Principle of commitment: Why learn? Source: Own elaboration

Item	Descriptor	Mean (M)	Standard Deviation (SD)	Range (Max–Min)
29	I feel more motivated to participate in academic activities when interactive technologies are used	4.17	0.852	Maximum 5 Minimum 1
30	Access to online educational content that relates to my interests increases my engagement	4.23	0.789	Maximum 5 Minimum 2
31	Participating in online discussions or academic forums helps me stay engaged in class	3.97	0.969	Maximum 5 Minimum 1
32	I prefer to receive instant feedback through online platforms to adjust my learning	4.02	0.924	Maximum 5 Minimum 1
33	Using educational mobile applications helps me integrate learning into my daily life	4.25	0.843	Maximum 5 Minimum 1
34	Using online multimedia resources, such as educational videos, increases my interest in academic subjects	4.26	0.836	Maximum 5 Minimum 1
35	I feel more engaged when academic activities incorporate elements of gamification or educational games	4.30	0.799	Maximum 5 Minimum 1
36	I find that access to online platforms allows me to set personalized learning goals and improve my motivation	4.17	0.852	Maximum 5 Minimum 1
37	Participating in online collaborative projects helps me feel more connected with my classmates	4.13	0.838	Maximum 5 Minimum 1
38	I prefer to access digital libraries and online databases for research and projects	4.08	0.859	Maximum 5 Minimum 2
39	I find classes offering self-directed online learning options to be more motivating for me	4.03	0.942	Maximum 5 Minimum 1
40	The ability to access online educational resources that challenge my skills increases my engagement in learning	4.25	0.778	Maximum 5 Minimum 1
41	I find the idea of using academic social networks to connect with experts and professionals on topics that interest me	4.21	0.794	Maximum 5 Minimum 1
42	I believe that using online learning platforms gives me the flexibility to tailor my learning to my interests	4.33	0.767	Maximum 5 Minimum 2

in their learning process. They undoubtedly find gamification motivating and engaging, possibly due to the challenge and interactivity offered by these games. This preference indicates that they are receptive to innovative teaching methods that lead to more enjoyable and participatory learning. Students also highly value using multimedia resources in learning (M = 4.26, SD = 0.836). They consider them effective in arousing and maintaining their interest in academic subjects. These resources' visual and auditory elements could be considered more engaging and accessible to process than traditional text-based materials.

Although students highly value digital tools, their scores on some aspects of online interaction, as we saw in the previous principles, are slightly lower. The item related to participation in online academic discussions or forums received the lowest score in this category (M = 3.97, SD = 0.969). It shows that not all students find online discussions equally attractive. This could be due to several factors, such as the quality of the discussions, the level of participation required, or personal preferences for other forms of participation. In this aspect, the personality of the student is very relevant. In this area, receiving instant feedback through online platforms also scored very similarly (M = 4.02, SD = 0.924). While still optimistic, it points out that while students appreciate quick feedback, they may not consider it the most engaging aspect of their learning experience. This could indicate a preference for more in-depth or personalized feedback or a desire to balance this immediate interaction and more reflective learning processes.

On the other hand, students show an outstanding interest in using educational mobile applications (M = 4.25, SD = 0.843). They value the convenience and accessibility offered by this medium, which allows them to interact with multiple contents and in various contexts throughout the day. The ability to access online educational resources also received a high score (M = 4.25, SD = 0.778), indicating that they are motivated by content that tests their abilities. They value learning experiences that are not only accessible but also stimulating and growth-oriented. Students also show appreciation for the social aspects of online learning, as seen in scores for connecting with experts through academic and social networks (M = 4.21, SD = 0.794) and participating in online collaborative projects (M = 4.13, SD = 0.838). This finding is essential, as it underscores the interest in the opportunities for connection and collaboration that digital platforms can offer, both with experts in their field of study and their peers.

As indicated, the inferential statistical analysis focused on detecting possible gender differences in the use of ICTs in the context of UDL. Independent samples t-tests were used to compare the mean differences between male and female participants on the survey items. The independent samples test is exposed in Table 5. The complete statistical analysis is presented in this table for transparency and replication purposes, providing detailed information about each item comparison. Table 6 (Appendix 1) shows the descriptive statistics with gender differences. In general, male students showed a greater preference for using ICT tools related to creativity, collaboration, and interactive projects in UDL contexts than female students. It was even possible to determine a preference for online materials over printed materials, where the most remarkable difference appears in favor of male students. In addition to these significant differences ($p < 0.05$) in some items (3, 17, 19, 22, and 23), there were some other items in which a marginal difference ($p < 0.10$) in favor of male students could be determined (as in the case of item 8, on the suitability of adapting content to mobile devices). Only in three items did female students show higher means, although not statistically significant (20, 29, and 32), related to discussions, motivation, and feedback. However, most importantly, most items do not show statistically significant differences between genders.

These results suggest that male students might be more inclined to adopt digital tools that enable creative, collaborative, and interactive learning experiences within a pattern where they would be slightly more engaged or appreciative of digital technologies in the UDL context. However, to confirm this possible finding, the effect size (Cohen's d) of each t-test was calculated to assess the magnitude of the differences, and the Bonferroni correction was applied to adjust the significance level in multiple comparisons. Applied to items where the differences were statistically significant at the conventional level ($p < 0.05$), the effect sizes (Cohen's d) were small to medium, indicating that the practical significance of these differences is limited. Furthermore, when the Bonferroni correction was applied to account for multiple comparisons, these differences did not maintain statistical significance, demonstrating that gender does not play a substantial role in how students perceive and use digital technologies within this UDL framework. Overall, thus, it could be concluded that both male and female students share similar attitudes toward using digital technologies in UDL. This analysis is very interesting in the context of our study, as it highlights the feasibility of applying UDL principles broadly across diverse groups while underscoring the importance of equitable implementation of digital tools for all learners.

Note on abbreviations: (VE) Assuming equal variances: homoscedasticity/homogeneous variance; (VNE) Equal variances not assumed: heteroscedasticity/heterogeneous variance; (Levene's test) Levene's test for equality of variances for equality of variances; (t-test) t-test for equality of means; (95% CI) 95% confidence interval of the difference; (Bil.) Bilateral/Two-tailed).

Table 5 Independent samples test. Source: Own elaboration

Variable		Levene's test		t-test						
		F	Sig	t	Gl	Sig. (bil.)	Mean difference	Standard error difference	95% CI	
									Lower	Upper
1	VE	2.997	0.085	0.984	232	0.326	0.089	0.090	−0.089	0.267
	VNE			0.870	81.192	0.387	0.089	0.102	−0.115	0.292
2	VE	0.987	0.322	1.227	232	0.221	0.138	0.113	−0.084	0.360
	VNE			1.123	84.914	0.265	0.138	0.123	−0.107	0.383
3	VE	5.396	0.021	−2.349	232	0.020	−0.371	0.158	−0.682	−0.060
	VNE			−2.568	114.933	0.012	−0.371	0.144	−0.657	−0.085
4	VE	0.014	0.905	0.698	232	0.486	0.081	0.116	−0.148	0.310
	VNE			0.686	94.544	0.495	0.081	0.118	−0.154	0.316
5	VE	0.199	0.656	−0.669	232	0.504	−0.098	0.147	−0.387	0.191
	VNE			−0.672	97.910	0.503	−0.098	0.146	−0.388	0.192
6	VE	1.004	0.317	0.821	232	0.412	0.099	0.120	−0.138	0.335
	VNE			0.748	84.432	0.457	0.099	0.132	−0.163	0.361
7	VE	0.094	0.759	−0.575	232	0.566	−0.091	0.158	−0.401	0.220
	VNE			−0.574	97.122	0.567	−0.091	0.158	−0.404	0.223
8	VE	1.128	0.289	1.715	232	0.088	0.207	0.121	−0.031	0.446
	VNE			1.573	85.249	0.119	0.207	0.132	−0.055	0.470
9	VE	8.991	0.003	1.397	232	0.164	0.186	0.133	−0.076	0.449
	VNE			1.196	77.980	0.235	0.186	0.156	−0.124	0.496
10	VE	0.094	0.759	0.068	232	0.946	0.009	0.136	−0.259	0.277
	VNE			0.067	96.163	0.947	0.009	0.137	−0.262	0.281
11	VE	1.845	0.176	−0.472	232	0.638	−0.078	0.166	−0.406	0.249
	VNE			−0.495	105.937	0.622	−0.078	0.158	−0.393	0.236
12	VE	0.371	0.543	0.714	232	0.476	0.101	0.142	−0.179	0.382
	VNE			0.665	87.094	0.508	0.101	0.153	−0.202	0.405
13	VE	1.286	0.258	−0.649	232	0.517	−0.093	0.143	−0.376	0.190
	VNE			−0.641	95.499	0.523	−0.093	0.145	−0.381	0.195
14	VE	0.028	0.867	1.027	232	0.305	0.135	0.132	−0.124	0.395
	VNE			0.994	92.316	0.323	0.135	0.136	−0.135	0.405
15	VE	0.629	0.429	−0.217	232	0.828	−0.032	0.149	−0.326	0.261
	VNE			−0.211	93.183	0.833	−0.032	0.153	−0.336	0.271
16	VE	2.540	0.112	0.811	232	0.418	0.114	0.141	−0.163	0.392
	VNE			0.751	86.384	0.455	0.114	0.152	−0.188	0.417
17	VE	0.764	0.383	2.182	232	0.030	0.272	0.125	0.026	0.517
	VNE			2.044	87.861	0.044	0.272	0.133	0.008	0.536
18	VE	1.040	0.309	−0.800	232	0.424	−0.129	0.161	−0.445	0.188
	VNE			−0.823	102.211	0.412	−0.129	0.156	−0.438	0.181
19	VE	0.002	0.967	2.248	232	0.026	0.301	0.134	0.037	0.564
	VNE			2.161	91.327	0.033	0.301	0.139	0.024	0.577
20	VE	0.088	0.767	−1.041	232	0.299	−0.179	0.172	−0.518	0.160
	VNE			−1.046	98.049	0.298	−0.179	0.171	−0.519	0.161
21	VE	0.193	0.661	1.477	232	0.141	0.205	0.139	−0.068	0.478
	VNE			1.437	92.998	0.154	0.205	0.143	−0.078	0.488
22	VE	2.008	0.158	2.186	232	0.030	0.278	0.127	0.027	0.529
	VNE			1.920	80.533	0.058	0.278	0.145	−0.010	0.566
23	VE	0.112	0.739	2.799	232	0.006	0.305	0.109	0.090	0.520
	VNE			2.699	91.729	0.008	0.305	0.113	0.081	0.530
24	VE	0.588	0.444	0.632	232	0.528	0.076	0.121	−0.162	0.314
	VNE			0.594	88.104	0.554	0.076	0.129	−0.179	0.332

Table 5 (continued)

Variable		Levene's test		t-test						
		F	Sig	t	Gl	Sig. (bil.)	Mean difference	Standard error difference	95% CI	
									Lower	Upper
25	VE	0.736	0.392	0.344	232	0.731	0.043	0.124	−0.202	0.288
	VNE			0.332	91.894	0.741	0.043	0.129	−0.213	0.299
26	VE	0.870	0.352	−0.147	232	0.884	−0.020	0.134	−0.283	0.244
	VNE			−0.143	93.091	0.887	−0.020	0.137	−0.292	0.253
27	VE	0.664	0.416	1.190	232	0.235	0.140	0.117	−0.092	0.371
	VNE			1.114	87.663	0.268	0.140	0.125	−0.110	0.389
28	VE	0.341	0.560	−0.440	232	0.660	−0.059	0.135	−0.325	0.207
	VNE			−0.451	101.500	0.653	−0.059	0.132	−0.321	0.202
29	VE	0.016	0.900	−1.214	232	0.226	−0.157	0.129	−0.411	0.098
	VNE			−1.271	105.628	0.206	−0.157	0.123	−0.401	0.088
30	VE	0.227	0.634	−0.884	232	0.378	−0.106	0.120	−0.342	0.130
	VNE			−0.894	99.276	0.373	−0.106	0.118	−0.341	0.129
31	VE	0.033	0.857	−0.933	232	0.352	−0.137	0.147	−0.427	0.153
	VNE			−0.945	99.510	0.347	−0.137	0.145	−0.425	0.151
32	VE	1.022	0.313	−1.311	232	0.191	−0.184	0.140	−0.459	0.092
	VNE			−1.449	117.488	0.150	−0.184	0.127	−0.435	0.067
33	VE	0.056	0.814	0.470	232	0.639	0.060	0.128	−0.192	0.312
	VNE			0.467	96.332	0.642	0.060	0.129	−0.196	0.316
34	VE	0.471	0.493	0.427	232	0.670	0.054	0.127	−0.196	0.305
	VNE			0.420	94.788	0.675	0.054	0.129	−0.202	0.311
35	VE	0.998	0.319	−0.453	232	0.651	−0.055	0.121	−0.294	0.184
	VNE			−0.488	111.606	0.626	−0.055	0.113	−0.278	0.168
36	VE	1.372	0.243	0.029	232	0.977	0.004	0.130	−0.251	0.259
	VNE			0.031	109.246	0.976	0.004	0.122	−0.237	0.245
37	VE	1.924	0.167	−0.102	232	0.919	−0.013	0.127	−0.264	0.238
	VNE			−0.111	114.029	0.912	−0.013	0.117	−0.245	0.219
38	VE	0.257	0.613	−0.798	232	0.426	−0.104	0.130	−0.361	0.153
	VNE			−0.829	104.182	0.409	−0.104	0.125	−0.353	0.145
39	VE	0.482	0.488	−0.965	232	0.336	−0.138	0.143	−0.420	0.144
	VNE			−1.051	114.114	0.295	−0.138	0.131	−0.398	0.122
40	VE	0.241	0.624	−0.898	232	0.370	−0.106	0.118	−0.339	0.127
	VNE			−0.954	108.579	0.342	−0.106	0.111	−0.326	0.114
41	VE	0.108	0.743	−1.260	232	0.209	−0.151	0.120	−0.388	0.085
	VNE			−1.384	116.039	0.169	−0.151	0.109	−0.368	0.065
42	VE	0.108	0.743	−0.180	232	0.857	−0.021	0.117	−0.251	0.209
	VNE			−0.185	102.123	0.854	−0.021	0.113	−0.246	0.204

The overall results obtained, as we can see, synthesizing all of the above, have allowed us to discover that, about the first principle analyzed, the university students surveyed have a positive perception of digital technologies when it comes to representing and accessing learning content. They particularly value multimedia resources, interactive technologies, and visual/auditory elements in online presentations. However, there seems to be a preference for combining digital and traditional methods rather than a complete shift to online platforms, especially when receiving feedback and accessing information. The findings also highlight areas where current digital learning tools may not meet their expectations, particularly regarding interactive learning platforms and online feedback systems.

On the second principle, the results paint a picture in which students highly value digital tools for creative expression, interactive presentations, and showcasing achievements. They show enthusiasm for innovative technologies such as virtual and augmented reality in their learning processes. However, they seem less comfortable with public or real-time

forms of online expression, such as debates, forums, or videoconferencing. This suggests a preference for digital tools that allow greater control over the timing and form of expression. In referring to the third principle, it is possible to highlight that students are very interested in digital learning tools that offer flexibility, personalization, and interactive elements, so they prefer gamified learning experiences and multimedia resources. They also value integrating learning into their daily lives through mobile applications and accessing stimulating content. Although they appreciate the social and collaborative aspects of online learning, they seem somewhat less committed to direct interaction.

In general, it can be corroborated that using different tools enriches the opportunity to present content in different formats—text, audio, video, images—and should be considered for inclusion in the design of educational material. They can improve learning processes in the UDL context, which promotes students to be more motivated to learn faster and with greater satisfaction. It is pertinent to highlight that the use of digital media does not guarantee by itself the improvement of teaching and learning processes; it offers both teachers and students an opportunity to diversify the paths that allow building learning with meaning and sense, as well as individualizing teaching [128].

It should not be forgotten that the purpose of UDL is to generate physical, cultural environments, and tools that are accessible to the greatest number of people. It is based on the principle that all learning involves a challenge in the specific area in which it is going to occur, and for this to be possible, possible barriers must be eliminated, seeking to favor access in all aspects of learning and meet the objectives of education from equity (Tobón and Cuesta, 2020). It favors educational inclusion by considering diverse open learning resources so people can build their learning spaces and environments differently. Therefore, the scope of the university curriculum promotes flexibility as a key strategy to meet group diversity according to the demands and interests of students.

In this way, through the practical implementation of the principles of UDL and the design of appropriate response strategies, the obstacles that limit some students given their characteristics can be eliminated, and learning to learn is favored permanently in order to continue training autonomously [105]. Remembering that there is no optimal way to perform a task or express learning that applies universally to all students is crucial. In teaching practice, it is essential to offer diverse options for carrying out learning tasks and expressing acquired knowledge. Thus, from the results obtained, it would be possible to argue that the educational use of ICT in the UDL context would greatly interest students.

5 Discussion

The presence of digital technologies in higher education is not without controversy as to how to use it properly in the service of better training and how to make it useful in most possible contexts. Besides, while this study relies substantially on student perceptions, it is essential to acknowledge the ongoing debate about the reliability of such measures in educational research. Kirschner and van Merriënboer [77] caution against uncritical acceptance of learner preferences as indicators of effective educational practice. What students believe is best for their learning may not align with evidence-based practices or optimal educational outcomes. However, student perceptions remain valuable for several reasons in the context of UDL and digital technology implementation. The success of educational technologies often depends on student buy-in and engagement, making their perspectives crucial for successful implementation. UDL's core principle of providing multiple means of engagement explicitly recognizes the importance of learner affect and motivation, areas where student perceptions provide direct insight [61, 75]. In higher education, where students are adult learners with developed metacognitive abilities, their perspectives on learning technologies can inform more effective implementation strategies [71].

The findings of this study highlight the critical potential of UDL in higher education when integrated with ICT. They reflect a favorable perception among college students toward using technologies for UDL, which aligns with the growing body of research on this topic. The principle of representation, or *what to learn*, received strong support from students in this study. Participants especially valued that the content to be learned was part of multimedia resources and interactive technologies. This aligns with previous research suggesting that multimodal approaches to content presentation can improve comprehension among diverse learners [123, 141]. The integration of ICT with UDL principles has been shown to improve accessibility and engagement in educational settings [3, 8, 132]. As Benton-Borghi [13] explored, merging UDL with Technological Pedagogical Content Knowledge (TPACK) provides a comprehensive model for leveraging technology

in teacher education and supporting diverse learners. This integration is crucial in today's digital age, where ICT has become essential in various spheres of daily life, including education [29, 82, 150]. Using diverse digital tools and platforms in UDL-based teaching for different content can create more engaging and inclusive learning environments [9, 86].

Regarding the principle of action and expression, or *how to learn*, students in this study preferred developing their learning through online projects and multimedia presentations. This preference aligns with UDL's emphasis on providing multiple means of action and expression. Research has demonstrated the importance of design for learner variability, the need for responsive approaches, and teamwork [79]. In addition, integrating technology in implementing UDL can improve the accessibility and engagement of diverse learners in different subject areas and educational contexts [45, 99]. The principle of engagement, or *why learn*, also received positive student responses. Participants expressed greater motivation and interest in learning when interactive technologies and gamification processes were incorporated into their academic experiences. This finding is consistent with previous research on UDL and engagement and the benefits for students considering these elements [83, 110]. Rappolt-Schlichtmann and Daley [116] demonstrated that implementing UDL can increase student motivation even in informal learning environments. Another finding of our research was a slightly higher use and acceptance of ICT in educational contexts in men compared to women, but these differences are minimal and not statistically relevant. It is also in line with other studies [106, 107, 155]. However, these gender differences concerning ICT use, as other studies have shown [124], are disappearing, although age differences remain, especially when it comes to different generations. The findings support the broad applicability of UDL strategies in fostering an accessible learning environment that addresses the diverse needs of all learners, regardless of gender.

The results of this study also align with the Sustainable Development Goals (SDGs), in particular SDG4-Education 2030. The adoption of the UDL principles is in line with seeking to improve the quality and accessibility of education worldwide, as pursued by this particular goal [149]. The application of UDL with ICT not only improves access to education but can address general educational problems [7, 103]. However, as Zhang et al. [157] have recently argued, there have been many criticisms of UDL for lack of clarity in definition, problems in its authentic implementation, and insufficient evidence of its effectiveness. These criticisms warrant further evaluation of UDL, mainly focusing on the theoretical foundations underpinning its conceptualization and implementation. It is important to note, of course, that effective application of UDL principles requires systemic application across educational institutions. As Katz and Sokal [73] point out, to integrate UDL models, the effects of the model on diverse students' conceptions of learning, learning processes, interdependence in learning, academic self-concept, and school engagement must be assessed from the learner's perspective. While the principles of UDL are promising, its effectiveness is closely linked to the quality and consistency of implementation. It is even much more important if digital technologies are present in the context.

This would be in line with the importance of integrating ICT into educational background, not only because they can be helpful as teaching resources as long as they are adequately and pedagogically used, but also in order to create critical attitudes in students because of the power of social influence that they can generate today [57] and [26, 58]. The transformative potential of the most recent technologies for implementing UDL from different didactic possibilities should undoubtedly be considered. We are talking about, among others, artificial intelligence and adaptive learning [68], virtual and augmented reality in relation to immersive learning experiences [140, 153], the Internet of Things (IoT) in education and accessibility [20, 154], advanced mobile technologies and ubiquitous learning systems [36, 144], simulation and gamification systems [83], natural language processing technologies and real-time translation systems [101] and others such as blockchain for educational environments where high security is required, new affective computing systems, or devices for learning analytics, where applications and methods should be explored in this context.. A crucial consideration in educational innovation is that technological sophistication alone does not guarantee pedagogical effectiveness,instead, these tools' thoughtful application and integration determine their educational value [53].

The future of UDL research and practice is likely to focus on several key areas. More empirical studies on the effectiveness of UDL are needed, mainly longitudinal studies that examine its long-term impact on student outcomes. Meta-analyses that analyze the most consistent and comprehensive approaches to measuring UDL implementation and its effects are needed. Studies such as those by Capp [23], Baybayon [12], or King-Sears et al. [76] may be an example. For our part, precisely, what we sought with the present study was to contribute to the growing body of literature on implementing UDL in higher education, particularly concerning digital technologies. Although the results suggest that undergraduate students perceive UDL-based approaches, supported in this case by ICT, as beneficial to their learning experiences, further

research is needed to understand the long-term impact of UDL implementation entirely and to develop best practices for its integration in various educational contexts. As we approach the target date set for the SDGs, the role of UDL in shaping versatile, equitable, and quality education globally is likely to become increasingly relevant.

6 Limitations

Regarding the study's limitations, it is essential to point out several factors that may affect the interpretation of the results. First, the size of the sample and its homogeneity, coming from a single public institution in the state of Hidalgo, limits the generalizability of the findings to larger populations or other educational contexts. The predominance of female participants (75.3%) and the concentration of ages between 18–19 years (90%)—since most of them are first-year students—also suggest the need for caution in generalizing these findings to more diverse student populations. However, it should be noted that these are common characteristics in all Latin American and, in general, Western university systems. For its part, the self-reported nature of the data collected through the survey may also be subject to bias. This corresponds to the cross-sectional design of the study, which limits causal inference about the relationship between UDL implementation and student perceptions or outcomes. Regarding the DUATIC instrument, although its high internal consistency has been demonstrated, further validation studies in different populations and educational settings will be necessary to strengthen its reliability as a measurement tool.

Also note the social desirability bias, which may have affected the responses, especially given the increasing emphasis on digital competence in higher education. Some students might express more positive attitudes towards digital technologies than they have, which would distort some answers. Related to this, we should also understand that the sample comprises university students primarily from the field of education. Although they will be future teachers—which was of particular interest to us—so can other professionals from other fields. Studying other academic majors may influence how students perceive and interact with digital technologies, as different fields of knowledge may have different requirements and approaches to using technology in learning. Therefore, future research should expand this work in several key directions. In terms of the *object of research* (A), it should examine a broader range of student characteristics, including socioeconomic background, prior technological experience, learning preferences and styles, academic discipline differences, cultural and linguistic diversity, different levels of technological access; and various types of learning needs. Additionally, regarding *methodology* (B), future research would benefit from longitudinal designs tracking technology use patterns over time, mixed-methods approach combining quantitative and qualitative data, cross-institutional studies comparing different technological infrastructures, international comparative studies examining cultural variations; studies examining the intersection of multiple student characteristics; and research on emerging technologies' impact on UDL implementation. Such expanded research would provide a more comprehensive understanding of how digital technologies can support diverse student populations within the UDL framework.

Another significant limitation relates to the timing of our study, which coincided with the emergence of AI technologies in educational contexts. While we considered including AI-related questions in the DUATIC instrument, the limited implementation of these technologies in our research context at the time suggested that such inquiries might yield unreliable results. However, the rapid development of AI-powered educational technologies offers promising new possibilities for UDL implementation. Recent advances in adaptive learning and personalized feedback systems [68, 93] suggest various potential enhancements to UDL principles. AI-powered systems can provide adaptive content presentation that automatically adjusts to individual learning patterns, while machine learning algorithms offer real-time responses to student needs. Natural language processing enables more sophisticated feedback mechanisms, and intelligent tutoring systems can provide scaffolded support aligned with UDL principles. Learning analytics capabilities help identify student engagement and achievement patterns, offering unprecedented opportunities for personalizing educational experiences [10, 97]. As Saborío-Taylor and Rojas-Ramírez [125] noted, AI technologies present remarkable opportunities for creating adaptive learning environments. However, future research must carefully examine how these emerging technologies can enhance UDL implementation in higher education while ensuring alignment with core principles of accessibility and equity. This includes investigating how AI tools support UDL's three fundamental principles, examining the impact of AI-powered personalization on learning outcomes, and studying the ethical considerations inherent in AI-enhanced educational environments. While our study provides valuable insights into current digital technology use,

the rapid evolution of AI in education suggests an urgent need for research examining these emerging technologies' potential within the UDL framework.

7 Conclusions

This study examined university students' perceptions of Universal Design for Learning (UDL) principles implemented through Information and Communication Technologies (ICT). The research, in general, provides information on the integration of digital technologies into UDL-based educational approaches. The results indicate that students respond positively to using multimedia resources and interactive technologies in learning environments. This is consistent with the UDL principle of multiple means of representation, suggesting that various content presentation methods can be adapted to different learning preferences. However, and as a relevant finding, a preference for blended learning approaches, combining digital and traditional resources, rather than a complete shift to online-only platforms, has also been identified. This data highlights the importance of balancing technological novelty and traditional teaching methods in higher education institutions.

In terms of the principle of action and expression, students highlighted the value of creative digital tools and interactive presentations to develop their learning. This suggests that UDL-based ICT approaches can offer them various options for demonstrating their knowledge and skills. However, the lower preference for online participatory activities and real-time digital interactions points to areas where processes and tools must be refined. This finding underscores the need to consider how different digital technologies are integrated into the learning process. For its part, the principle of engagement was clearly defined, demonstrating that ICTs significantly motivate students. The positive response to gamification elements and multimedia resources in academic activities suggests that these approaches can increase motivation and engagement. However, the different levels determined for this among the different digital tools and activities indicate that a one-size-fits-all approach to digital learning may not be the best option.

A noteworthy aspect of this study is its focus on the intersection of UDL principles with specific digital technologies in a higher education context. Most research typically examines UDL implementation or technology integration separately; however, in our case, we have sought to provide insight into how these two elements interact from the student's perspective. The results suggest that the effectiveness of UDL principles can be enhanced or hindered by the specific digital tools used for implementation, offering a nuanced view of technology-enhanced UDL practices. Another element that we consider relatively original is the exploration of student preferences for different types of digital interactions within a UDL framework. The study reveals a complex picture in which students value certain forms of digital engagement (such as interactive presentations) more than others (such as online discussions). This nuanced understanding of their preferences could inform a more targeted and practical application of UDL principles in digital learning environments.

Considering all of the above, it is nevertheless essential to underline that the success of implementing digital technologies in educational contexts cannot be based only on mere technological adoption. Our results indicate a favorable attitude of students to using these tools in line with UDL principles, which is positive, but this must be done by integrating them into sound pedagogical frameworks to achieve the intended benefits. Without careful consideration of pedagogical principles and learning objectives, introducing digital technologies may not only fail to enhance learning but could hinder formative processes by creating unnecessary complexity or distracting attention from the leading educational goals. Moreover, it should be remembered that these are not tools originally created for education, with all that this implies. Technology should serve pedagogical purposes rather than direct educational decisions [54]. The effectiveness of digital tools in supporting UDL principles depends critically on their thoughtful, careful, and rigorous integration into existing educational frameworks, which are linked directly to learning objectives and careful consideration of student needs. Therefore, educational institutions must prioritize pedagogical training and teacher support alongside the development of technological infrastructures, ensuring that digital tools facilitate learning and not hinder it.

The research also contributes to the understanding of UDL implementation in non-English speaking contexts, specifically in the Latin American and, specifically, Mexican university environment. This cross-cultural perspective adds to the growing body of international research on UDL, potentially highlighting cultural factors that may influence the reception and effectiveness of UDL principles. However, while this makes an innovative contribution, it also entails several limitations. The homogeneity of the sample and the concentration in a single institution limit the generalizability of the results.

Table 6 Descriptive statistics: Gender. Source: Own elaboration

Item	Gender	N	Media	Standard deviation	Mean standard error
1	Female	176	4.76	0.555	0.042
	Male	58	4.67	0.711	0.093
2	Female	176	4.47	0.708	0.053
	Male	58	4.33	0.846	0.111
3	Female	176	3.77	1.084	0.082
	Male	58	4.14	0.907	0.119
4	Female	176	4.44	0.761	0.057
	Male	58	4.36	0.788	0.103
5	Female	176	4.04	0.970	0.073
	Male	58	4.14	0.963	0.126
6	Female	176	4.43	0.752	0.057
	Male	58	4.33	0.906	0.119
7	Female	176	3.88	1.040	0.078
	Male	58	3.97	1.042	0.137
8	Female	176	4.45	0.762	0.057
	Male	58	4.24	0.904	0.119
9	Female	176	4.31	0.798	0.060
	Male	58	4.12	1.093	0.144
10	Female	176	4.20	0.895	0.067
	Male	58	4.19	0.907	0.119
11	Female	176	3.82	1.122	0.085
	Male	58	3.90	1.021	0.134
12	Female	176	4.17	0.904	0.068
	Male	58	4.07	1.041	0.137
13	Female	176	4.10	0.942	0.071
	Male	58	4.19	0.963	0.127
14	Female	176	4.24	0.855	0.064
	Male	58	4.10	0.912	0.120
15	Female	176	3.81	0.970	0.073
	Male	58	3.84	1.023	0.134
16	Female	176	4.05	0.893	0.067
	Male	58	3.93	1.041	0.137
17	Female	176	4.36	0.794	0.060
	Male	58	4.09	0.904	0.119
18	Female	176	3.68	1.075	0.081
	Male	58	3.81	1.017	0.133
19	Female	176	4.34	0.866	0.065
	Male	58	4.03	0.936	0.123
20	Female	176	3.58	1.139	0.086
	Male	58	3.76	1.129	0.148
21	Female	176	4.17	0.904	0.068
	Male	58	3.97	0.955	0.125
22	Female	176	4.31	0.778	0.059
	Male	58	4.03	1.008	0.132
23	Female	176	4.44	0.707	0.053
	Male	58	4.14	0.760	0.100
24	Female	176	4.35	0.771	0.058
	Male	58	4.28	0.874	0.115

Table 6 (continued)

Item	Gender	N	Media	Standard deviation	Mean standard error
25	Female	176	4.28	0.806	0.061
	Male	58	4.24	0.865	0.114
26	Female	176	4.20	0.871	0.066
	Male	58	4.22	0.918	0.121
27	Female	176	4.35	0.748	0.056
	Male	58	4.21	0.853	0.112
28	Female	176	4.16	0.901	0.068
	Male	58	4.22	0.859	0.113
29	Female	176	4.14	0.871	0.066
	Male	58	4.29	0.795	0.104
30	Female	176	4.20	0.795	0.060
	Male	58	4.31	0.777	0.102
31	Female	176	3.93	0.977	0.074
	Male	58	4.07	0.953	0.125
32	Female	176	3.97	0.965	0.073
	Male	58	4.16	0.790	0.104
33	Female	176	4.27	0.843	0.064
	Male	58	4.21	0.853	0.112
34	Female	176	4.28	0.833	0.063
	Male	58	4.22	0.859	0.113
35	Female	176	4.29	0.829	0.062
	Male	58	4.34	0.715	0.094
36	Female	176	4.18	0.880	0.066
	Male	58	4.17	0.775	0.102
37	Female	176	4.13	0.873	0.066
	Male	58	4.14	0.736	0.097
38	Female	176	4.05	0.877	0.066
	Male	58	4.16	0.812	0.107
39	Female	176	4.00	0.980	0.074
	Male	58	4.14	0.826	0.108
40	Female	176	4.22	0.801	0.060
	Male	58	4.33	0.711	0.093
41	Female	176	4.18	0.826	0.062
	Male	58	4.33	0.685	0.090
42	Female	176	4.32	0.780	0.059
	Male	58	4.34	0.739	0.097

In future research, it would be advisable to use more extensive and diverse samples and longitudinal studies to assess the long-term impact of UDL and ICT integration on learning outcomes. In addition, comparative studies across different cultural and institutional contexts could shed more light on the universality or context-specificity of the outcomes. This would align with the challenges pursued in the scope of SDG4.

In conclusion, this contribution adds to the literature on UDL implementation in higher education, particularly in the context of digital technology integration. The results can inform educational researchers, practitioners, and managers to develop technology-enhanced learning environments that meet the diverse needs of students. As educational systems evolve, further empirical research on UDL and ICT integration will be crucial to refine pedagogical approaches and improve the quality and accessibility of higher education. While the results reveal the potential of UDL principles applied through ICT to enhance learning experiences at this educational level, they also highlight the complexities involved in this integration. They reveal, first and foremost, the need for reflective and evidence-based approaches to educational

technology implementation. As the field of education continues the integration of the digital paradigm, research must continue to delve deeper into linking pedagogical theory with technological practice, ultimately working toward more accessible and effective learning environments for all students.

Author contributions "Conceptualization, M.G.V.B., J.G.-G., M.L.C.M.; methodology, M.G.V.B., J.G.-G.; validation, M.G.V.B., J.G.-G., M.L.C.M.; formal analysis, M.G.V.B., J.G.-G.; investigation, M.G.V.B., J.G.-G., M.L.C.M., L.L.C.; data curation, M.G.V.B., J.G.-G.; writing-original draft preparation, M.G.V.B., J.G.-G., M.L.C.M., L.L.C.; writing-review and editing, M.G.V.B., J.G.-G.; supervision, J.G.-G., M.L.C.M.; project administration, M.G.V.B., J.G.-G., M.L.C.M., L.L.C. All authors read and agreed to the published version of the manuscript."

Funding None.

Data availability Data sets generated and/or analyzed during the present study that do not compromise data protection can be requested from the authors.

Declarations

Ethics approval and consent to participate In this study, all codes of good practice for human subjects research of the ethics committees of the participating universities were adhered to, and the guidelines of the Declaration of Helsinki were followed at all times. The study was registered and approved by the Ethics Committees of the EduInnovagogy (HUM-971), the Observatory on Mediation and Social Intervention in Organizations (ref. 940102), and the ICT in Education and Training Processes-CENID research groups (with assigned code no. PEM-2023-13c), and the Consolidated Body of Evaluation, Planning and Curricular Development, belonging to the Academic Area of Educational Sciences of the UAEH, following the guidelines and regulations of all of them. It was jointly signed by the research team that conducted the entire research process.

Competing interests The authors declare no competing interests.
Appendices Appendix 1 Descriptive statistics: GenderSec Table 6

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