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Enhancing STEAM education through augmented reality: the EduAR open platform experience

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Quality education is pivotal for fostering innovation and development, with Augmented Reality (AR) offering transformative learning experiences. The absence of open-access platforms for AR resources hinders the democratization of educational technology. This study introduces EduAR, an open-access platform designed to provide validated AR resources for STEAM education, aiming to enhance learning processes and promote equitable access to quality education. Employing a mixed-methods approach, the platform's usability was assessed using the System Usability Scale (SUS), where it achieved a high usability score, highlighting its user-friendliness and effectiveness. Additionally, qualitative feedback through focus groups provided insights into the platform's impact on learning engagement and skill development. The study yielded the following findings: (a) Incorporating AR in STEAM disciplines through an open validated platform is an effective strategy for enriching learning and teaching processes; (b) The EduAR platform allows effective adoption due to its high usability and accessibility; (c) Design-Based Research is useful when looking to improve an AR educational platform; (d) EduAR is a valuable tool for providing equitable access to quality educational resources; and (e) EduAR promotes problem-solving and critical thinking among students. This comprehensive research underscores the potential of EduAR in enhancing educational outcomes, establishing a solid foundation for future advancements in educational technology and open educational resources (OER). Its benefit is foreseen for both teachers and researchers interested in the implementation of AR in courses within the framework of openness.

KEYWORDS
augmented reality, OER, educational innovation, platform, higher education, technological platform, open education resources

1 Introduction

The United Nations' Sustainable Development Goals (SDGs) emphasize the significance of quality education (SDG 4), advocating for equitable and inclusive access to education while adapting to technological advances to meet current needs (ONU, 2019; UNESCO, 2020). Technology, particularly Information and Communication Technologies (ICTs), is integrated into education to facilitate learning, overcoming time and space barriers, and promoting a flexible environment for students and teachers (Kirimi, 2014; Cabero Almenara and Fernández Robles, 2018). It is crucial to focus on Learning and Knowledge Technologies (LKTs) to encompass the entire educational process beyond merely incorporating new technologies (Santos Baranda and Armas Velasco, 2020).

In the dominion of educational innovation, augmented reality (AR) emerges as a key tool, blending digital elements with the real world to create immersive experiences. It is part of a spectrum that also includes virtual reality and mixed reality, offering a complete sensory experience and allowing the use of everyday devices, such as smartphones, to enrich physical reality with digital information (Milgram and Kishino, 1994; Tecnológico de Monterrey, 2017). AR is defined as the fusion of virtual objects with the real environment, offering significant potential to enhance learning and teaching through real-time real-virtual interaction (Azuma, 1997; Tecnológico de Monterrey, 2016). For effective implementation of AR in education, devices that capture the real environment, systems that generate integrable virtual images, and a well-designed user experience are required, leveraging various technological devices to interact with educational content. However, despite its accessibility and potential, AR has not yet been fully integrated into education, underscoring the need for research and development of AR-based educational applications (Cabero Almenara, 2015; Cabero-Almenara et al., 2022).

The incorporation of STEAM (Science, Technology, Engineering, Arts, and Mathematics) themes and Open Educational Resources (OER) represents a significant evolution in education, allowing for a multidisciplinary and accessible approach that fosters creativity, innovation, problem-solving and deeper learning (Madden et al., 2013; Ge et al., 2015; Khine and Areepattamannil, 2019) which along with critical, systemic and scientific thinking are features related to the development of complex thinking (Ramírez-Montoya et al., 2022).

AR, combined with STEAM principles, can offer rich and contextualized educational experiences that stimulate students' interest and engagement in key areas for future development. OERs, in turn, provide freely accessible materials and resources that can be adapted and used to enrich educational content and make it more inclusive, thus promoting a culture of collaboration and knowledge sharing.

The combination of AR, STEAM, and OER not only enriches the learning process but also prepares students to face future challenges with a solid foundation in key competencies and complex thinking. Until now, there was no repository of OERs that could be consulted, highlighting the need to create and validate an important resource for the community of teachers, researchers, and students, named EduAR.

The aim of this study is to provide a scientific foundation demonstrating the proper development of EduAR through a series of comprehensive validation processes. Upon completion of these processes, the outcome will be a valuable tool for researchers, students, and educators, enabling the integration of augmented reality as an innovative approach in education.

2 Literature review

2.1 Augmented reality

Immersive technologies aim to involve the user in an all-embracing experience (Cummings and Bailenson, 2016), with the goal of blurring the distinction between the physical world and the virtual world (Suh and Prophet, 2018). These technologies range from virtual reality (VR), through mixed reality (MR), to augmented reality (AR) (Milgram and Kishino, 1994). The latter (AR), unlike VR and MR, has a significant advantage: it only requires a smartphone or tablet for its use, making it an accessible immersive technology as opposed to the additional equipment such as virtual visors required by other technologies (Rebollo et al., 2022).

In the 1960s, Ivan Sutherland created "The Sword of Damocles" the first device to combine virtual elements in real contexts (Sutherland, 1968; Billinghurst, 2021). Currently, AR can be classified into four levels, ranging from the mere evocation of elements by quick response (QR) codes to the use of augmented reality glasses (Prendes Espinosa, 2015). AR has been culturally appropriated by society, especially with the combination of 3D elements for construction and virtual museums (Boboc et al., 2022), like the current and popular Apple Vision Pro. Likewise, it has made important advances in the world of education with significant benefits (Zhang et al., 2022).

Some of the benefits of AR in classrooms have been detailed by Cabero Almenara and Barroso Osuna (2016): (a) increase in the information available to the user; (b) creation of "safe" artificial scenarios; (c) interaction with objects for observation from different perspectives. Thus, one of the main areas of educational development that has benefited from the appropriation of AR has been the STEAM disciplines (science, technology, engineering, arts, and mathematics) (Jesionkowska et al., 2020; Soroko, 2021), demonstrating the significant positive effect it has on the teaching process.

One of the main barriers perceived by teachers in the process of incorporating new technologies is the assumption that it is complex and complicated (Martínez Pérez and Fernández Robles, 2018), a lack of computational knowledge (Mota et al., 2018), and especially a need for a platform with a user-friendly interface and free access for users (Dengel et al., 2022).

2.2 Open educational resources (OER)

The concept of open educational resources (OER) was initially introduced at a UNESCO forum in the early 2000s (Duval and Wiley, 2010). OERs are educational materials in the public domain. This initiative has been driven by social movements focused on quality education (Peters and Britez, 2008) and equity (UNESCO, 2020).

The purpose of OERs is to make known the resources developed under a practice of collaboration and sharing (Yin and Fan, 2011). This movement has grown so much that there are now chairs bringing together various actors: academics, civil society, policymakers, and companies to collaborate for the benefit of education (UNESCO, 2024). Furthermore, OERs have been exponentially driven by information and communication technologies (ICT) (Belawati, 2014), such as repositories, blogs, websites, platforms, etc. Beyond being open, their reusability is also gaining importance when looking at the development of complex thinking (Sanabria-Z et al., 2024).

2.3 Educative platforms

The creation and validation of platforms have been promoted by learning and knowledge technologies (LKT). Haiyan (2022) built a platform focused on smart education using network infrastructure, aimed at different types of schools and educational institutions. Duran and Ramirez (2021) created and validated the MIIDAS platform, an

OER focused on being a repository where teachers can find and publish different educational resources. Huang (2021) designed a web platform aimed at teaching the English language. Cheng-Chao (2005) developed an open educational platform where teachers could autonomously save and share the resources, they were developing to provide material for their colleagues.

After reviewing various educational platforms, it has been observed that there has been no consensus on the use of a specific methodology for the development of these platforms, hence the need for one that meets the needs of the present research.

3 Methodology

3.1 Design study

The primary goal of this research was to create and validate an open educational platform focused on augmented reality resources in education. For this study, Design-Based Research (DBR) was utilized, a methodology widely adopted in educational sciences (Cobb et al., 2003; Tinoca et al., 2022), and has been supported due to its main advantages (Velasco et al., 2021): (a) fostering advances in education based on theories that contribute to the improvement of student learning, and (b) generating theories derived from implementations, in particular, from the findings obtained. By adopting DBR as our methodological framework has allowed us to embark on a journey through an iterative process (Anderson and Shattuck, 2012). This approach has led us through various phases, each iterative, enabling continuous improvement of EduAR at every stage of the process.

A mixed-methods approach, combining quantitative and qualitative methodologies, was proposed, which served to enrich the fashion data were collected (Tashakkori et al., 2020). This method is also characteristic of DBR, as it handles information by collecting data with this multi-methodology (Bell, 2004). The selection of these methodologies provides an agile framework for a holistic implementation.

3.2 Procedure

Initially, the effort to create a repository of OER about AR was launched by the UNESCO Chair for the Open Educational Movement (Tecnológico de Monterrey, 2021). As a first step, throughout 2021 and 2022, a compilation of various AR OERs, including applications, platforms, news, and articles, was initiated. The second stage focused on the creation of the platform, which was developed using Google Sites technology; the diverse resources were organized under the STEAM disciplines as they support students in promoting critical thinking (as a dimension of the complex thinking) (Vázquez-Parra et al., 2022) and problem-solving skills (HADDAR et al., 2023).

The third stage of the EduAR project was identified as crucial for its conclusion, focusing on the validation of the project itself. Support was requested from a specific group of collaborators: four researchers, six teachers, and seven students. These participants were selected through non-probabilistic convenience sampling, ensuring their direct alignment with the project's objectives. Their perspectives were shared via focus groups, thus contributing to the proposal of significant improvements and recommendations. To ensure broad participation and accommodate the logistical needs of the collaborators, the sessions were organized virtually through Zoom, lasting 60 min each. This method not only facilitated the inclusion of a diversity of opinions but also promoted the efficiency and effective reach of the feedback process. Following the improvements from the validation recommendations, a dissemination process by training teachers on AR using the EduAR platform is currently in progress.

3.3 Participants

Table 1 reflects the composition of the validators, showcasing diversity in both the type of role within the educational community and the geographic origin of the participants. Predominantly female, the sample includes most students and a significant representation of teachers and researchers. In terms of origin, there is a concentration of participants from Campeche and Hidalgo, with a lesser presence from other states and a symbolic international inclusion. The equitable distribution between types of private and public educational institutions adds an additional dimension of variety to the studied group, suggesting a reach that encompasses different modalities of educational management.

3.4 Data collection

3.4.1 System usability scale

The System Usability Scale (SUS) is an assessment tool that measures the usability of products and services. Created by John Brooke in the 1980s (Brooke, 1996), it is widely used in the user interface design, software, websites, and mobile applications industries, among others. The SUS is a brief 10-item scale that provides an overall view of a system's subjective usability from the user's perspective (Lewis, 2018). The SUS has been employed in the educational context, as it contributes to enhancing the quality of educational technologies by providing an objective and comparative assessment of usability, which in turn positively impacts users' learning experiences (Vlachogianni and Tselios, 2022).

Each item on the questionnaire is answered on a 5-point Likert scale, ranging from "Strongly disagree" to "Strongly agree," designed

TABLE 1 Sociodemographic characteristics of validator participants.

Type		*N*
Role	Student	7
	Researcher	4
	Teacher	6
Gender	Female	12
	Male	5
Place of Origin	Bogota (Colombia)	1
	Campeche (Mexico)	7
	Estado de México (Mexico)	1
	Hidalgo (Mexico)	6
	Monterrey (Mexico)	2
Type of institution	Private	9
	Public	8

to assess different aspects of usability like ease of use, efficiency, and overall satisfaction with the system (Grier et al., 2013). To calculate the total SUS score, responses to odd-numbered, positive items are subtracted by one, and responses to even-numbered, negative items are subtracted from five, converting the scale from 1–5 to 0–4. This enhances the instrument's sensitivity. The adjusted scores are then summed and multiplied by 2.5, shifting the scale from 0–40 to 0–100, making the score intuitive as a percentage. A higher score indicates better usability, with below 50 viewed unfavorably, 51 to 75 as marginal, above 76 acceptable, and above 85.5 considered excellent.

Although the SUS does not provide a detailed diagnosis of specific usability problems, it is useful for obtaining a quick comparative assessment of the usability of different systems or versions of a system. The results can help designers and developers to determine if a product meets basic usability requirements and to establish a benchmark for future improvements (Lewis, 2018).

3.4.2 Focus group

Focus groups are a qualitative research technique that gathers small groups to discuss specific topics, allowing for the collection of detailed information on perceptions, opinions, and attitudes (POWELL and SINGLE Powell and Single, 1996). This methodology is effective as a validation tool in various areas (Vaughn et al., 2013), especially in education. Through the careful selection of participants (researchers, teachers, and students) representing the target audience, and the use of structured discussion guides, focus groups provide valuable feedback for adjusting products, services, or strategies before their launch or implementation.

3.4.3 Open-ended question response

An open-ended question was posed to the participants: "Use this space to leave us an additional comment on the perceived utility of the website and suggestions for improvement." This question represented a valuable opportunity to gain a detailed and open understanding of users' perceptions of the website, thereby collecting their viewpoints and suggestions for future improvements.

4 Results

4.1 Validation's result

4.1.1 System usability scale

Based on an experience using the EduAR platform, with the participation of students, teachers and researchers, the results of the application of the SUS instrument are presented below. Although the implementation was carried out in Spanish, a parallel translation is presented for information purposes in this paper. The distribution of the information in the table corresponds to the item number, followed by the question in Spanish and English and closing with the average score of the total number of participants. The scale ranges from 1 to 5, where 1 is completely disagree and 5 is completely agree (Table 2).

Items Q1, Q3, Q5, Q7, and Q9 are positive statements about the ease of use and integration of the site's features, with scores ranging from 4.12 to 4.53, indicating an overall positive perception of the usability of the repository website. These questions have relatively low SDs, ranging from 0.51 to 0.70, indicating that the users' scores are quite clustered around the mean; this suggests a consistent perception of ease of use and integration of the site's features.

Items Q2, Q4, Q6, Q8, and Q10 are negative statements reflecting issues of complexity, the need for technical support, inconsistency, cumbersome usage, and the necessity to learn many things before using the site. The low scores on these questions (between 1.65 and 2.53) reinforce the idea that, while there are areas for improvement, the

TABLE 2 Results of system usability scale.

	Question (Spanish)	Question (English)	Average	SD	CI 95%
Q1	Creo que me gustaría usar este repositorio con frecuencia.	I think I would like to use this repository frequently.	4.53	0.51	4.26–4.79
Q2	*Encontré la página web del repositorio innecesariamente complejo.	*I found the repository website of the unnecessarily complex.	2.53	1.37	1.82–3.24
Q3	Pienso que la página web del repositorio es fácil de usar.	I think the repository website is easy to use.	4.35	0.86	3.91–4.80
Q4	*Creo que necesitaría el apoyo de un técnico para poder utilizar la página web del repositorio	*I think I would need the support of a technician to use the repository website.	1.65	1.17	1.05–2.25
Q5	Descubrí que las diversas funciones de este la página web del repositorio estaban bien integradas.	I found that the various functions of this the repository website were well integrated.	4.12	0.70	3.76–4.48
Q6	*Pienso que hay demasiada inconsistencia en la página web del repositorio	*I think there is too much inconsistency on the repository website.	2.18	1.13	1.59–2.76
Q7	Me imagino que la mayoría de la gente aprendería a usar la página web del repositorio muy rápidamente.	I imagine that most people would learn to use the repository website very quickly.	4.35	0.70	3.99–4.71
Q8	*Encontré la página web del repositorio muy engorroso de usar.	*I found the website of the very cumbersome repository to use.	2.00	0.94	1.52–2.48
Q9	Me siento muy confiado usando el repositorio.	I feel very confident using the repository.	4.35	0.70	3.99–4.71
Q10	*Necesito aprender muchas cosas antes de poder utilizar la página web del repositorio.	*I need to learn many things before you can use the repository website.	1.94	0.75	1.56–2.33
	SUS Score		78.52		

SD, Standard deviation; CI, Confidence interval. *, inverse item.

issues are not extremely severe. These questions have higher SDs, from 0.94 to 1.37, indicating greater variability in user responses. This could be interpreted as a sign that there is less consensus among users regarding these aspects of the site's usability, pointing out areas where user experiences vary more and where improvements may be necessary.

The usability assessment with the SUS yielded a score of 78.52 out of 100 for EduAR. This score suggests good overall usability of the site, with users showing a positive perception toward the ease of use and integration of its functions. However, responses to negatively phrased questions indicate specific areas where the site could improve, such as reducing its perceived complexity and improving its consistency. Although the obtained score is above average, implying a favorable user experience, opportunities still exist to reach excellence levels in usability.

4.1.2 Focus group

The methodological process of the focus groups unfolded in three distinct phases, each aimed at the three target populations of EduAR. The sessions were held on consecutive days, using the Zoom video conferencing platform, starting with the students, followed by the researchers a month later, and finishing with the teachers 2 weeks after the meeting with the researchers. Each session began with a presentation of the study's purpose and the request for informed consent from the participants. Then, they were invited to navigate freely through the EduAR platform. Subsequently, a detailed analysis of various sections of the website was conducted, including the homepage, applications, articles, platforms, other resources, authors section, and the contact section, with the goal of gathering impressions and suggestions for improvement from each of the participating groups.

Due to the characteristics of the Design-Based Research (DBR) methodology, the conducted process was iterative (Laleka and Rasheed, 2018), which allowed the improvement of EduAR after each focus group. Below are the codes that were identified in the focus groups.

Table 3 meticulously displays the codes that emerged from the qualitative analysis of various focus groups. The process commenced with a detailed transcription of each session, followed by an initial exploration to capture primary insights. Through open coding, descriptive labels were assigned to specific segments, facilitating their subsequent organization into central themes. This thematic organization was further refined by the careful assignment of weights

TABLE 3 Coding of focus groups.

	Students	Researchers	Teachers
General perception	Navigation: tedious Design: demotivating (5) Design: Focused on teachers (2) Navigation: Non -intuitive Design: more agile Design: Include examples (2)	Navigation: Brief and concise Content: Add environment Design: Incongrente text color (2) Content: Add news Accessibility: Sound Design: The magnifying glass is not seen (2) Content: articles metadata	Design: Incongrente text color Content: Add organic chemistry Content: Add art applications Navigation: adequate Content: Add robotics
Section 1: Home	No comments	Content: Add environment Design: Incongrente text color Content: Add Target (2) Design: more vivid color	Content: Add geography
Section 2: Applications	Design: more agile Design: demotivating (2) Design: Colors Design: Include examples	Content: Add environment Content: Add Target (4) Design: Incongrente text color	Content: Add more than mathematics
Section 3: Articles	Content: Include APA references Content: Information is adequate	Content: Add Description (2) Content: Add Target Content: Add APA Navigation: Classification Content: more visual summaries	Content: add articles referring to games
Section 4: Platforms	Design: text size Design: demotivating (2) Content: Explain utility	Navigation: Sort alphabetically (2) Content: Add databases Content: Explain utility	Content: Add simulators Content: Explain utility
Section 5: Other resources	Content: Explain utility	Content: Add YouTube videos Content: Add examples	Content: Add Science Communities Content: Add events Content: Add simulators Content: Add contests
Section 6: Authors and contact us	Design: saturated Content: Include review Design: Include better photos Content: Make more personal Design: demotivating	Content: Include review Content: Verify Logos permission Content: change "authors" to creators (2)	Content: Include experience in teaching Content: Include experience level Content: Add presentation video clip

TABLE 4 Summary of codes by themes.

	Students	Researchers	Teachers	Total
Navigation	2	5	1	8
Design	21	7	1	29
Content	6	23	15	44
Total	29	35	17	

to each code and theme, reflecting their significance and frequency within the participants' discourse. This methodical approach not only ensures a rigorous interpretation of the data but also an authentic representation of the perspectives and experiences of the involved users.

Three main themes were identified: (a) navigation, focusing on how users can independently navigate the website; (b) design, centered on the user's perception of the site's esthetics, motivation, and imagery; (c) content, pertaining to the topics and themes that should be featured in EduAR. To aid the optimization process of EduAR, a summary of the themes that were identified was prepared. Table 4 shows the weight per code that were obtained by each of themes along students, researchers, and teachers.

In the first focus group, conducted with students, there was a noticeable preference for comments related to design, accounting for 72% of the code frequencies. Design-related codes addressed issues such as text size, improving color combinations, enhancing photos, and more. As a result, the site's creators decided to enlist the help of a professional graphic designer from outside the staff to address the students' recommendations.

The second focus group took place a month later, with the participation of various researchers specializing in educational innovation and technology. 66% of the comments focused on content, particularly on incorporating elements such as targeting the resource to its audience, adding APA citations, including examples, etc. To integrate these elements, the site's creators conducted a detailed search of the topics mentioned by the researchers.

Finally, the third focus group, conducted with the assistance of upper high school teachers, saw a significant shift in the total number of codes from the different focus groups, representing 20%. Of these comments, 15 out of 17 were directed at the content of EduAR: incorporating elements like robotics content, arts topics, organic chemistry, among others. This led to the optimization of EduAR through an analysis of its content.

4.1.3 Open-ended question response

Participants were given the opportunity to freely express themselves at the end of the online questionnaire. They highlighted and commended the EduAR project initiative, also pointing out some areas for improvement:

- Design: There is a clear demand for a more attractive and professional design, with suggestions toward incorporating more striking visual elements and the possibility of hiring a designer.
- Content and Specifications: There is a recommendation to expand the information available, particularly in the descriptions of the applications and to add specific content in areas such as organic chemistry.
- Accessibility: Improving accessibility for people with disabilities and ensuring the functionality of links is essential for its continued success.

4.2 EduAR

As a result, an open-access platform for open educational resources on augmented reality was created, accessible directly at.[1]

This platform features 6 different areas:

- Home: This section provides various general concepts about AR and its difference from VR, as well as definitions of AR contributions and STEAM education.
- Apps: This section, divided by STEAM disciplines, includes specific sub-areas such as biology, physics, chemistry, among others. This division was considered due to the large number of application resources (71) provided on the platform. It is noteworthy that an individualized analysis was performed so that the user can know the recommended educational level for application, as well as the compatible operating system.
- Articles: This section provides a curated collection of papers published in the last 10 years, compiled from the comprehensive review conducted by Velarde-Camaqui et al. (2024). Each entry summarizes the target study population, the type of AR resource examined, the research methodology employed, and the publication year. For convenience and further reading, a direct link to the journal where each article is published is also included.
- Platforms: This section is aimed at users with more experience who seek to create their own AR resources with the help of various repositories.
- Other resources: This section includes various news related to conferences, communities, and updates from the educational environment of augmented reality.
- Site creators: This section aims to introduce each EduAR collaborator, giving a brief overview of their personal trajectory, research focus, and contact for potential collaborations (Figure 1).

5 Discussion

Incorporating AR in STEAM disciplines through an open validated platform is an effective strategy for enriching learning and teaching processes. This research has applied a scientific process for the creation and validation of an AR platform that contributes to quality education. According to Jesionkowska et al. (2020) and Soroko (2021), AR facilitates rich and contextualized educational experiences that increase student interest and participation in key areas for their future development. As Billinghurst (2021) highlight, educational platforms that use AR have the potential to significantly improve learning and teaching. This multidisciplinary approach not only promotes deeper and more innovative learning but also prepares students to face future challenges with a solid foundation in key competencies and complex thinking, highlighting the importance of researching and developing educational applications based on AR.

The EduAR platform allows effective adoption due to its high usability and accessibility. The evaluation using the System Usability Scale revealed exceptionally high scores, reflecting a positive user

1 https://www.EduAR.net

FIGURE 1
Collage of EduAR screenshots, produced by the authors.

experience. As Lewis (2018) suggests, high usability is crucial for the adoption and effectiveness of educational technologies. The ease of use of EduAR not only facilitates its integration into the educational process but also makes it more attractive to researchers and developers interested in educational technologies.

Design-Based Research (DBR) is useful when looking to improve an AR educational platform. Feedback collected from students, researchers, and teachers highlighted specific areas for improvement in navigation, design, and content, facilitating targeted optimization of the EduAR platform. The DBR methodology, emphasized by Laleka and Rasheed (2018), allowed for refinement based on real feedback, ensuring that modifications effectively responded to users' needs. This approach to continuous improvement, grounded in the active participation of the educational community, underscores the potential of focus groups not only to evaluate educational technologies but also to enrich them, offering a replicable path for future technological development initiatives in education.

EduAR is a valuable tool for providing equitable access to quality educational resources. The wide range of materials available on the platform has enabled researchers, students, and teachers from various regions to access relevant and updated AR content. This approach, aligned with the principles of Open Educational Resources (OER) as mentioned by UNESCO (Tecnológico de Monterrey, 2021), promotes inclusion and equity in education. Open access platforms promote the democratization of quality education.

EduAR promotes problem-solving and critical thinking among students. Direct observation and feedback from students underline an increase in the ability to creatively address and solve problems which is characteristic of complex thinking development (Ramírez-Montoya et al., 2022). Following Cabero Almenara and Barroso Osuna (2016), the integration of immersive technologies in education fosters deeper and more meaningful learning. This finding underscores the value of EduAR as a key pedagogical tool to prepare students for future challenges.

6 Conclusion

This study has demonstrated that integrating Augmented Reality (AR) into STEAM education through the EduAR platform significantly enhances learning and teaching. By offering free access to validated educational resources, EduAR not only enriches the educational experience but also facilitates the development of key competencies and complex thinking among students. The high usability and accessibility of the platform ensure its effective adoption in diverse educational settings, highlighting the importance of educational technology in the 21st century. The empirical results highlight the value of EduAR as a tool to promote equitable access to quality education, aligning with the principles of Open Educational Resources (OER) and contributing to the democratization of knowledge. Furthermore, the promotion of 21st-century skills through the platform underscores its essential role in preparing students for future challenges, reaffirming the relevance of AR in interactive and contextualized learning.

The implications for practice of this study focus on the possibility of enriching the students' learning experience by providing access to an open tool with up-to-date AR resources. Moreover, the EduAR platform provides room for teachers to rethink their courses using this technology. In terms of research, a proven methodological process for the collection and analysis of data from an AR implementation in the classroom is provided. Ultimately, the concept of openness-based resources production is a relevant example in the framework of the OER movement.

Addressing the limitations of this study, it is essential to note that while the research conducted on EduAR has demonstrated considerable promise in revolutionizing STEAM education, certain constraints must be considered. The participant count, though subjected to an exhaustive and in-depth analysis, was limited, potentially introducing bias that future analyses aim to mitigate by encompassing a broader spectrum of EduAR's end users. Currently limited to the Spanish-speaking context, EduAR's efforts to reach a global audience are ongoing, with plans to expand into additional languages in subsequent phases to ensure wider accessibility and impact. Furthermore, the evaluations carried out have been short-term, emphasizing the need for longitudinal studies to assess EduAR's support for its diverse user base over time for a deeper, more sustained analysis of its effectiveness. The early results and the narrow variety of application contexts highlight the importance of exploring EduAR's long-term impact in various educational settings. Future research will focus on adapting and personalizing AR resources to meet the specific needs of diverse student groups and evaluating their effectiveness in improving specific learning outcomes, thereby affirming EduAR's pivotal role in enhancing inclusive, engaging, and effective learning experiences worldwide.

The continuous development of educational technologies like EduAR represents an invaluable opportunity to advance the effective integration of AR in global education. All in all, this study positions EduAR as a promising platform to transform education through AR. The platform's ability to effectively integrate AR into the STEAM curriculum and provide access to a wide range of resources has been well received by the educational community. This outcome not only validates the importance of EduAR in the current educational context but also suggests a promising path for future research and developments in the field of educational technology.

In conclusion, this paper underscores the strengths of integrating AR with STEAM education and the development of an open-access platform, highlighting a significant stride in educational innovation. The fusion of AR with STEAM disciplines through EduAR not only enriches the learning environment by offering immersive and interactive experiences but also embodies the forward-thinking approach necessary for preparing students to navigate the complexities of the future. The creation of an open-access platform further amplifies this impact by democratizing educational resources, enabling learners and educators worldwide to access cutting-edge AR applications that foster critical thinking, creativity, and problem-solving skills. These efforts signify a pivotal advancement in harnessing technology to enhance educational outcomes, positioning EduAR as a beacon for future educational technologies and a model for successful integration of digital tools in teaching and learning processes.

Data availability statement

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

Ethics statement

The studies involving humans were approved by Instituto Tecnologico y de Estudios Superiores de Monterrey. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

DV-C: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Validation, Writing – original draft, Writing – review & editing. RC-R: Conceptualization, Data curation, Investigation, Validation, Writing – review & editing. YC-F: Conceptualization, Data curation, Investigation, Validation, Writing – review & editing. JS-Z: Funding acquisition, Resources, Supervision, Writing – review & editing.

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Conflict of interest

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

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