Mapping Augmented Reality Tools for Digital Learning in STEM Education: A Scoping Review of English, Spanish, and German Products

Delsa Silva Amino Cufuna[1]**, Miriam Mulders**[2] **and Michael Kerres**[3]

[1] Universitat Oberta de Catalunya, Barcelona, Spain
[2] University of Duisburg-Essen, Essen, Germany
[3] University of Duisburg-Essen, Essen, Germany

Abstract

The integration of Augmented Reality (AR) into digital learning holds considerable significant promise for enhancing learner engagement, particularly in STEM disciplines (Science, Tech- nology, Engineering, and Mathematics). AR applications provide immersive and interactive learning experiences that can actively stimulate students' curiosity and foster deeper un- derstanding, making them promising tools for rethinking engagement in higher education. However, effectively leveraging AR for remote learning environments remains challenging, especially across diverse linguistic and educational contexts. This scoping review system- atically identifies and maps available AR tools aimed at supporting digital learning in STEM fields, accessible in English, Spanish, or German, between 2019 and 2025. Following the PRISMA guidelines, a structured search was conducted across digital distribution platforms (Apple App Store, Google Play Store). Inclusion criteria targeted AR applications with a clear educational focus on STEM, available in at least one of the three specified languages, and compatible with mobile devices. The search strategy employed natural language search terms tailored to Spanish, English, and German, reflecting the absence of Boolean opera- tors in mainstream mobile app distribution platforms. The app titles and descriptions were manually screened to ensure their relevance. Data extraction captured core attributes, in- cluding educational level, device compatibility, cost model, language availability, and the geographical origin of the developers. The scoping review is expected to provide insights into the current landscape of AR tools for STEM digital learning. By identifying strengths and gaps in existing offerings, the study will inform educators, developers, and policymakers on how to better harness AR technologies to promote engagement, adapt teaching to diverse needs, and foster inclusive learning environments. Particular attention will be given to the accessibility of AR tools across different educational levels and linguistic groups, support- ing the broader goal of rethinking higher education through engagement, adaptation, and inclusion.

Keywords

Augmented Reality, Digital Learning, STEM Education, Scoping Review, Educational Tech- nology, Higher Education

1. Introduction

The integration of digital technologies has served to complement existing educational prac- tices, particularly in response to the demand for more accessible and flexible learning en- vironments (Valverde et al., 2021; Kerimbayev et al., 2023; Marienko et al., 2020). Aug- mented Reality (AR), in particular, has gained prominence for its ability to create immersive and interactive experiences by overlaying digital elements onto the physical world. This technology enhances student engagement, conceptual understanding, and motivation, of- fering new ways to approach complex content across various disciplines (Akçayır & Akçayır, 2017; Bujak et al., 2013).

At the same time, STEM education (Science, Technology, Engineering, and Mathematics) presents unique challenges in digital learning due to its experimental and abstract nature. The rapid shift to online education, particularly during the COVID-19 pandemic, highlighted both the limitations of traditional instruction and the need to adopt innovative pedagogical strategies (Means et al., 2013; Bao, 2020). Teaching STEM in digitally mediated environ- ments requires tools that support visualisation, experimentation, and student interaction in the absence of physical labs and materials. In this context, AR emerges as a promising resource to bridge these gaps. By enabling virtual simulations of scientific processes and interactive manipulation of 3D content, AR can enrich digital STEM education and improve learning outcomes.

Given the growing number of AR applications available on digital platforms, this review dis- tinguishes between commercial and non-commercial tools to better understand the diver- sity of resources and their accessibility. Commercial AR tools often benefit from profes- sional development, robust design, and technical support, but they may pose financial bar- riers for institutions or learners (Radianti et al., 2020). In contrast, non-commercial tools, often developed by educational institutions or open-source communities, can increase eq- uity and support inclusive education, although they may face limitations in scalability or user experience (Klopfer & Sheldon, 2011; Santos et al., 2014). This distinction allows for a more comprehensive analysis of the educational potential of AR in different usage con- texts.

In addition, the selection of English, Spanish, and German as target languages for this re- view was based on practical and linguistic considerations. These languages reflect the lin- guistic competencies of the research team, ensuring accurate interpretation and analysis of the available tools. English, as the world lingua franca in science and technology, domi- nates the field of educational technology (Montgomery, 2013; Ammon, 2012). Spanish and German, although not as dominant globally, represent language communities in Europe and Latin America, where educational innovation, including the use of AR, is actively ex- panding (United Nations Educational, Scientific and Cultural Organization, 2023). This mul- tilingual scope allowed for a manageable inclusion of applications from diverse educa- tional and cultural contexts.

1.1. Augmented Reality (AR)

AR has emerged as an educational technology, garnering significant interest over the past two decades due to its potential to enhance teaching and learning outcomes (Chadeea & Prinsloo, 2022). AR overlays digital content onto the physical world, creating interactive and immersive learning experiences that combine virtual and real elements. Studies such as those by Cheng and Tsai (2013), Gittinger and Mulders (2024), Dede (2009), Wu et al. (2013), and Akçayır and Akçayır (2017) indicate that AR enhances student engagement, motivation, and achievement across various academic settings.

By allowing individuals to visualise and interact with virtual objects in a real-world setting, AR helps bridge the gap between abstract concepts and tangible understanding. It enables the representation of phenomena, objects, and content that are typically invisible to the naked eye, thereby enhancing both comprehension and knowledge retention. According to Bujak et al. (2013), AR supports learning by transforming abstract information into percep- tible experiences and facilitating the visualisation of processes that would otherwise re- main inaccessible to students.

However, this visualisation requires mobile devices such as smartphones and tablets that are compatible with AR applications. The widespread availability of mobile devices allows a broader and more diverse group of learners to engage with AR-enhanced educational con- tent, regardless of their geographic or institutional context. The proliferation of mobile de- vices has facilitated access to AR, enabling learners from different locations and educa- tional environments to participate in enriched learning experiences (Itransition, 2023).

By leveraging the ubiquity of mobile technology, AR tools reduce access barriers and make immersive, interactive learning experiences more inclusive and scalable (Del Cerro & Mo- rales, 2018). The accessibility of AR is strengthened by the use of standard mobile devices, allowing a greater number of students to participate in AR-enhanced educational activities (Itransition, 2023).

In particular, technological advances have lowered the barriers to integrating AR. Unlike early implementations that required expensive headsets, modern AR can be accessed via ordinary smartphones and tablets. This increased accessibility has led to a growing number of commercial and non-commercial AR tools and platforms for educational use, making the exploration of AR-supported learning more feasible on a large scale (Akçayır & Akçayır, 2017; Garzón & Acevedo, 2019)

1.2. STEM subjects (Science, Technology, Engineering, and Mathematics) in digital learning

STEM education (Science, Technology, Engineering, and Mathematics) plays a fundamental role in fostering innovation, problem-solving, and scientific literacy in contemporary soci- ety. However, teaching these disciplines in a digital learning context presents unique chal- lenges due to their inherently practical, abstract, and often experimental nature.

Digital education itself has evolved with the advancement of digital technologies, becoming a key educational modality in contexts marked by unequal access, reduced mobility, or global health crises such as the COVID-19 pandemic (Bao, 2020). This model allows stu- dents to access educational content from virtually anywhere, removing the geographical and temporal barriers associated with traditional face-to-face instruction (Means et al., 2013). Nonetheless, the effectiveness of remote instruction in STEM fields depends on sev- eral factors, such as access to stable internet connections, the availability of appropriate technological devices, and the adequate preparation of both teachers and students to func- tion in digital learning environments. Instructional design must also prioritise interaction, continuous feedback, and active student participation to ensure quality learning experi- ences outside the physical classroom (Garrison et al., 1999).

Recent scholarship has emphasised that digital learning is not simply a substitute for tradi- tional classroom instruction, but a transformative modality that redefines the nature of learning itself. According to Basak et al. (2018), digital learning represents a comprehensive framework that encompasses e-learning, mobile learning, and blended approaches, unit- ing them under a pedagogical model driven by technology-enhanced engagement. Vaicon- dam et al. (2022) further argue that digital learning supports the personalisation of instruc- tion, accessibility for diverse learners, and the integration of emerging tools such as artifi- cial intelligence and extended reality.

In STEM education, these benefits become particularly salient. Zou et al. (2025) note that digital learning environments offer opportunities to integrate flexible, student-centered ap- proaches, including flipped classrooms and gamified activities, which are well-suited to the problem-solving and experimental ethos of STEM fields. This theoretical foundation under- scores that digital learning is not merely about remote access, but about fostering mean- ingful, technology-mediated experiences that extend the reach and depth of STEM instruc- tion across varied educational contexts.

These challenges become even more pronounced in STEM disciplines, where students must grasp complex spatial concepts, conduct virtual experiments, and engage with ab- stract content, often requiring tools that extend beyond traditional theory and practice. A promising response to these challenges is the integration of AR into digital STEM education. AR enables the virtual simulation of laboratory experiments and scientific phenomena, helping to overcome the physical limitations of remote learning environments. Through var- ious applications, students can perform scientific practices or explore three-dimensional structures without the need for expensive lab equipment, thereby bringing interactive learn- ing experiences into the home or classroom through digital simulations.

Studies have shown that these AR-based visualisations can support deeper conceptual un- derstanding and foster the development of key skills in STEM education, such as critical thinking and problem-solving (Garzón & Acevedo, 2019), autonomous learning and self-reg- ulation (Garzón & Acevedo, 2019), as well as spatial and visual reasoning skills (Bujak et al., 2013).

In fields such as mathematics and engineering, AR-based educational interventions have been shown to enhance both academic performance and student motivation compared to traditional approaches, including textbooks (Ibáñez & Delgado, 2018; Petrov & Atanasova, 2020). By enabling "authentic exploration" and encouraging inquiry in virtually enriched real-world contexts, AR helps bridge the gap between theory and practice. Ultimately, the incorporation of AR into STEM education holds considerable potential to enhance both digital and in-person learning, providing students with immersive, practical, and meaningful experiences that were previously difficult to achieve outside of physical laboratories.

To address this need, the present review sets out to identify and analyse available AR appli- cations that support STEM education across all educational levels. The guiding research question is: What AR tools are commercially and non-commercially available in English, Spanish, or German that support digital learning in STEM disciplines across all educational levels? Thereby, we aim to describe their main characteristics, including platform compati- bility, cost model, target education level, and STEM discipline focus.

2. Methods

2.1. Study Design

This scoping review was conducted in accordance with the methodological framework out- lined by Tricco et al. (2018) and the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews) guidelines. The purpose of the review was to identify and map AR tools aimed at supporting digital learning in STEM disci- plines, focusing on tools accessible in English, Spanish, or German between 2019 and 2025.

2.2. Eligibility criteria

Tools were included based on predefined inclusion and exclusion criteria (see Table 1). Table 1: Inclusion and Exclusion Criteria.

Criteria	Inclusion Criteria	Exclusion Criteria
a) Availability	AR applications launched or actively updated be- tween 2019 and 2025	Applications originally launched before 2018, with no recent updates, are not functional/do not exist any- more, even when they were launched after 2019
b) Educational focus	Aimed at learning or educa- tional support in STEM dis- ciplines (natural sciences, mathematics, technology, engineering)	General-purpose or enter- tainment AR apps without a clear educational STEM fo- cus.
c) Supported languages	Available in at least one of the target languages (Span- ish, English, or German), ei- ther in the user interface, content, or documentation	Tools available only in other languages
d) Device compatibility	Compatible with mobile, tablet, or computer devices	Applications not compati- ble with mobile devices, tablets, or computers

e) Commercial and non-commercial availability	Commercially and non-commercially available (Apple App Store, Google Play Store)	Tools that are no longer available or accessible to the public

2.3. Information sources

Information sources included mainstream mobile app distribution platforms. Specifically, the following platforms were searched: Apple App Store and Google Play Store.

The search was conducted using mainstream mobile app distribution platforms, specifi- cally the Apple App Store and Google Play Store. These sources were selected to reflect real-world conditions of how users search for and access educational AR tools.

2.4. Search strategy

Due to the limitations of app stores, which do not support Boolean operators or advanced search filters, natural language phrases were used in three languages:

- English: “Augmented Reality Learning”
- German: “Augmented Reality Lernen”
- Spanish: “Realidad Aumentada Aprendizaje”

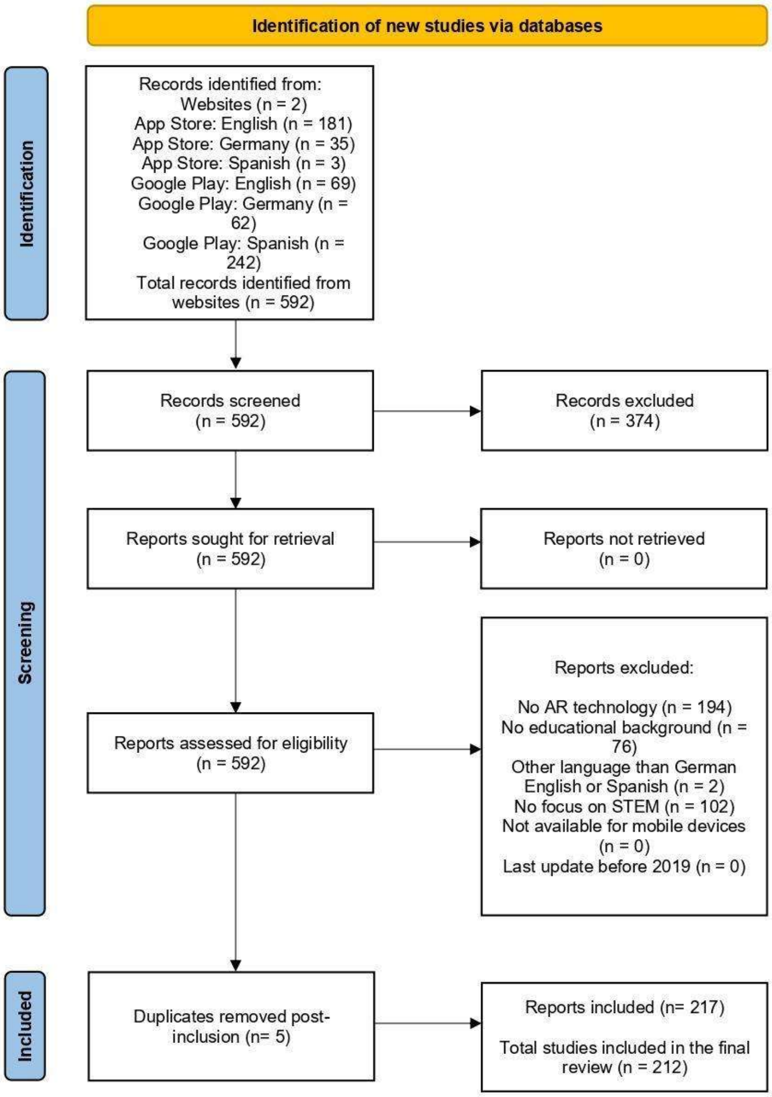
App titles and descriptions were manually reviewed to assess relevance. The search strat- egy focused on identifying tools aligned with five conceptual categories: AR technology, STEM focus, educational level, language availability, and platform compatibility.

Searches were conducted by trained student research assistants using their personal mo- bile devices to simulate authentic user experiences across different operating systems and device types.

2.5. Selection process

A total of 592 applications were identified through initial searches across both app stores. After applying the eligibility criteria and removing duplicates, 212 unique AR applications were included in the final synthesis. The selection process is summarised in the PRISMA flow diagram (see Figure 1).

Figure 1: Flow diagram for scoping review (adapted after Haddaway et al., 2022).



The flow diagram (see Figure 1) shows the retrieval of 592 records identified from two sources, the Apple App Store in English (n=181), German (n=35), and Spanish (n=3), and the Google Play Store in English (n=69), German (n=62), and Spanish (n=242). After the initial screening, 374 applications were excluded for not meeting the predefined inclusion criteria.

Following the screening, 592 applications were retained for eligibility assessment. During this phase, several were excluded based on specific criteria such as not being AR technol- ogy (n=194), not corresponding to the educational level defined in our inclusion criteria (n=76), use of a language other than English, Spanish, or German (n=2), or no focus on STEM areas (n=102). No records were excluded based on outdated versions prior to 2019, 2, or unavailability for mobile platforms.

After reviewing the exclusion process and the reasons mentioned, a total of 217 applica- tions were initially included. However, some duplicates were identified, as certain applica- tions appeared in both the Apple App Store and the Google Play Store. After removing these five duplicates, the final number of applications included in the analysis was 212.

The final 212 applications were categorised and analysed using a system based on a struc- tured ontology, adapted for this scoping review. All data processing and classification were conducted using Excel spreadsheets, ensuring consistency and traceability throughout the analysis. No manual annotation was performed. The full dataset, including the criteria used for inclusion and exclusion, is available in the online Supplementary Material.

2.6. Data collection

A standardised data extraction form was developed to capture key characteristics of each tool, including:

- Platform compatibility (iOS, Android)
- Language availability (English, Spanish, German)
- Developer and country of origin
- Cost model (free, freemium, paid)
- Target educational level mapped using the International Standard Classification of Education: ISCED (2012) classification

Data were charted manually in a structured spreadsheet, with each entry double-checked for accuracy.

3. Results

The results were synthesised in a descriptive manner, highlighting frequency counts and representative examples to provide insights into the identified apps.

3.1. Devices

Of the 212 apps analysed, 99 (46.7%) were available on both iOS and Android, 94 (44.3%) were iOS-only, and 19 (9.0%) were Android-only. This suggests a strong preference for iOS support among developers.

3.2. Language

Our analyses reveal a clear predominance of English as the primary language of distribu- tion. In comparison, a significantly smaller number of applications are available in German and Spanish. Out of the total applications reviewed, 198 apps are available in English (82.2%), 64 apps in German (26.6%), and 43 apps in Spanish (17.8%). It is important to note that many of these applications are multilingual, appearing in more than one language cat- egory.

For example, in English, there are several notable applications that utilise the language as a primary medium of interaction. *Quiver Education* brings coloring pages to life using inter- active AR, promoting creativity and engagement. The interface and all instructions are in English. Similarly, *Ocean 4D+* provides an English-language immersive educational journey through underwater ecosystems, offering detailed 3D models of marine life.

In Spanish, *Aventura Aumentada* is a gamified learning platform that employs AR storytell- ing to reinforce educational content in Spanish. Here, Spanish is not just the interface lan- guage but an integral part of the educational experience. *Head Atlas*, on the other hand, is a 3D anatomy visualisation app designed for Spanish-speaking students in biology and health sciences. While it does not teach Spanish, it is fully localised to make complex sci- entific content accessible to Spanish speakers.

In the case of German, apps like *simpleclub – Die Lernapp* and *CarolAR* illustrate how the language can be used both as a medium and as part of the content itself. *CarolAR* also sup- ports German education in subjects like science, using AR to create interactive experi- ences. It is especially geared toward enhancing comprehension in the German language, making it more than just a translated interface.

In terms of linguistic diversity, 140 apps are available in only one language (58.0%), while 42 apps support two languages (17.4%), and even 27 apps are trilingual (11.2%). This distribu- tion shows that although most apps are monolingual, a significant portion is accessible to broader audiences through multilingual support.

3.3. Country of development

Based on the analysis of developer origins, the top three countries leading the development of educational AR applications are the United States, with 43 apps (24.0%), India, with 35 (19.6%), and Germany, with 20 (11.2%). These countries show strong involvement in edu- cational technology, reflecting both technological capacity and market orientation (Table 2).

Table 2: Distribution of the Top Five Countries Developing AR Applications by Price Type.

Country	Total Apps	Free	Freemium	Paid
United States	50	73%	0%	27%
India	35	60%	25%	15%
Germany	20	67%	17%	16%
Spain	8	86%	0%	14%
Indonesia	8	57%	29%	14%

Note. The table 2 represents the five countries with the highest number of registered AR ap- plications in the dataset. Each circle shows the relative proportion of free, freemium, and paid applications developed in each country.

The United States has the highest volume, likely due to its well-established industry, while India is experiencing rapid growth in this sector (Kapoor et al., 2024). Germany, although smaller in volume, makes notable contributions with content tailored to its local educa- tional standards.

3.4. Price level

The pricing analysis of educational AR applications reveals that the majority are offered at no cost, with 150 apps classified as free (70.8%). Meanwhile, 47 apps fall under the paid category (22.2%), indicating a moderate presence of monetised content. Additionally, 15 apps use a freemium model (7.1%), providing basic features for free while charging for pre- mium content (see Table 2). This distribution suggests a strong emphasis on accessibility, with developers favouring low-barrier entry points to reach broader educational audiences.

3.5. Educational level

The analysed apps span a wide range of educational contexts, with many addressing multi- ple levels simultaneously. While our analysis initially focused on applications relevant to digital learning, it quickly became evident that only a small fraction of the identified studies tools are explicitly designed for digitally mediated learning contexts. Instead, most applica- tions are tailored to K-12 education, particularly elementary and middle school levels. The distribution is as follows:

- Preschool: 21 apps (10.9%), e.g., *Montessori Preschool:* This app offers interactive AR activities that support early childhood learning in numeracy, literacy, and practi- cal life skills through playful exploration.
- Kindergarten: 20 apps (10.4%), e.g., *AR Flashcards:* This app is designed for young learners. It uses AR flashcards to present animated 3D models that help develop vocabulary, recognition, and imagination.
- Elementary School: 98 apps (51.0%), e.g., *BuchTaucher*: This app augments text- books with videos, audio, and animations to support learning in subjects like math, language, and science.
- Middle School: 98 apps (51.0%), e.g., *AR-Physics – Physik lernen*: With this app, stu- dents can conduct interactive experiments, simulate forces and motion, and deepen their understanding of physics concepts through AR.
- High School: 50 apps (26.0%), e.g., *Die Klima App*: This app uses AR to immerse learners in climate-related scenarios such as floods and wildfires and encourages reflection through interactive simulations and narrative experiences.
- University/College: 55 apps (28.6%), e.g., *BioDigital Human – 3D Anatomy:* This app provides interactive 3D and AR visualisations of human anatomy and health condi- tions, supporting life science and medical education at the university level.
- Vocational Education: 26 apps (13.5%), e.g., *INNIO Learning Experiences*: Tailored for vocational learners in the energy sector, this app uses AR to simulate technical procedures and safety training in realistic work environments.
- Adult Education: 37 apps (19.3%), e.g., *Augmented Instructor:* This app provides AR- enhanced training for adults, offering instructional support across various STEM-re- lated topics in continuing education.

These numbers reveal a strong focus on K-12 education, particularly at the elementary and middle school levels, which together account for more than half of all analysed apps. At the same time, a substantial number of apps target higher education, vocational training, and adult learning, highlighting the versatility of AR technology in STEM education. Neverthe- less, the overall low visibility of digital learning-specific implementations raises critical questions about the extent to which AR is currently leveraged to support flexible, location- independent learning experiences.

4. Discussion

This scoping review offers a systematic mapping of both commercial and non-commercial AR applications designed to support digital learning in STEM education across English, Spanish, and German-speaking contexts. Our findings provide critical insights into the accessibility, linguistic diversity, educational levels, and pedagogical relevance of these tools, thereby informing future integration efforts of AR in digital learning environments.

First, our data highlights a promising level of accessibility. More than 70% of the identified applications are available free of charge, with additional tools offered under freemium mod- els. This finding reinforces earlier research suggesting that mobile AR technologies can sup- port equitable learning opportunities when cost barriers are minimised (e.g., Del Cerro & Morales, 2018). Nonetheless, the discoverability of high-quality educational tools remains an issue. For instance, prominent applications like *Merge Cube* were not identified through standard app store searches due to limitations in platform indexing. This suggests a need for improved metadata, categorisation, and searchability mechanisms on mainstream mo- bile app distribution platforms to facilitate effective adoption by educators, particularly those with limited technical expertise.

Second, our review demonstrates a clear predominance of English-language AR applica- tions, while Spanish and German are significantly underrepresented. Although some tools are multilingual, the majority support only one language, potentially reinforcing educational inequalities for non-English-speaking learners. This underscores the need for culturally and linguistically adaptive AR content to ensure meaningful learning across diverse contexts. Expanding localisation efforts remains critical for inclusive and globally relevant AR-based education. As Nye (2015) and Eppard et al. (2021) emphasise, the cultural and linguistic adaptation of educational technology is essential not only for usability but also for learner engagement and comprehension. Language and culture shape how users interact with dig- ital tools, and ignoring this dimension may hinder the pedagogical effectiveness of AR inter- ventions.

Moreover, the decision to include English, Spanish, and German as target languages in this review was based not only on the linguistic competence of the research team but also on methodological and cultural considerations. Limiting a review to English-only sources can introduce language bias and exclude regionally relevant tools or practices (Rasmussen & Montgomery, 2018).

English, spoken by over 1.4 billion people worldwide, serves as the dominant global lan- guage in science, technology, and education, and is officially used in more than 50 coun- tries (Crystal, 2003; Eberhard, 2021). Spanish, with approximately 483 million native speak- ers and over 558 million total users, is the second most spoken native language globally and holds official status in 20 countries across Latin America and Europe (Instituto Cervantes, 2023; Eberhard, 2021). German, in turn, is the most widely spoken native language within the European Union, with an estimated 90 to 95 million native speakers and up to 220 mil- lion total users worldwide, making it a key language for identifying tools developed in re- gions with a strong educational and technological tradition (European Commission, 2023).

The inclusion of Spanish and German enabled the review to capture educational tools de- veloped in culturally diverse regions such as Latin America and Central Europe, where AR is increasingly being adopted for pedagogical innovation (United Nations Educational, Scien- tific and Cultural Organisation, 2023). Furthermore, incorporating multiple languages aligns with international best practices in systematic reviews, which recommend minimising language bias by including non-English sources whenever possible (Glanville et al., 2021). In this way, the multilingual scope of the review supports a broader and more inclusive un- derstanding of the development and implementation of AR tools across diverse linguistic and cultural educational ecosystems.

Third, although AR tools span all educational levels, there is a particularly strong emphasis on K-12 contexts, with over 50% of the tools targeting elementary and middle school. In con- trast, applications explicitly designed for higher education or vocational contexts are com- paratively fewer, despite growing interest in leveraging AR for professional and academic training. The scarcity of AR tools for advanced STEM topics may limit the potential of immer- sive learning at higher cognitive levels. Future development should therefore aim to address this gap by creating tools tailored to university curricula and complex scientific concepts.

The review identified 55 applications (28.6%) specifically designed for university and higher education contexts, particularly in fields such as anatomy, engineering, and medical edu- cation. These tools highlight the potential of AR to enhance advanced STEM learning by en- abling the visualisation of complex structures, simulating laboratory experiments, and fa- cilitating training in professional practices. Such applications are particularly relevant to higher education institutions, where the demand for flexible, technology-enhanced learn- ing has increased following the COVID-19 pandemic (Bao, 2020; Radianti et al., 2020). Strengthening the integration of these tools into university curricula would help bridge the gap between theoretical knowledge and practical application at higher cognitive levels, thereby better preparing students for both academic and professional challenges.

In contrast, although the prevalence of AR tools for K–12 levels suggests strong potential for early engagement with STEM concepts, their adaptation to digital learning contexts remains limited and often ambiguous (Zhang & Wang, 2021). Many of the applications aimed at younger students, especially in preschool and elementary education, depend on adult su- pervision or classroom interaction, which complicates their independent use in digitally mediated settings without the support of a caregiver or teacher (Ibáñez & Delgado, 2018).

This presents a significant challenge for equitable implementation in home-based environ- ments, particularly when parents may lack the time or digital literacy to facilitate learning. As highlighted by Means et al. (2013), the effectiveness of digital tools in digital learning is closely tied to the surrounding instructional infrastructure and support systems. Therefore, although the availability of AR tools for young learners is promising, their deployment in fully remote contexts may require additional scaffolding or the development of pedagogically in- tegrated AR experiences specifically designed for self-directed learning. Future research should explore how these tools can be adapted or complemented with digital learning-ap- propriate methodologies to ensure meaningful learning across all age groups in virtual en- vironments.

This is particularly relevant in digital learning, where AR has demonstrated positive effects on the comprehension of abstract and experimental content, especially in STEM disciplines (Iqbal et al., 2022; Eldokhny & Drwish, 2021). By simulating laboratories, 3D models, and interactive experimentation, AR can bridge the gap between theory and practice even in remote environments, supporting the development of spatial reasoning, critical thinking, and autonomous learning (Garzón & Acevedo, 2019).

Finally, during our analysis, we also recognised that the current landscape of mobile app- based AR tools lacks systematic pedagogical frameworks guiding the design and imple- mentation of AR for digital learning. As Akçayır and Akçayır (2017) argued, effectiveness is not inherent to technology itself but depends on thoughtful integration into instructional design. We therefore would suggest that while the technological infrastructure exists, ped- agogical guidance for educators remains limited.

In the context of digital learning, where teacher-student interaction is often asynchronous and mediated by technology, clear instructional design becomes even more essential. Lit- erature recommends that AR content for digital learning be usable, goal-aligned, and con- textually relevant to avoid cognitive overload and ensure learner autonomy (Eppard et al., 2021). Moreover, the combination of AR with artificial intelligence and virtual agents has been identified as a promising avenue for enhancing guidance and feedback in self-directed learning scenarios (Iqbal et al., 2022), particularly when physical presence and real-time facilitation are not feasible.

5. Limitations

This review has several limitations that should be acknowledged. First, the search strategy was constrained by the limitations of mainstream mobile app stores, which do not support Boolean operators or advanced filters. As a result, some relevant applications, especially those with non-standardised titles or less optimised metadata, may have been overlooked. This is exemplified by the exclusion of widely used tools such as *Merge Cube*, which were not detected through our natural language-based search.

Second, while our multilingual approach covered English, Spanish, and German, it ex- cluded other major world languages, potentially omitting AR tools used in regions such as East Asia or the Middle East. Similarly, apps available only on less commonly used plat- forms such as the *Microsoft Store* or *Amazon App Store* were not included due to accessi- bility constraints and limited adoption among educators, particularly in mobile-first envi- ronments.

Third, our classification relied on app store descriptions and screenshots rather than in- depth testing of each tool's functionality. While this reflects the typical experience of edu- cators browsing these platforms, it may not fully capture the pedagogical quality or usability of the applications. Additionally, the absence of user analytics or long-term usage data lim- its our ability to assess sustainability and real-world impact.

Finally, the dynamic nature of mobile app marketplaces means that app availability, pricing, and functionality are subject to frequent change. The results of this review represent a snap- shot within the defined time frame (2019 to 2025) and may not reflect future developments or trends in AR-enhanced digital learning.

6. Conclusion

This scoping review provides a timely and systematic overview of the current landscape of both commercial and non-commercial available AR tools for STEM digital learning educa- tion in English, Spanish, and German-speaking contexts. The findings highlight a growing number of accessible applications, particularly for younger educational levels, with a strong emphasis on English-language content and mobile compatibility.

While the reviewed tools show great potential to enhance engagement, visualisation, and conceptual understanding in STEM subjects, important gaps remain. These include limited language diversity, inconsistent pedagogical alignment, and concerns about long-term sus- tainability. Educators and developers should therefore consider not only the technical fea- tures of AR applications but also their fit with curricular goals, language accessibility, and visibility within app marketplaces.

Future research should explore the classroom use of these tools in real-world settings and examine how AR can be integrated into teacher education and institutional strategies. Only through such combined efforts can the full educational potential of AR be realised, promot- ing more inclusive, engaging, and adaptive learning environments in STEM education.

Funding

This research was supported by AGAUR-FI ajuts (2025 FI-2 00899) Joan Oró of the Secretaria d'Universitats i Recerca del Departament de Recerca i Universitats de la Generalitat de Ca- talunya i del Fons Europeu Social Plus.

Acknowledgments

Special thanks to Josep M Duart and Gizéh Rangel de Lázaro for their continuous support and guidance.

Gratitude is also extended to the Edul@b research group at the Universitat Oberta de Cata- lunya and the Learning Lab research group at the Universität Duisburg-Essen.

Competing interests

We have no conflicts of interest to declare.

7. References

Akçayır, M., & Akçayır, G. (2017). Advantages and challenges associated with augmented reality for education: A systematic review of the literature. *Educational Research Re- view, 20*, 1–11. https://doi.org/10.1016/j.edurev.2016.11.002

Ammon, U. (2012). Linguistic inequality and its effects on participation in scientific dis- course and on global knowledge accumulation – With a closer look at the problems of the second-rank language communities. *Applied Linguistics Review, 3*(2), 333–355. https://doi.org/10.1515/applirev-2012-0016

Bao, W. (2020). COVID-19 and online teaching in higher education: A case study of Peking University. *Human Behavior and Emerging Technologies, 2*(2), 113–115. https://doi.org/10.1002/hbe2.191

Basak, S. K., Wotto, M., & Bélanger, P. (2018). E-learning, M-learning and D-learning: Con- ceptual definition and comparative analysis. *E-Learning and Digital Media, 15*(4), 191–216.

https://doi.org/10.1177/2042753018785180

Bujak, K. R., Radu, I., Catrambone, R., MacIntyre, B., Zheng, R., & Golubski, G. (2013). A psychological perspective on augmented reality in the mathematics classroom. *Computers & Education, 68*, 536–544. https://doi.org/10.1016/j.compedu.2013.02.017

Chadeea, T. K., & Prinsloo, P. (2022). Adoption of augmented reality in distance education: A scoping review. *Journal of Learning for Development, 11*(2), 190–205. https://doi.org/10.56059/pcf10.583

Cheng, K., & Tsai, C. (2013). Affordances of augmented reality in science learning: Sugges- tions for future research. *Journal of Science Education and Technology, 22*(4), 449–462. https://doi.org/10.1007/s10956-012-9405-9

Crystal, D. (2003). *English as a global language* (2nd ed.). Cambridge University Press.

Dede, C. (2009). Immersive interfaces for engagement and learning. *Science, 323*(5910), 66–69. https://doi.org/10.1126/science.1167311

Del Cerro, F., & Morales, G. (2018). Augmented Reality and Mobile Devices: A Binominal Methodological Resource for Inclusive Education (SDG 4). An Example in Secondary Education. *Sustainability*, *10*(10), 3446. https://doi.org/10.3390/su10103446

Eberhard, D., Simons, G., & Fennig, C. (Eds.). (2021). *Ethnologue: Languages of the world* (24th ed.). SIL International. https://www.ethnologue.com

Eldokhny, A., & Drwish, A. (2021). Effectiveness of Augmented Reality in Online Distance Learning at the Time of the COVID-19 Pandemic. *International Journal of Emerging Technologies in Learning, 16*(9), 198–218. https://doi.org/10.3991/ijet.v16i09.17895

Eppard, J., Kaviani, A., Bowles, M., & Johnson, J. (2021). EdTech culturation: Integrating a culturally relevant pedagogy into educational technology. *The Electronic Journal of e-Learning, 19*(6), 516–530.

European Commission. (2023). *Special Eurobarometer 540: Europeans and their Lan- guages*. Publications Office of the European Union.

Garrison, D., Anderson, T., & Archer, W. (1999). Critical inquiry in a text-based environment: Computer conferencing in higher education. *The Internet and Higher Education, 2*(2–3), 87–105. https://doi.org/10.1016/S1096-7516(00)00016-6

Garzón, J., & Acevedo, J. (2019). Meta-analysis of the impact of augmented reality on stu- dents' learning gains. *Educational Research Review, 27*, 244–260. https://doi.org/10.1016/j.edurev.2019.04.001

Gittinger, M., & Mulders, M. (2024). Using Augmented Reality for Teaching. *Weizenbaum Journal of the digital society, 4*(4), 1-26.

Glanville, J., Dooley, G., Wisniewski, S., & Lefebvre, C. (2021). *Systematic searching for stud- ies for systematic reviews: Guidance from the Information Retrieval Methods Group of the Cochrane Collaboration*. Cochrane Training.

Haddaway, N., Page, M., Pritchard, C., & McGuinness, L. (2022). PRISMA2020: An R package and Shiny app for producing PRISMA 2020-compliant flow diagrams, with interac- tivity for optimised digital transparency and Open Synthesis. *Campbell Systematic Reviews, 18*(2), e1230. https://doi.org/10.1002/cl2.1230

Ibáñez, M., & Delgado, C. (2018). Augmented reality for STEM learning: A systematic review. *Computers & Education, 123*, 109–123. https://doi.org/10.1016/j.com- pedu.2018.05.002

Instituto Cervantes. (2023). *El español en el mundo*. Madrid: Instituto Cervantes.

Iqbal, M. Z., Mangina, E., & Campbell, A. G. (2022). Current challenges and future research directions in augmented reality for education. *Multimodal Technologies and Inter- action, 6*(9), 75. https://doi.org/10.3390/mti6090075

Itransition. (2023). AR in education: Applications, benefits, & adoption barriers. https://www.itransition.com/augmented-reality/education

Kapoor, A., Ezell, S., Ostertag, M., & Zutshi, S. (2024). *US-India Subnational Innovation Com- petitiveness Index*. Information Technology and Innovation Foundation (ITIF) & Insti- tute for Competitiveness (IFC).

Kerimbayev, N., Umirzakova, Z., Shadiev, R., & Jotsov, V. (2023). A student-centered ap- proach using modern technologies in distance learning: A systematic review of the literature. *Smart Learning Environments, 10*, 61. https://doi.org/10.1186/s40561- 023-00280-8

Klopfer, E., & Sheldon, J. (2011). Augmenting your own reality: Student authoring of science- based augmented reality games. *New Directions for Youth Development,* (128), 85–94. https://doi.org/10.1002/yd.378

Marienko, M., Nosenko, Y., & Shyshkina, M. (2020). *Personalization of learning using adap- tive technologies and augmented reality*. *arXiv*. 10.31812/123456789/4418

Means, B., Toyama, Y., Murphy, R., & Baki, M. (2013). The effectiveness of online and blended learning: A meta-analysis of the empirical literature. *Teachers College Rec- ord, 115*(3), 1–47.

Montgomery, S. (2013). *Does Science Need a Global Language? English and the Future of Research*. University of Chicago Press.

Nye, B. (2015). Intelligent Tutoring Systems by and for the Developing World: A Review of Trends and Approaches for Educational Technology in a Global Context. *Int J Artif Intell Educ, 25*, 177–203. https://doi.org/10.1007/s40593-014-0028-6

Petrov, M., & Atanasova, T. (2020). The Effect of Augmented Reality on Students' Learning Performance in Stem Education. *Information, 11*(4). https://doi.org/10.3390/info11040209

Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, les- sons learned, and research agenda. *Computers & Education, 147*, 103778. https://doi.org/10.1016/j.compedu.2019.103778

Rasmussen, K., & Montgomery, P. (2018). The prevalence of and factors associated with in- clusion of non-English language studies in Campbell systematic reviews: A survey and meta-epidemiological study. *Systematic Reviews, 7*, 129. https://doi.org/10.1186/s13643-018-0786-6

Santos, M., Chen, A., Taketomi, T., Yamamoto, G., Miyazaki, J., & Kato, H. (2014). Augmented reality learning experiences: Survey of prototype design and evaluation. *IEEE Trans- actions on Learning Technologies, 7*(1), 38–56. https://doi.org/10.1109/TLT.2013.37

Tricco, A., Lillie, E., Zarin, W., O'Brien, K., Colquhoun, H., Levac, D., Moher, D., Peters, M., Horsley, T., Weeks, L., Hempel, S., Akl, E., Chang, C., McGowan, J., Stewart, L., Hartling, L., Aldcroft, A., Wilson, M., Garritty, C., Straus, S. (2018). PRISMA Extension for Scoping Reviews (PRISMA-ScR): Checklist and explanation. *Annals of Internal Medicine, 169*(7), 467–473. https://doi.org/10.7326/M18-0850

UNESCO Institute for Statistics. (2012). *International Standard Classification of Education: ISCED 2011 operational manual*. UNESCO.

United Nations Educational, Scientific and Cultural Organization. (2023). *Global Education Monitoring Report, technology in education: a tool on whose terms?* UNESCO. https://doi.org/10.54676/UZQV8501

Vaicondam, Y., Sikandar, H., Irum, S., & Khan, N. (2022). *Research landscape of digital learning over the past 20 years: A bibliometric and visualization analysis*. Interna- tional Journal of Online and Biomedical Engineering (iJOE), 18(08), 4–18. https://doi.org/10.3991/ijoe.v18i08.31963

Valverde, J., Fernández, M., Revuelta, F., & Sosa, M. (2021). The educational integration of digital technologies preCovid-19: Lessons for teacher education. *PLoS ONE, 16*(8).

https://doi.org/10.1371/journal.pone.0256283

Wu, H., Lee, S., Chang, H., & Liang, J. (2013). Current status, opportunities and challenges of augmented reality in education. *Computers & Education, 62*, 41–49. https://doi.org/10.1016/j.compedu.2012.10.024

Zhang, W., & Wang, Z. (2021). Theory and practice of VR/AR in K–12 science education: A systematic review. *Sustainability, 13*(22), 12646. https://doi.org/10.3390/su132212646

Zou, Y., Kuek, F., Feng, W., & Cheng, X. (2025). *Digital learning in the 21st century: Trends, challenges, and innovations in technology integration*. Frontiers in Education, 10. https://doi.org/10.3389/feduc.2025.1562391