

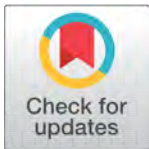
Moving Learning: A Systematic Review of Mobile Learning Applications for Online Higher Education

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ABSTRACT

Technological revolutionary changes have boosted mobile learning's evolution from supplementary material for teaching to a flexible, strategic, and convenient resource, driving new paths in higher education. With global increases in wireless internet access and the advent of highly functional smartphones and tablets, which have impacted the rise in mobile device ownership, mobile learning has expanded its applications as a direct way to implement tailored learning settings. Notably, during the COVID-19 pandemic, together with other educational technologies, it became a solicited tool in remote education. In this systematic review, we will explore how educators and researchers have been documenting the development and impact of mobile learning tools in the teaching and learning process since the COVID-19 outbreak. Results show that, embedded with online higher education programs, mobile learning has empowered interaction in content creation, communication, and collaboration between learners and instructors, significantly impacting learning effectiveness. Moreover, although this technology is well established in higher education, it remains attractive for educators who actively use it because of its pedagogic potential.



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1 INTRODUCTION

Mobile learning (also known as m-learning) has been characterized as a multifaceted process involving theoretical-based pedagogical approaches to tackle educational requirements (Hao, Dennen, & Mei, 2017). Revolutionary changes in the 1980s, with the introduction of pocket and handheld computers, have been recognized as the first steps of what we today consider mobile learning (Educause, 2019). With time, the functional advantages of mobile devices such as smartphones and tablets, compared to laptops or desktop computers, made them a solicited resource for teaching-learning (Măță et al., 2021). Likewise, the integration of smartphones and tablets into learning processes, the availability of powerful and intuitive mobile applications, and accelerating mobile internet

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connection have facilitated the creation and sharing of content (Adanir & Muhametjanova, 2021).

The responsive design of mobile learning content available on all platforms also drives its success in online higher educational contexts (Yu, Yan, & He, 2022). Understanding how to structure material for shorter attention spans, choosing optimized mobile-friendly formats, and maintaining active communication with students are key factors of faculty development (Minichiello et al., 2021; O'Connor & Andrews, 2018; Pham & Chen, 2018). These design tenets promote a more consistent user experience across platforms and devices within the academic environment.

Unquestionably, integrating mobile devices as an educational asset also exposes the gap between those who can afford to have rapid access to the internet connection and those who cannot. In 2021 nearly 15 billion mobile devices were operating worldwide (Radianti, Majchrzak, Fromm, & Wohlgenannt, 2020). However, up to 3.2 billion people did not have access to mobile internet services, even though they lived in areas with a mobile broadband network (GSMA, 2022). The usage gap is notable in low- and middle-income countries; for example, up to 40% of Latin America and the Caribbean population and 53% of the population in Sub-Saharan Africa. In contrast, North America represents 24%, and Europe and Central Asia represent 26% (Bahia & Delaporte, 2020). Moreover, there are still considerable differences in average mobile connection speeds worldwide, with the United Arab Emirates (125 Mbps), for example, being 25 times faster than Cuba (5 Mbps). Among other factors, this has a notable impact on the implementation of mobile learning initiatives, including those integrated with XR and AI resources via mobile connections (Kemp, 2022).

Mobile learning has been a resource of attraction for researchers actively investigating its academic potential for many years (Crompton & Burke, 2017; Liaw, Hatala, & Huang, 2010; Matzavela & Alepis, 2021; Motiwalla, 2007; Yu et al., 2022). Especially during the COVID-19 pandemic, mobile learning became a solicited tool in remote education (Dhawan, 2020; Muthuprasad, Aiswarya, Aditya, & Jha, 2021).

In this systematic review, we will explore how educators and researchers have been documenting the development and impact of mobile learning tools in the teaching and learning process since the COVID-19 outbreak. To that end, we have designed the following questions:

- RQ1. What is the geographical distribution of the publications, and which languages were used?
- RQ2. Which sources are most frequently used for publication, and who are the most cited authors in the literature?
- RQ3. Which devices, data collection, and research design methods were set out to support mobile learning and teaching, and within which disciplines are they integrated?
- RQ4. What is the scope and nature of mobile learning applications in online higher education?

2 METHODS

To address the research questions defined in this systematic review, we will localize, synthesize and analyze peer-reviewed publications with a precise, standardized, and reproducible search strategy following the Preferred Reporting Items for Systematic reviews and Meta-Analyses system (PRISMA; Page et al., 2021).

Additionally, we will employ the R program *litsearchr* to systematically define our search terms (Grames, Stillman, Tingley, & Elphick, 2019). In order to compile a set of keywords relevant to our review, this package will run the Rapid Automatic Keyword Extraction (RAKE) algorithm (Rose, Engel, Cramer, & Cowley, 2010), identifying keywords from the titles and abstracts from publications and extracting the author-tagged keywords.

2.1 Pipeline

A "naive search" was conducted on 6 June 2022 in Scopus, Web of Science, and EBSCO Education sources with no date restrictions to gather relevant publications, including the following terms (Figure 1): ("higher education" OR "college" OR "undergrad" OR "graduate" OR "postgrad") AND ("mobile application" OR "virtual reality" OR "augmented reality" OR "mixed reality" OR "haptic technology" OR "artificial intelligence") AND ("e-learning" OR "online learning" OR "virtual learning" OR "distance learning" OR "remote learning"). As a result, we identified records from Scopus (n = 2984), Web of Science (n = 529), and EBSCO Education sources (n = 24) and removed duplicated publications (n = 1026).

Potential keywords for the systematic review were extracted from the publications retrieved using the RAKE algorithm (500) and tagged method (523). Additionally, we quantitatively assessed the strength of the keywords compiled. Relevant terms frequently appeared with other terms from the set, and non-essential ones appeared associated with others (147 keywords removed). Finally, to define the search strategy for the Boolean searches in English and Spanish, the remaining keywords were organized into three groups: Emerging technologies, Education level, and Learning setting (Table 1).

Table 1 Search string in English after the naïve search

Topic	Search terms
Education level	"higher* educ*" OR "colleg* student*" OR "univers* student*" AND
Emerging technologies	"artifici* intellig*" OR "360 video*" OR "immers* learn*" OR "machin* learn*" OR "mixed realit*" OR "virtual* realit*" OR "augment* realit*" OR "intellig* tutor*" OR "mobil* applic*" OR "mobil* devic*" OR "XR* technolog*" AND
Learning setting	"distanc* educ*" OR "distanc* learn*" OR "onlin* educ*" OR "onlin* learn*" OR "onlin* teach*" OR "remote* learn*" OR "e-learn*" OR "onlin* cours*"

Furthermore, we collected ten key publications to test the accuracy and recall of the systematic review search strategy using Scopus, Web of Science, and EBSCO Education. We were able to retrieve the ten papers selected using the search terms defined, confirming that we could run the final search string for the systematic review.

2.2 Final Search, Screening, Coding, and Data Extraction

Based on the Boolean search terms outlined (Table 1) and the inclusion and exclusion criteria (Table 2), the final search was limited to the three abovementioned databases, including titles, abstracts, and keywords of publications. A total of 424 initial observations were identified. This list was narrowed down after removing 70 duplicates.

Two further articles were excluded because they were accessible neither through journal publications nor by contacting authors. Afterwards, publications were filtered to those peer-reviewed research articles, reviews, and book chapters submitted after the COVID-19 outbreak in March 2020 (70 articles excluded). We set further exclusion criteria by only including those focused on mobile learning (181 papers discarded) in online higher education (46 publications removed).

Fifty-five publications remained for screening on full text and coding (Figure 1). We coded articles based on a hierarchical ontology of associations between subjects (Table 2). The codes used comprised: the author's name, year of publication, source name, times cited, country of origin of the first author, type of publication (research article, review, or book chapter), the language used, data collection method, type of mobile device, research design, technology application in higher education, domain, and scope of application. Data analyses and graphics were done using the R package *tidyr* (Wickham, Vaughan, & Girlich, 2023), *dplyr* (Wickham, François, Henry, Müller, & Vaughan, 2023), *tidyverse* (Wickham et al., 2019), *bibliometrix* (Aria & Cuccurullo, 2017), *maps* (Becke, Wilks, Brownrigg, Minka, & Deckmyn, 2021), *ggplot2* (Wickham, 2016), *ggraph* (Pedersen, 2021), and *igraph* (Csárdi & Nepusz, 2006).

Table 2 Inclusion and Exclusion criteria

Inclusion Criteria	Exclusion Criteria
Indexed in Web of Science, Scopus, or EBSCO Education.	Not indexed publication in these three platforms.
Peer-reviewed research articles, reviews, and book chapters.	Not peer-reviewed research articles, reviews, or book chapters
Publications including updated information on the application of Mobile learning in education	Publications not including updated information on the application of Mobile learning in education
Online higher education	No online higher education
Submitted after the COVID-19 outbreak in March 2020	Submitted before the COVID-19 outbreak in March 2020

In this systematic review, we defined a set of categories to code the publications. First, we wanted to know the *Type of device* reported in each study. We identified four groups: 1) mobile devices (used as a generic term), 2) mobile phones (also encompassing smartphones), 3) laptops, mobile phones, and tablets, and 4) mobile phones and tablets.

In terms of *Research design*, we considered a combination of the Creswell and Creswell (2017) and Wendler (2012) frameworks suitable for our systematic review scope, including 1) quantitative, 2) qualitative, 3) mixed methods, and 4) design-oriented research.

The *Data collection* method followed by the authors was distributed across eight groups assigned following Cohen, Manion, and Morrison (2018), Creswell and Creswell (2017), Wendler (2012), and Paré, Trudel, Jaana, and Kitsiou (2015). Each article screened was assigned to one of the following categories: 1) case study, 2) development, 3) exper-

imental design, 4) focus group and interview, 5) literature review, and 6) survey, along with a combination of methods such as 7) interview and survey, and 8) literature review, interview, and survey.

Moreover, we were interested in how mobile learning was applied in online higher education. To that end, we further analyzed only the primary research extracted by customizing eight categories following Crebert, Bates, Bell, Patrick, and Cragolini (2004), Zawacki-Richter, Marín, Bond, and Gouverneur (2019), and Radianti et al. (2020). A description can be found in Table X, and it includes 1) Adaptive learning systems and Personalization, 2) Analytical and Practical knowledge, 3) Assessment and Evaluation, 4) Behavioral and Psychological impact, 5) Best practices, 6) Communication and Collaboration, 7) Learning a language, and 8) Profile and Prediction.

2.3 Scope of Application

As part of the coding process, we aimed to assign, where possible, each article to a particular discipline. To that end, as indicated in Table 3, we followed and adapted the list of groups and fields provided by the UNESCO International Standard Classification of Education (UNESCO Institute for Statistics, 2012). Additionally, we created the category *No particular domain* to group those papers that, due to the interdisciplinary nature of the study or the lack of additional details, did not fall within a specific discipline.

Table 3 Scope of application of Mobile learning in higher education

Group	Field
Arts	Fine arts; Performing arts; Graphic and audio-visual arts; Design
Behavioural sciences	Psychology; Psychobiology; Anthropology; Cognitive science
Business and Administration	Accounting; Economics; Management; Public administration
Computer sciences	System design; Computer programming; Data processing; Networks; Computer information technology; Information systems; Software development
Communication and Information	Journalism and Social Communication
Education science	Teacher training programs; Curriculum development; Educational assessment; Educational research
Engineering	Chemical engineering; Mechanical engineering; Thermal engineering; Informatics; Computer engineering; Robotics; Electric engineering; Architecture; Design and Technical Drawing; Aviation engineering; Civil engineering
Health sciences	Medicine; Nursing; Medical services
Humanities	Foreign and native languages; Cultural studies; History; Archaeology; Philosophy; Ethics
Sciences	Biology; Zoology; Astronomy; Physics; Chemistry; Mathematics
Social sciences	Political science; Sociology
Sports	Physical education; Sports
No particular domain	Including multidisciplinary research articles and those where the field of application was not specified.

3 RESULTS

3.1 RQ1. What is the Geographical Distribution of the Publications, and Which Languages Were Used?

From mapping the literature reviewed, we recognized a progressive increase in publications addressing mobile learning resources in higher education over the past two years. Notably, 91% of the publications retrieved were research articles, and 9% were literature reviews. We traced 55 published pieces of research across 27 countries (Figure 2). The implementation of mobile learning for teaching-learning practices in higher education was localized to four continents. Figure 2 shows that most of the publications came from Asia (62%), followed by Europe (22%), Latin America (15%) and, to a lesser extent, Africa (2%). China was the country showing the largest publication productivity in mobile learning ($n = 8$, e.g., Cui, 2022; Ding et al., 2020; Fan et al., 2022; Lin et al., 2021; Yu et al., 2022). This trend was followed by Spain ($n = 6$; e.g., Navandar et al., 2021; Romero-Rodriguez et al., 2020; Verdes et al., 2021), Saudi Arabia (e.g., Almaiah et al., 2022; Iqbal et al., 2020) and India ($n = 5$; e.g., Mubayrik & Alabbad, 2021; Neffati et al., 2021). On the opposite side, for countries such as Ghana (Yeboah & Nyagorme, 2022), Cyprus (Cavus, 2020), Ecuador (Rodríguez Muñoz & Formoso Mieres, 2020), and Norway (Egilsdottir et al., 2021), only one publication was retrieved for each.

Furthermore, in Figure 3 the yearly contribution in both languages can be seen. A large majority (93%) of the publications mapped were published in English. Most were published in 2021, closely followed by those from the following year. In contrast, only 7% of the screened papers were in Spanish, and these were issued between 2020 and 2022 (Borroto, Medina Olazabal, & Fonseca Montes E Oca, 2021; Rodríguez Muñoz & Formoso Mieres, 2020; Salas-Rueda, Ramírez-Ortega, Eslava-Cervantes, Castañeda-Martínez, & De-La-Cruz-Martínez, 2022; Vigil García et al., 2020).

3.2 RQ2. Which Sources Are Most Frequently Used for Publication, and Who are the Most Cited Authors in the Literature?

Figure 4 shows the journals most frequently found in our database with articles published between 2020 and the current year. At the top of the list were Education and Information Technologies ($n = 5$), followed by Sustainability ($n = 4$) and Electronics ($n = 3$). With two articles each, we also found IEEE Access, International Journal of Emerging Technologies in Learning, International Journal of Interactive Mobile Technologies, Revista Conrado, and Wireless Communications and Mobile Computing. The remaining 33 sources were only represented by one article in our analysis.

To get an updated picture of the most cited authors, we returned to the online databases on 26 August and revised the number of citations received by each of the publications reviewed. In this case, two research papers published in 2020 led the way: Romero-Rodriguez et al. (2020) with 35 citations and Ding et al. (2020) with 33 citations. They were closely followed by (Akour, Alshurideh, Kurdi, Ali, & Salloum, 2021), cited 26 times. The Sankey diagram displayed in Figure 4 shows the interconnected relationship between the

Figure 2.



Figure 2 Geographical distribution of the publications reviewed in Spanish and English.

ten most cited authors, the keywords most frequently found in the articles, and the journals where they were published.

3.3 RQ3. Which Devices, Data Collection, and Research Design Methods Were Set Out to Support Mobile Learning and Teaching, and Within Which Disciplines Are They Integrated?

A matter relevant to this review was to identify the type of device reported in the literature analyzed. Over half of the papers reviewed (56%) indicated mobile phone use in mobile learning activities (Figure 5a). Notably, 28 of these papers specifically reported using smartphones. We also found that in 20% of the cases, authors used mobile device as a generic term without further clarification. Moreover, authors frequently combined several terms, such as mobile phones and tablets in 13% of records retrieved. Similarly, the use of laptops, mobile phones, and tablets was reported in 11% of the cases.

Furthermore, we traced the association between data collection and research design methods according to each type of device identified (Figure 5b). A majority of the

Figure 3.

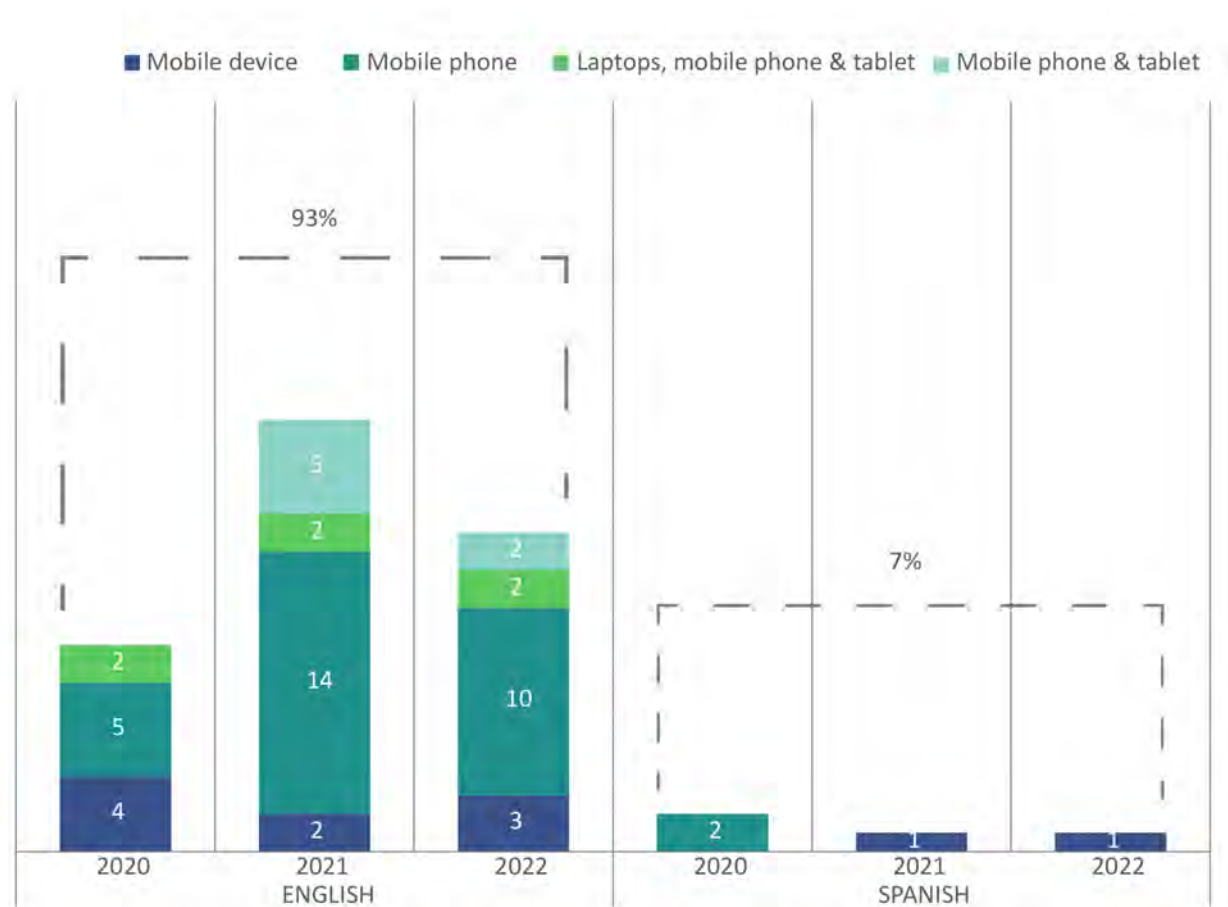


Figure 3 The number of publications retrieved in English and Spanish according to the type of device used.

papers (45%) focused on mobile learning were quantitative-based combined with a survey approach (Akour et al., 2021; Almaiah et al., 2022; Yuan, Tan, Ooi, & Lim, 2021). The authors implemented a qualitative strategy in 25% of the studies analyzed and used the following as collection methods: surveys (Sooryah & Soundarya, 2020; Vigil García et al., 2020), literature reviews (Gupta, Khan, & Agarwal, 2021) case studies (Borroto et al., 2021; Gurevych et al., 2021), and focus groups and interview (Pramana et al., 2020). Only 7% of the publications reviewed used a mixed methods approach paired with a literature review, interviews, and surveys. Likewise, only 7% of the research was design-oriented and used development approaches for collecting data (Ding et al., 2020; Márquez-Díaz, 2020; Verdes et al., 2021; X. Zhang, 2022).

Figure 4.

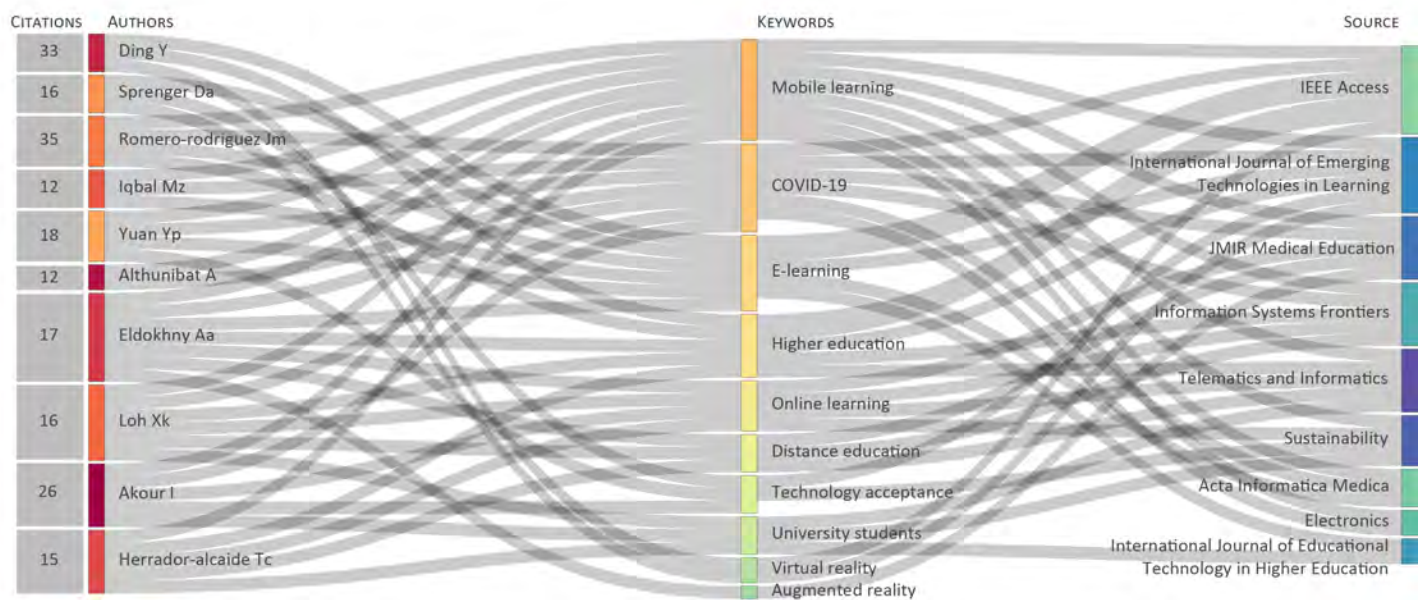


Figure 4 The interconnected relationship between the ten most cited authors, the keywords most frequently found in the articles, and the journals where they were published.

3.4 RQ4. What Is the Scope and Nature of Mobile Learning Applications in Online Higher Education?

Figure 6 shows the scope of application of research articles distributed across the types of devices identified. Particularly when considering the use of mobile phones, Engineering ($n = 7$; e.g., Diaz-Nunez et al., 2021; Laurens-Arredondo, 2022), Humanities ($n = 6$; e.g., Lan, 2022; Ugur-Erdogmus & Cakir, 2022), and Business and Administration ($n = 5$; e.g., Thedpitak & Somphong, 2021; Voshaar et al., 2022) predominated among all disciplines analysed. By looking in detail at the chart, it can be seen that publications reporting the use of either mobile devices (in general terms) or combined applications of laptops, mobile phones, and tablets are clustered together in the centre of the radar with one or two publications each across Arts (Cui, 2022), Communication and Information (Stephens, Rudiger, & Faires, 2021), Education Science (Romero-Rodriguez et al., 2020), Sciences (Borroto et al., 2021), Social Sciences (L. Zhang & He, 2022), and Sports (Ding et al., 2020). Notably, the four series of devices categorized had research papers where no particular domain or specific discipline was outlined, as illustrated in Figure 6 (Almaiah et al., 2022; Althunibat, Almaiah, & Altarawneh, 2021; Antee, 2021).

Further to the above, using the eight categories described in Table 4, we assessed the relationship between the scope and the nature of mobile learning applications in the 50 research articles analyzed. The nature and aim of some studies coincided in part with mul-

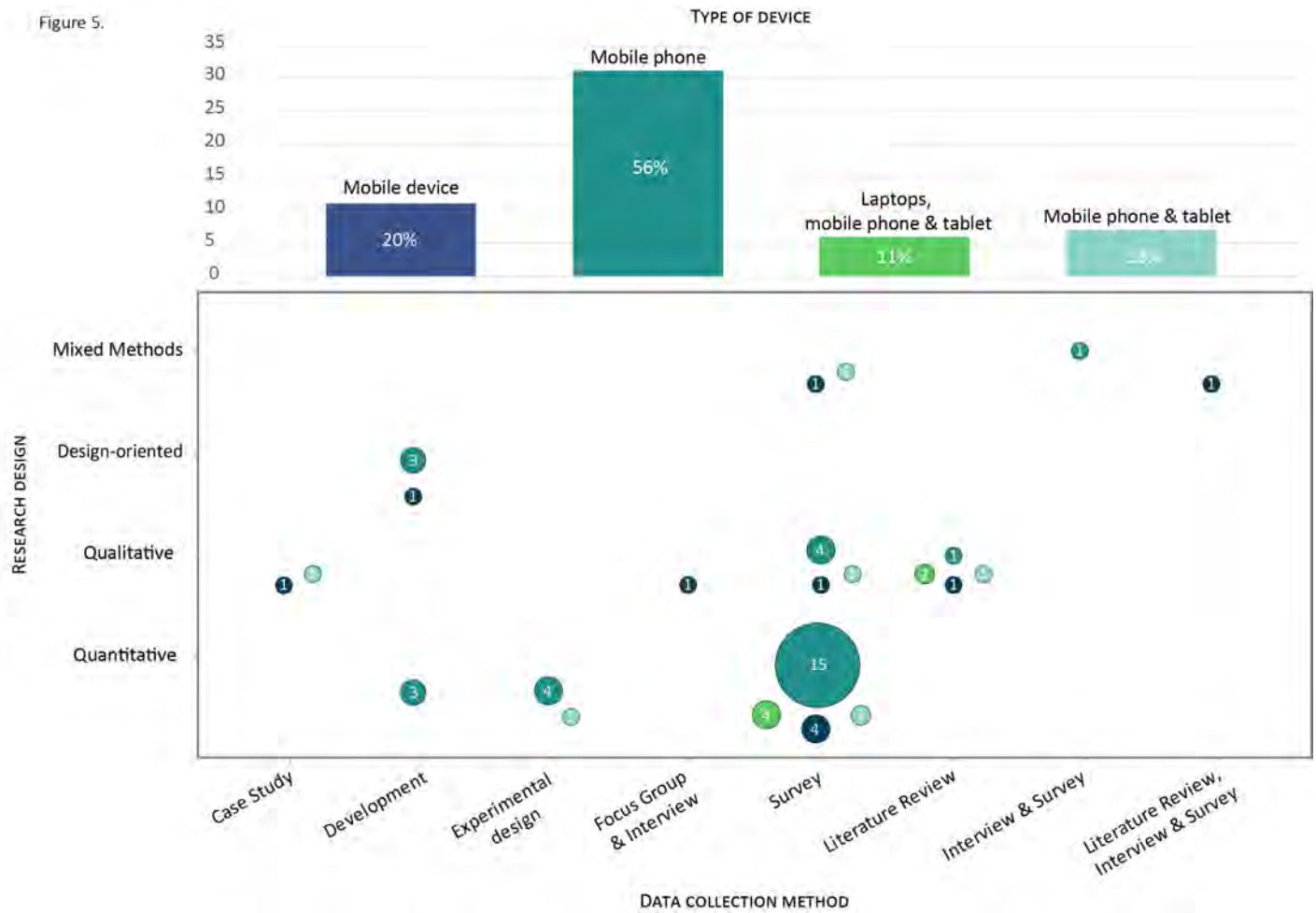


Figure 5 a. Type of device reported in the literature analyzed. b. The relationship between data collection and research design methods (the number of publications retrieved determines the bubble size).

multiple categories. In those cases, we assigned them to the one where their applicability is most significant.

3.4.1 Adaptive Learning Systems and Personalization

Research articles within this scope accounted for a significant proportion (22%) of those analyzed. Three studies were included in Humanities (Figure 7); two focused on History-related topics (Sarkadi, Cahyana, & Paristiowati, 2020; Ugur-Erdogmus & Cakir, 2022), and the other on mobile application development to reduce difficulties in listening to lectures online in a foreign language (Sooryah & Soundarya, 2020). We retrieved two Engineering-related publications. The first presented the design of a virtual world to make student and teacher access to knowledge through mobile learning more accessible and adaptive (Márquez-Díaz, 2020). The second one reported the creation of an augmented reality platform for improving mobile e-learning in software engineering (Neffati et al., 2021).

Figure 6.

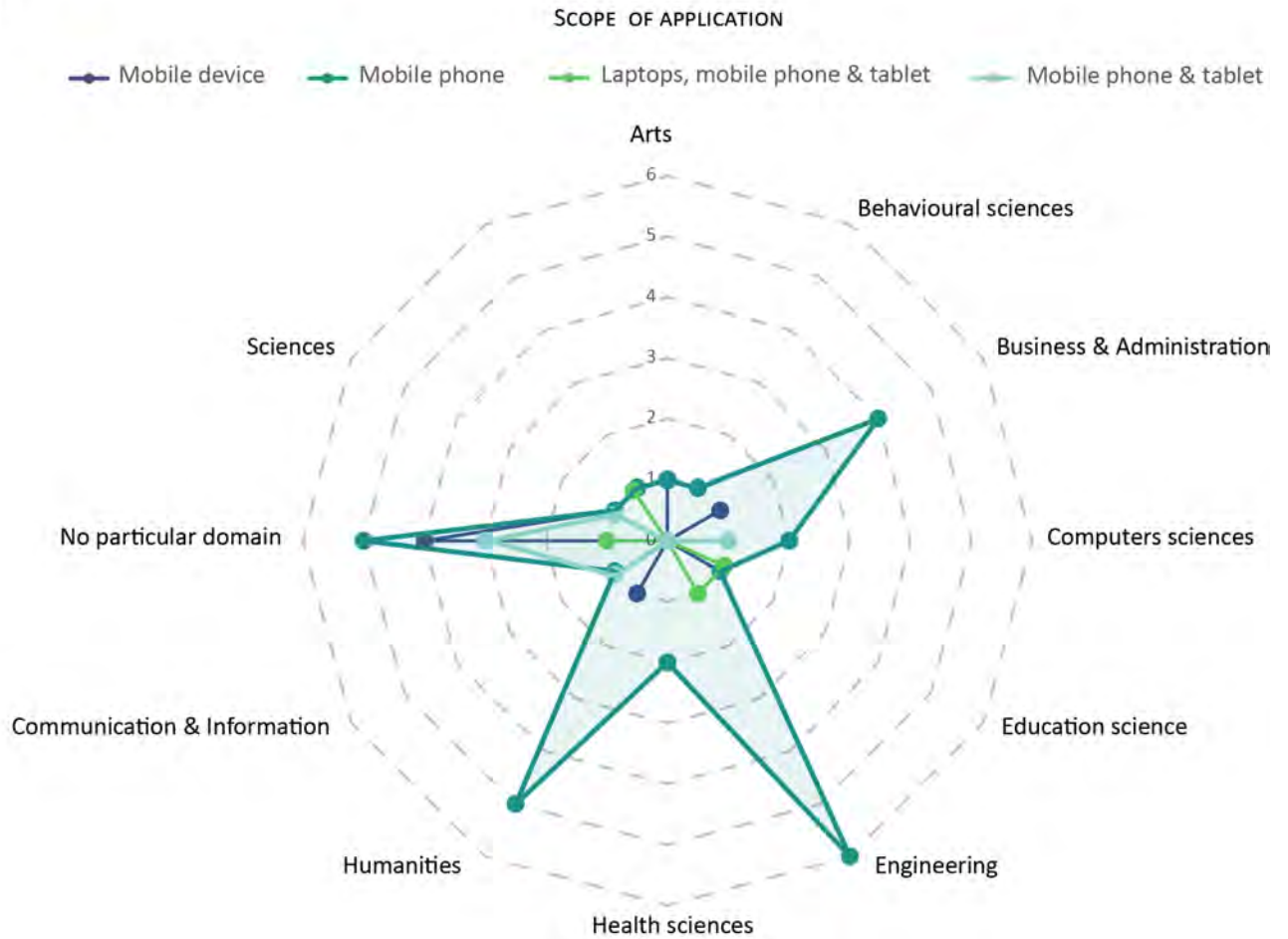


Figure 6 Scope of mobile learning applications in higher education in the research articles coded according to the type of device used.

In this same line, the paper by (Cavus, 2020) tested a novel unified mobile system with instructors and students from Education, Engineering, Law, and Languages to customize interactive teaching activities.

A few publications supported mobile learning implemented with XR technologies. Two were in Science-related disciplines, one for teaching invertebrate zoology online (Verdes et al., 2021) and the other for learning physics (Gurevych et al., 2021). Ding et al. (2020) relied on virtual reality and mobile learning to improve physical education. Likewise, Eldokhny and Drwish (2021) assessed the effectiveness of augmented reality in online distance learning to support academic achievement in Computer Science education. Finally, an artificial neural network algorithm (X. Zhang, 2022) found that a personalized mobile learning system may supplement and optimize the learning experience compared to traditional teaching.

Figure 7.

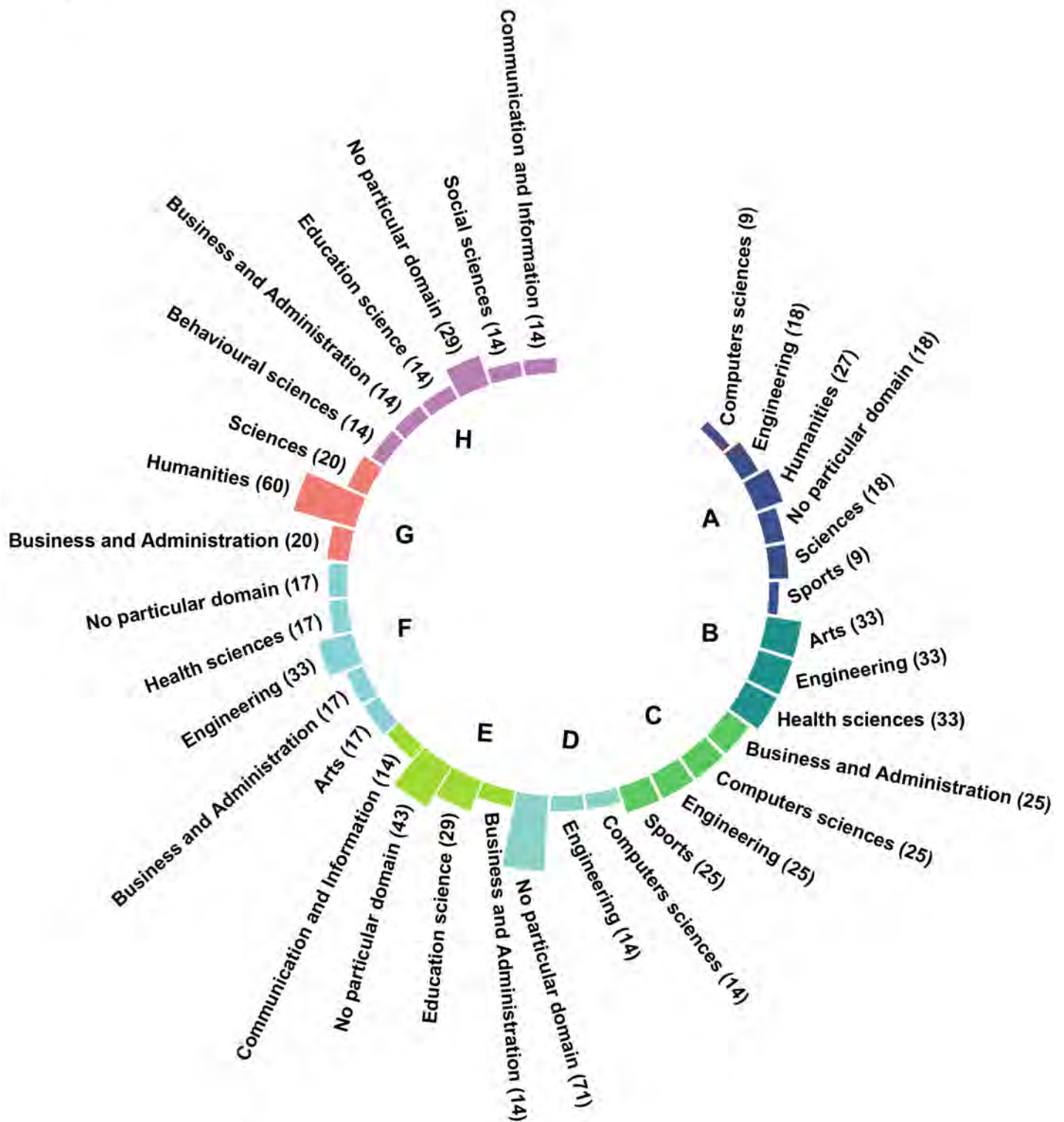


Figure 7 Mobile learning applications in higher education are distributed into seven categories: A. Adaptive learning systems and Personalization; B. Analytical and Practical knowledge; C. Assessment and Evaluation; D. Behavioural and Psychological impact; E. Best practices; F. Communication and Collaboration; G. Learning a language; H. Profile and Prediction

Table 4 Mobile learning technology application in higher education

Categories	Definition
Adaptive learning systems and Personalization	A study where Mobile learning has been used to either design or implement learning content dynamically adjusted to the pace and progress of students, helping improve their performance with automated and instructor interventions. Integrating personalized learning models facilitates student guidance, knowledge, and skill-sharing between learning teams.
Analytical and Practical knowledge	A publication where emerging technologies helped students improve analytical skills, such as collecting and analyzing data, programming, or making complex decisions like designing a manufacturing system. It also includes research articles reporting the use of Mobile learning to instruct learners on performing hands-on and field-specific practical training.
Assessment and Evaluation	Mobile learning implements evaluation methods such as remotely proctored exams, measure knowledge acquisition and engagement, and provides automated grading and feedback, ensuring integrity and academic honesty.
Behavioural and Psychological impact	When Mobile learning aims to assess the behaviour of learners or the psychological impact and awareness of the pandemic on learning habits, academic performance, and mental health issues. These tools are also be used to change perceptions, improve peer interest, and enhance engagement and learning motivation.
Best practices	When Mobile learning is implemented at the universities as a factor of change to favour teaching practices quality and improve learners' involvement, motivation, and development of skills.
Communication and Collaboration	It refers to research articles explaining the application of mobile learning to reinforce teamwork and communication skills and enhance collaboration experience and engagement.
Learning a language	Publications addressing the application of mobile learning to enhance students' foreign language skills.
Profile and Prediction	When Mobile learning is applied to assess students' progress throughout the learning process to provide feedback and recommendations in learning-related matters. It also considers the development of early warning systems detection of students at risk of failing, dropping out, or struggling with mental health issues due to the pandemic.

3.4.2 Best Practices

This category accounted for 14% of all research articles reviewed. The scope of the application was not specified in the three publications (Figure 7). [Almaiah et al. \(2022\)](#) explored quality impacting mobile learning usage. At the same time, [Coskun-Setirek and Tanrikulu \(2021\)](#) presented a guideline for sustainable education with mobile learning initiatives. Finally, [Althunibat et al. \(2021\)](#) highlighted the benefits of institutional policy, change management, and top management support in the usability of mobile learning systems.

Interestingly, the two papers retrieved within the Education Science scope focused on advancing and applying mobile applications from different perspectives and regions. The results of [Salas-Rueda et al. \(2022\)](#) regarding the Innovation in University Teaching diploma in Mexico revealed the positive influence on student engagement and academic activities of introducing web games and mobile devices in teaching-learning practices, while [Romero-Rodriguez et al. \(2020\)](#) investigated the level of implementation of mobile learning in Spanish universities and the sociodemographic features impacting the advancement of best teaching practices. Following a similar trend, [Teymurova et al. \(2020\)](#) examined university teacher integration levels in mobile entrepreneurial learning. The final publication coded within this category analyzed student perceptions of mobile devices in the Library and Information Science course, using this information to design a mobile-friendly training program ([Stephens et al., 2021](#)).

3.4.3 Profile and Prediction

14% of research papers coded fell within this category and were distributed across multiple disciplines. As illustrated in Figure 7, three articles looked at combined approaches for predicting technology acceptance and usability—the first implemented mobile learning and XR in a Psychology class (Sprenger & Schwaninger, 2021). In the second, machine learning was employed to predict the usefulness, effectiveness, efficiency, and acceptance of mobile learning, although no specific application domain was specified (Almaiah, Almani, Al-Khasawneh, & Althunibat, 2021). The third study assessed Ghanaian distance learners' acceptance of WhatsApp as an educational tool at the University of Education during the pandemic (Yeboah & Nyagorme, 2022).

The three remaining publications addressed matters linked to Business and Administration (Herrador-Alcaide et al., 2020) and Journalism, Communication and Information (Humida, Mamun, & Keikhosrokiani, 2021). Yuan et al. (2021) reported that learning content quality, user interface, and connectivity are the leading drivers influencing students' perceptions, ease of use and experience when using mobile learning. Meanwhile, L. Zhang and He (2022) proposed a machine learning algorithm to optimize and monitor student performance in Ideological and Political Education using mobile learning during the pandemic. To a lesser extent, with only nine publications retrieved, mobile learning also appeared in higher education teaching and learning.

3.4.4 Behavioural and Psychological Impact

Five research articles did not centre on one specific domain. Akour et al. (2021) applied machine learning algorithms to predict the benefits of using mobile learning platforms during the pandemic (Figure 7). After analyzing a dataset of 10,000 college students, Lin et al. (2021) suggested that mobile learning and news applications positively impact academic development while playing mobile games, using social media, listening to music and watching videos, and entertainment book-reading applications have negative implications, while Fan et al. (2022) highlighted attitude, need, emotion, ability, and reinforcement as essential characteristics in improving mobile learning motivation in higher education students. Following this line, Alturki and Aldraiweesh (2022), using a technology acceptance model to evaluate satisfaction, behavioural intention, and perceptions, found that using mobile learning had an excellent and constructive influence on higher education students during the COVID-19 pandemic. Looking in the opposite direction, Loh et al. (2021) drew attention to the antecedents and consequences of technostress and fatigue on learners' intention to use mobile learning via social media.

The other two papers coded within this category relied on mobile learning, exploring, respectively, the drivers influencing its adoption in students from the College of Information Technology (Almaiah et al., 2022), and combining mobile learning and augmented reality to explore their positive implications for motivation and education in Engineering-related programs (Laurens-Arredondo, 2022).

3.4.5 Communication and Collaboration

In this category, the mapping of application domains of mobile learning was distributed across heterogenic disciplines in six research papers (Figure 7). Three articles used mobile learning as a resource for videoconferencing applications and instant messaging applications, strengthening interaction, communication and collaborative learning during teaching and learning processes in Engineering (Diaz-Nunez et al., 2021; Kumar et al., 2022) and Medicine students (Iqbal et al., 2020). One example can be taken from Diaz-Nunez et al. (2021), who found that students used mobile devices to access online learning activities and virtual classes to cope with learning and daily life during the pandemic. Similar applications were reported by Pramana et al. (2020) in a study conducted across 40 universities in Indonesia, although no specific domain was mentioned. The fifth paper added to this group investigated the effect of flipped teaching on cognitive load in online learning when using mobile devices in a graphic design course (Chen, Fan, & Fang, 2021). Rodríguez Muñoz and Formoso Mieres (2020) noticed increased knowledge sharing, reconfiguration and reorganization of learning during the pandemic when using YouTube and WhatsApp with students of Professional Ethics, Entrepreneurship and Innovation.

3.4.6 Learning a Language

Figure 7 displays the emerging technologies and their corresponding application domains extracted from the research papers reviewed. In terms of language learning, mobile learning was favoured by most authors in three different disciplines. Three articles were classified within the Humanities disciplines. The first one showed the positive effects of mobile-assisted pronunciation training on students majoring in English Lan (2022). The second focused on Japanese language learners, identifying three different types of students and investigating the critical factors pushing them to continue using language learning apps (Huang & Chueh, 2022). The third, Vigil García et al. (2020) embedded WhatsApp in BA Education Major Foreign Languages activities to enhance communicative, interactive and intercultural competence in the teaching-learning process of the English language. Boroto et al. (2021) reported the application of mobile learning resources for teaching Biology online in Spanish for non-Spanish Speakers. Following this trend, Thedpitak and Somphong (2021) highlighted positive attitudes toward learning English as a foreign language using mobile applications among Thai students.

3.4.7 Assessment and Evaluation

Online education has benefited from mobile learning assessments and evaluations during the COVID-19 pandemic, as noted in the 12 articles assigned to this category in this literature review (Figure 7). Students frequently use smartphones in their daily lives and are progressively integrating them as assessment and evaluation resources in online education. Four papers using mobile learning were coded in this category. The first introduced a mobile educational application providing theoretical knowledge and question-based tests for computer engineering undergraduate students (Kayaalp & Dinc, 2022). Singh et al. (2021) devel-

oped a progressive model calibrating the difficulty level based on learner understanding in Computer Science education, which will prepare institutions for the transition from paper-based to mobile-based online tests. [Voshaar et al. \(2022\)](#) measured how a gamified mobile learning application influenced exam success on a course in the field of Business and Administration Studies. The fourth study evaluated the change in undergraduate Sports Science course perception when using Instagram as a learning medium and the benefits of doing assignments via social networks ([Navandar et al., 2021](#)).

3.4.8 Analytical and Practical Knowledge

16% of the research articles reviewed were coded within this category. As shown in Figure 7, one study focused on improving learner programming skills in Computer Engineering education [Mir and Lluca \(2020\)](#). [Egilsdottir et al. \(2021\)](#) explored the application of mobile learning tools to enhance skills and knowledge transfer and reduce the gap between theory and practice in nursing education. [Cui \(2022\)](#) delved into the potential of using augmented reality and mobile applications in acquiring piano skills, providing a novel opportunity to revolutionize Arts education.

4 DISCUSSION

Mobile learning has progressively evolved from an in-class and asynchronous learning supportive resource to a critical part of the learning experience ([Educause, 2019](#); [Gupta et al., 2021](#)). Mainly influenced by the global increase in wireless internet access, which has impacted the rise in mobile device ownership, mobile learning has become a direct way to implement personalized learning settings ([Cavus, 2020](#); [Neffati et al., 2021](#); [Verdes et al., 2021](#)).

The evidence from this systematic review indicates that an increasing number of mobile educational projects are actively being integrated into online higher education, teaching and learning, specifically since March 2020. The preferred use of mobile phones for mobile teaching and learning activities correlates with findings previously reported by [Crompton and Burke \(2017\)](#) and [Wu et al. \(2012\)](#). Moreover, the publications reviewed suggest that learners retain more knowledge and are more interested in completing the assigned exercises when they feel inspired to learn. In this sense, significant technological advances play a relevant role in contributing to elevating instructional design so that educational materials that are more specifically applicable are provided to students at their appropriate level of learning.

The advent of highly functional smartphones and tablets has increased the preference for using these devices over laptops or computers in countries with emerging economies ([Diaz-Nunez et al., 2021](#); [Márquez-Díaz, 2020](#); [Mubayrik et al., 2021](#); [Pramana et al., 2020](#); [Sooryah & Soundarya, 2020](#)). Using such devices helped learners to stay connected to academic activities and communicate with teachers and classmates during the COVID-19 pandemic. Despite the usage gap in low- and middle-income countries, there is a noticeable increase in the implementation of mobile learning resources ([Borroto et al., 2021](#); [Diaz-Nunez et al.,](#)

2021; Humida et al., 2021; Rodríguez Muñoz & Formoso Mieres, 2020).

Based on previous experience and following experiments in universities supporting distance and online learning formats, many higher education institutions have introduced (or expanded) their mobile learning courses, allowing learners to continue their academic activities while shifting from face-to-face to virtual forms. This solution has empowered interaction in content creation, communication, and collaboration between learners and instructors and significantly impacted learning effectiveness (Iqbal et al., 2020; Pramana et al., 2020).

Mobile learning has progressively evolved from supplementary material for teaching to a flexible, strategic, and convenient resource, driving new paths in higher education. Its acceptance and adoption are growing in higher education, with it being an easy, convenient, and flexible way to access learning materials anytime and anywhere (Almaiah et al., 2021; Bernacki, Crompton, & Greene, 2020; Kumar et al., 2022; Sprenger & Schwaninger, 2021).

Notably, over the past two years, efforts have been made to make learning self-paced and collaborative using key technologies. Amid the COVID-19 outbreak, many higher education institutions faced multiple challenges when transitioning from face-to-face to virtual teaching. One of them was to provide materials that are accessible, useful, effective, and efficient to learners (Almaiah et al., 2021; Herrador-Alcaide et al., 2020). In this context, mobile learning tools' adoption, behaviour and integration into the educational process are critical factors in the training experience (Akour et al., 2021). Integrating social media platforms, such as Instagram, into the learning process has also improved self-learning, increased online contribution and facilitated active participation (Navandar et al., 2021).

The fact that educators now rely on technology to provide flexible and customized learning curricula more than ever before has led to a greater reliance on technology in the classroom. Notably, since Engineering and Humanities were the scopes of application more repeatedly reported in the literature, this allowed for a diverse appraisal. Seven of the articles reviewed describe the implementation of mobile learning in Engineering learning processes, showing the consolidation of its applicability in different categories in higher education (Diaz-Nunez et al., 2021; Kayaalp & Dinc, 2022; Kumar et al., 2022; Laurens-Arredondo, 2022; Mir & Lluca, 2020). Following this line, studies distributed in the field of Humanities were evenly focused on language learning (Huang & Chueh, 2022; Lan, 2022; Vigil García et al., 2020) and the adaptable and personalized potential (Sarkadi et al., 2020; Ugur-Erdogmus & Cakir, 2022) of this technology towards building a constructivist and activity-based education.

Nowadays, embedded with other resources supporting AI, XR and Internet of Things devices, mobile learning is expanding and becoming more active, with the expectation that educational experiences can adapt to current learner needs and academic trajectories (Chu, 2022; Laurens-Arredondo, 2022; Rangel-de Lázaro & Duarte, 2023). Still, co-design processes combining mobile learning with more traditional resources benefit learning. Building on co-design, new forms of collaboration between educators and researchers are developed, resulting in the development of innovations that impact teaching practice (Couso, 2016; Voogt et al., 2015). As a result, teachers and students benefit from deepening educa-

tional designs, knowledge and development of new skills (Penuel et al., 2022). Egilsdottir et al. (2021) followed this methodology to reduce the gap between theory and practice in basic physical assessment skills and knowledge transfer between university and clinical sites for nursing courses. The participants considered digital simulations with virtual patients, massive open online courses, and multimedia learning material, and evaluated their potential and benefits in academic and clinical contexts. Furthermore, these students endorsed the inclusion of multiple-choice tests and written assignments to deliver feedback and support learning progress.

Similarly, there is a continuing trend towards using XR and mobile learning to encourage academic achievement and gaining skills in virtual classrooms, as shown by Eldokhny and Drwish (2021) and Chessa and Solari (2021) when using XR in online distance learning through the pandemic. In some areas, VR seemed to be mature enough to be used for teaching procedural, practical knowledge, and declarative knowledge. Examples included Fire Safety, Surgery, Nursing, and Astronomy. In these cases, more professional VR applications were used. However, most articles indicated that VR for education is still in its experimental stages, involving prototyping and testing with students.

The literature reviewed indicates that mobile learning is a solicited resource for customizing courses and curricula to fit student needs and to encourage flexible learning to effectively impact a massive online learning experience (Verdes et al., 2021; X. Zhang, 2022). This is more noticeable in those with complex academic trajectories who require synchronous and asynchronous tools, increasingly turning to online university education for their educational needs (Herrador-Alcaide et al., 2020).

Interestingly, keeping track of and enhancing communication and collaboration in online education is also a critical concern when using mobile learning tools. Authors have relied on a vast diversity of existing platforms such as Whatsapp, Telegram, Microsoft Teams, Google Classroom, Google Meet, Zoom, and Edmodo, among many others, to investigate whether they are effective learning platforms that also facilitate engagement, collaborative learning, and ensure the wellbeing and security of students during the most critical times of COVID-19 (Iqbal et al., 2020; Kumar et al., 2022; Pramana et al., 2020).

However, beyond the many benefits mobile learning provides to higher education, attention must be paid to its downsides, such as information overload, distraction, and time-wasting. Furthermore, there is a risk of discrimination against those who cannot access these services fully. Various factors may contribute to this problem, including complex interfaces, limited access to unstable smart devices, or a low network signal. As a result, some students may find themselves alienated from communication and collaboration within the educational environment. Contrary to other studies, after comparing technology acceptance of e-lectures, classroom response systems, classroom chat, and mobile virtual reality, Sprenger and Schwaninger (2021) noticed a decrease in the perceived usefulness and behavioural intention after three months of students using mobile virtual reality. The main reasons for such poor technology acceptance feedback were mainly related to functional and technical issues of mobile virtual reality. It is clear that the problems presented above are not new. However, it highlights the necessity for a critical re-evaluation

of the appropriate implementation of emerging technologies in terms of curriculum design, educational policies, technological resource implementation, and digital competencies and skills at all higher education levels. Likewise, X. Zhang (2022) noticed that despite challenges, students believe that the traditional face-to-face method is the best way to carry out the entire teaching and learning process and that digital platforms should be used as a supplement to facilitate the educational process.

5 CONCLUSIONS

Here we presented a systematic review mapping the implementation and influence on online higher education of mobile learning after the COVID-19 pandemic outbreak. In this literature analysis, only peer-reviewed publications in English or Spanish published in Scopus, Web of Sciences, and EBSCO Education were considered. Moreover, as we included papers submitted after March 2020, we acknowledged that the data provided would, in most cases, have been collected before then. Nevertheless, upon careful evaluation, we recognized that the impact of the pandemic on university agents had influenced the process of producing the selected articles.

Despite it already having been present for years, mobile learning has been embedded in higher education by the pandemic. Since its start, face-to-face learning-teaching activities have had to migrate into virtual settings, and those already working in online environments have also needed to adapt to the new circumstances. All this has resulted in a need for tailored and effective support schemes for educators and learners.

Nowadays, implementing key emerging technologies has a critical role in shaping the future of online higher education. Consequently, educators and students will see digital resources as an accessible toolbox to amplify a personalized, active, learner-centred method. While institutions are getting ready to face new forms of educational settings, future critical implications of using mobile devices are pointing towards improving data literacy and skills, data security and protection against threats to personal privacy, and continuing with the normalization of hybrid and remote learning settings.

We cannot deny that applying mobile learning to educational settings requires an economic investment. However, as these technologies become more ubiquitous, their deployment costs decrease, making them more sustainable in the long term than traditional analogue learning. Looking ahead, it is plausible that this trend will continue evolving worldwide to make access to remote education more effective and adapted to current needs.

In the future, it would be beneficial to implement the search string developed here in a larger number of databases and languages to expand the scope of this review. Further, as education evolves to meet the needs of the current times, we aim to focus future research on other critical technologies such as micro-credentials, open educational resources, and XR and AI.

6 AUTHORS' CONTRIBUTION

- Conceptualization, methodology, analysis, investigation, data curation, writing-original draft, review, editing, visualization: G.R.-d.L.
- Conceptualization, writing-review & editing: J.M.D.
- All authors have read and agreed to the published version of the manuscript.

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