Mobile Learning in University Science Education: A Systematic Literature Review

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Mobile Learning in University Science Education: A Systematic Literature Review

This study adopts a robust systematic literature review (SLR) to investigate the use of mobile devices to support learning (mobile learning) in university science education. It analyses 24 high quality studies over the past decade to generate insights into contemporary mobile learning developments in relation to settings, applications and pedagogical approaches, as well as trends in research methodologies and outcomes. The results show that the use of mobile devices is providing university science learners with peer learning opportunities and supporting their networked interactions with the science community and resources. However, the study also uncovers more constrained use of mobile devices associated with traditional didactic approaches, often in formal settings. The study identifies key differences from other SLR findings on mobile learning in school science education, most notably with respect to adopted pedagogies. It suggests future research directions, including the need for more qualitative studies of mobile learning in university science education.

Keywords: mobile learning, university science education, systematic literature review, digital pedagogies.

1. Introduction

The adoption of mobile devices and associated applications (or apps) to support learning has proliferated at all levels of education (Kearney, Burden, and Schuck 2020a). The ease of access, affordability and flexibility of these portable technologies, such as mobile phones, tablets and laptops, have been key factors in their increased use. This paper conceptualises learning with mobile devices (or mobile learning) from a socio-cultural perspective, acknowledging the importance of context and social interactions for learning (Salomon and Perkins 1998; Vygotsky 1978) and the mediation of learning through the use of tools (Wertsch 1991). This perspective suggests that the learning process is affected by the technologies used; and conversely these tools are modified by the ways that they are used for learning. Mobile learning (m-learning) practices can be defined as approaches supporting "learning across multiple contexts, through social and content interactions, using personal electronic devices" (Crompton, 2013, p.47). From a socio-cultural perspective, m-learning can enhance students' experiences of personalisation, authenticity and collaboration (Kearney et al., 2012); and these experiences are influenced by how they exploit an increasing variety of learning contexts (Kearney, Burden, and Schuck 2020a). M-learning can take place within a range of temporal and spatial boundaries, including more learner-controlled task pacing, scheduling and use of physical and virtual learning spaces (Kearney, Burden, and Schuck 2020b). Students can learn with mobile devices across formal and informal settings, sometimes referred to as 'seamless learning' (Burden and Kearney 2016). For example, connecting learning between a classroom and excursion, or between school and home. Recently enforced remote teaching periods due to the pandemic were a catalyst for further development of m-learning practices (Kearney, Schuck, and Burden 2022) and further highlighted their potential for supporting digital pedagogies (Burke et al. 2021).

Science education researchers have explored discipline-specific m-learning practices, with a strong focus on approaches supporting inquiry-based learning (Liu et al. 2020). However, existing mobile science learning research has mostly occurred in school contexts (Burden and Kearney 2016; Crompton et al. 2016), and there is a danger of lagging developments with mobile digital pedagogies in university science contexts. This study addresses this problem by focusing on m-learning practices in university science education.

This study adopts a robust systematic literature review (SLR) methodology to examine m-learning trends in university level science education reported in publications written in the English language. It explores how m-learning has been adopted in this context since 2011, seeking to identify and examine m-learning settings, applications and pedagogical approaches, as well as trends in research methodologies and outcomes. It aims to inform stakeholders about these trends, and to provide research directions for future studies. The following research questions (RQs) guide this SLR study of m-learning in university science education:

RQ1: What are the adopted m-learning settings, applications and pedagogical approaches?

RQ2: What are the trends in research methodologies and outcomes?

2. Related studies

As depicted in Table 1, there are several existing SLR studies focusing on m-learning *in higher education* (Alrasheedi, Capretz, and Raza 2015; Crompton and Burke 2018; Kaliisa and Picard 2017; Krull and Duart 2017; Pimmer, Mateescu, and Gröhbiel 2016; Sophonhiranrak 2021) but these reviews covered multiple disciplinary domains and were not exclusively focusing on science education in universities (see Table 1). Pimmer, Mateescu, and Gröhbiel (2016) examined 36 studies on the use of mobile and ubiquitous learning in higher education. They revealed a focus on instructionist pedagogical approaches, followed by constructionist, situated and collaborative learning practices. Another review explored the application, impact and challenges of m-learning in higher education in African countries by reviewing 31 studies published from 2010 to 2016 (Kaliisa and Picard 2017). The results showed a growth of interest in the use of m-learning and addressed the challenges in integrating m-learning in higher education curriculum. These researchers did not mention the subject areas and only included studies conducted within Africa.

In addition, Krull and Duart (2017) analysed the research trends in m-learning in higher education and found an increasing variety of studies in this area with a focus on m-learning applications and systems. Furthermore, Crompton and Burke (2018) reviewed the use of m-learning in higher education and found language instruction was the most studied subject domain. Seventy-four percent of studies in their SLR were at undergraduate level and 54% of studies was conducted in formal settings. More recently, Sophonhiranrak (2021) analysed the features, barriers and influencing factors of using mobile devices in higher education. The result of this SLR showed mobile devices can be used as tools to enhance various activities including reflection, knowledge-sharing and assessment procedures.

Insert Table 1 about here

There have been numerous SLRs focusing on m-learning *in school education* in the past two decades, as shown in Table 1. SLRs on m-learning at school levels have focused on multiple academic disciplines such as literacy, special education, science, mathematics, interdisciplinary, social studies, arts and music (Burden et al. 2019; Crompton and Burke 2020; Crompton, Burke, and Gregory 2017; Crompton, Burke, and Lin 2019; Liu et al. 2014); science and mathematics (Bano et al. 2018). When considering science-specific SLRs, Liu et al. (2020) reviewed the types of mobile inquiry-based learning in secondary school science, including benefits and constraints.

Some of the SLRs listed in Table 1 have investigated *multiple educational levels*. Sung, Chang, and Liu (2016) conducted a meta-analysis study on the effects of mobile device integration on students' learning performance across a range of learning stages from kindergarten to adult education. The result of their study revealed a positive effect on students' learning performance through the use of mobile devices. Chee et al. (2017) evaluated m-learning in K-12 and higher education settings across multiple disciplines. Science was the second most frequently reported domain in their SLR. Fu and Hwang's (2018) review found an increased focus on collaborative learning and explored connections between the use of mobile technologies and collaborative learning tasks.

Suárez et al. (2018) analysed 62 studies on mobile inquiry-based learning (IBL) to identify frequently used mobile activities, and provide an analytical framework to evaluate how the use of mobile technologies supports learners' agency. Pishtari et al. (2020) provided an overview of how learning design and learning analytics support m-learning by analysing 54 papers published from 2008 to 2019. Additionally, Gao, Li, and Sun (2020) investigated the use of mobile game-based learning on STEM (Science, Technologies, Engineering and Mathematics) subjects. Lastly, the only two m-learning studies exclusively focusing on science education, albeit at all educational levels, were published by Crompton et al. (2016) and Zydney and Warner (2016). The majority of studies in Crompton et al. (2016) SLR focused on life science subjects taught at primary education levels. Zydney and Warner (2016) reviewed existing research (mainly school levels) on science mobile apps design, theoretical foundations and student outcomes measures.

All the above-mentioned studies emphasised positive outcomes and provided valuable insights on the use of m-learning in different educational levels and subjects. For example, the benefits of collaborative learning were frequently mentioned in these SLRs. However, there are no reviews on m-learning exclusive to university science education, and there is an urgent need for a focused SLR in this area. In summary, our systematic review differs from existing reviews in the following facets:

(1) Educational level and subject domain: our review focuses exclusively on m-learning studies in university science education. This is due to the lack of systematic reviews focusing specifically on this subject domain and educational level, as shown in Table 1.

(2) Focus: This study goes well beyond a technical focus (a common criticism of m-learning research) to provide analysis of different attributes of the results from the reviewed studies such as m-learning settings, applications and pedagogical approaches, as well as research methodologies and outcomes.

(3) Timeline: Our review covers publications from 2011–2021. This period allows us to interrogate contemporary research trends in relevant m-learning studies over the past decade—a similar period to other SLRs in this area (e.g., Bano et al. 2018; Burden et al. 2019; Fu & Hwang 2018; Suáre et al. 2018), as shown in Table 1.

(4) Guidelines: In this SLR, we strictly follow guidelines from the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Liberati et al. 2009) to investigate teaching and learning with mobile devices in university science education. PRISMA is a widely used evidence-based procedure for systematic reviews and meta-analyses reports (Liberati et al. 2009).

3. Study design

Following the PRISMA guidelines, all selected studies adopted rigorous research designs and provided high-quality empirical evidence on m-learning in science higher education. The primary reviewer conducted the initial search, reading all titles and abstracts and checking the inclusion, exclusion criteria (see Table 3) on the selected studies. To reduce selection bias, any paper selection issues were resolved through discussion against inclusion, exclusion criteria with two secondary reviewers. The final set of 24 quality outputs (see Figure 1) were peer reviewed by all team members to ensure the inclusion of best evidence.

3.1 Search Strategy

The following steps were conducted to search for relevant studies globally. The researchers:

(1) Identified major search terms from the research questions;

(2) Identified relevant minor terms, synonyms and equivalent spellings from existing literature;

(3) Built a search string using Boolean operators;

(4) Selected high-ranking Education databases for searching purposes;

(5) Applied the resulting search string on abstracts to find journals, articles and book chapters written in the English language; and customised the search string according to different databases;

(6) Searched period January 2011 to December 2021;

(7) Used Endnote to store the selected results, and Microsoft Excel for tracking purposes;

(8) Used Mendeley to share the final set of included papers for all authors.

Based on our research questions, we generated the following three major search terms: mobile learning, science, and university. From these major search terms, we identified alternative terms to construct our search string, as shown in Table 2. To find and select empirical articles for this review, the following search string was used to scan abstracts and titles of potential studies: ("Mobile learning" OR "mlearning" OR "m-learning" OR "mobile pedagog*" OR "mobile technolog*" OR "context aware" OR "seamless learning" OR (mobile AND ("technology enhanced" OR "technology supported" OR "technology enabled" OR "technology mediated") AND ("teaching" OR "learning"))) AND (science* OR astronomy OR biology OR chemistry OR geology OR physics) AND (universit* OR college OR "higher education" OR "post-secondary" OR "tertiary education").

Insert Table 2 about here

The following databases were selected in our search: ACM Digital Library, Education Research Complete, Science Direct, ERIC, ProQuest, SAGE journals, Scopus and Web of Science.

3.2 Study selection criteria

After obtaining all the results from selected sources, duplicate papers were removed before applying the inclusion and exclusion criteria filter process by the review team. Based on the retrieved results, secondary searches were performed by scanning and reviewing the references listed of the selected papers. Those papers that were eligible for consideration were treated with the same inclusion/exclusion criteria set for the primary search selection. Once the selection process was completed, identification numbers were given to the included studies. The inclusion and exclusion criteria are summarised in Table 3.

Insert Table 3 about here

All the selected studies needed to meet all inclusion criteria, and not match any exclusion criteria. Figure 1 provides an overview of the search and selection process used in this SLR, including the number of studies at each stage. A final set of 24 papers (see Appendix) met all criteria and were used in this SLR. There were 21 journal articles in the final set of studies, in addition to three book chapters. The journal papers were published in a range of high-ranking science education or educational technology journals.

Insert Figure 1 about here

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4. Results

This section presents findings from the analysis of the 24 selected studies of m-learning in university science education (listed in Appendix), addressing the two research questions for this SLR. These studies were conducted in a variety of countries, including USA (6 studies), UK (3 studies), Taiwan (3 studies) and Australia (3 studies). We firstly present insights relating to adopted m-learning settings, applications and pedagogical approaches, then report on trends in research methodologies and outcomes.

4.1 Mobile learning settings and adopted applications

4.1.1 Settings

There were four main types of settings in the selected studies. These were classified using the definitions used by Bano et al. (2018). *Formal* settings refer to traditional learning environments such as university lectures, tutorials or laboratory classrooms. *Semi-formal* settings are outdoor spaces chosen by teachers, such as botanic gardens and field trips. *Informal* settings are learner-generated, typically daily-life spaces chosen by students, such as home, playgrounds or coffee shops. Lastly, *multiple* settings refer to the use of mobile technologies in more than one setting. The distribution of settings featured in the selected studies is shown in Table 4.

Insert Table 4 about here

Most studies examined science m-learning in formal (37.5%) and multiple settings (33%), while there was a lack of focus on semi-formal (17%) and informal settings (12.5%). The studies in the multiple settings category featured students' m-learning across varied contexts, or 'seamless learning'. This seamless learning trend emerging from this SLR aligns with a recent emphasis on mobile learning across multiple contexts (e.g. Schuck, Kearney, and Burden 2017), including in science education (Burden and Kearney 2016). Indeed, the frequency of seamless learning across multiple settings in this SLR was higher compared to a previous m-learning SLR (Crompton and Burke 2018) covering all disciplines in higher education. Nevertheless, within the multiple settings category, formal settings were typically used in combination with other settings.

4.1.2 Use of apps

There was almost an equal distribution of discipline-specific and generic m-learning apps in the included studies. A slight majority of apps featured in the studies were science-specific (58%). For example, games-based apps were used in three app trial studies in the context of chemistry learning (Fonseca, Zacarias, and Figueiredo 2021; Jones, Spichkova, and Spencer 2018; Winter, Wentzel, and Ahluwalia 2016). The gamification features of these apps were valuable for students to understand concepts and motivate them in their chemistry learning. One of the recommendations from Jones, Spichkova, and Spencer (2018) was to have both chemists and game designers involved in the game design and development process.

Slightly less apps (42%) from the set of studies were classified as more generalised, or discipline agnostic. For example, three studies explored the effectiveness of using social media apps in learning science, with a focus on the use of TikTok (Escamilla-Fajardo, Alguacil, and López-Carril 2021), Facebook (Bidarra and Sousa 2020) and Twitter (Lackovic et al. 2017). These three studies focused on a connectivist pedagogical approach detailed in the next section.

It was notable that almost all studies were silent on learners' agency in app choice, with only one study, Bidarra and Sousa (2020), featuring student control over the selection of apps. They examined how m-learning influenced students' personal learning environments and discussed the benefits of learners choosing their preferred tools rather than relying on pre-assigned apps.

4.2 Pedagogical approaches

The most frequently reported pedagogical approaches in the included studies were collaborative and inquiry-based learning (IBL). There were also multiple studies focusing on connectivist learning, traditional instructionist learning (relying on transmissive, didactic teaching approaches), context-aware/ ubiquitous learning, field-based learning, problem-based learning and flipped learning. There was a lower frequency of studies focused on blended learning.

Insert Table 5 about here

4.2.1 Collaborative learning

Collaborative learning, mediated by the use of mobile devices, was the most frequently reported pedagogical approach. Collaborative learning concerns groups of student peers interacting with each other to work toward a mutual learning goal (Jeong and Hmelo-Silver 2016). For instance, students may use their devices to work together to co-create a short movie on a selected science topic, or make a poster on an assigned chemistry topic (Bartle, Dook, and Mocerino 2011). In one of the selected studies, synchronous activities (e.g., via Zoom meetings) leveraged opportunities for student participants to solve problems together, co-participate in group discussions and group annotation tasks (Baldock et al. 2021). Overall, eleven of the selected studies focused on collaborative m-learning approaches for university science education.

4.2.2 Connectivist learning

Connectivist learning approaches featured in six of the selected studies. These approaches emphasise learning through networks mediated by technology (Siemens 2004). Learners use their devices to connect with others within these networks to engage with learning resources and to seek knowledge and information. For example, students used the Chirality-2 mobile app to learn chemistry together in classrooms and at home via game playing (Jones, Spichkova, and Spencer 2018). In the Fonseca, Zacarias, and Figueiredo (2021) study, the use of MILAGE LEARN+ app connected teachers and students together for peer review purposes, and to support other interactions using features such as the chat function. Networked learning was also evident in the three studies that examined students' use of social media to support students' interactions with teachers and peers (Bidarra and Sousa 2020; Escamilla-Fajardo, Alguacil, and López-Carril 2021; Lackovic et al. 2017). For example, in the Escamilla-Fajardo, Alguacil, and López-Carril (2021) study, the use of TikTok was shown to foster students' creativity and develop their knowledge of course content.

4.2.3 Inquiry-based learning

Inquiry-based pedagogies were also a strong theme, but with an unexpected focus on teacher-controlled, *structured inquiry* (Banchi and Bell 2008). Inquiry-based learning (IBL) approaches have been used widely in science education to support students working actively to investigate key questions, test hypotheses and solve problems (Pedaste et al. 2012), and to develop competencies such as experiment design and observation skills (Lazonder and Harmsen 2016). However, there were no studies in this SLR focusing on the use of mobile devices to support more autonomous *open inquiry,* where students enjoy more agency, for example, posing their own investigation questions and procedures (Banchi and Bell 2008). Students engaging in structured inquiry in this SLR were typically provided with teacher-led instructions and questions, before finding solutions through the use of apps on their mobile devices (Chen, Xin, and Chen 2017; Jeno, Dettweiler, and Grytnes 2020; Jeno, Grytnes, and Vandvik 2017; Roman, Delgado, and García-Morales 2021; Thomas and Fellowes 2017; Wang et al. 2020). For example, using a structured inquiry-based approach, visitors to a science museum explored the "Hand Battery" exhibition with the use of iBeacon context-aware technology on their mobile devices to guide them through different learning activities (Chen, Xin, and Chen 2017).

There was a noteworthy crossover of studies using inquiry-based and field-based pedagogical approaches. Students in these studies used mobile technologies in outdoor environments to investigate and learn about plant ecology (Wang et al. 2020), to identify plant species in a biology course (Jeno, Dettweiler, and Grytnes 2020; Jeno, Grytnes, and Vandvik 2017) and to identify bird species in field-based sessions (Thomas and Fellowes 2017). Students used their mobile devices to synthesise information and knowledge to identify unknown species in the natural outdoor environment. However, given the portable nature of mobile devices, there was an unexpected shortage of field-based pedagogies in the data.

4.3 Adopted methodologies and outcomes

4.3.1 Emphasis on quantitative designs

There was a paucity of qualitative designs, with only one paper (Lee et al. 2021) in this category, as shown in Table 6. The large majority of selected studies (67%) adopted quantitative study designs, followed by mixed method studies (29%), to generate insights into m-learning in university science education. Thirty-three percent of these studies included a control group in their investigations to test the effects on m-learning interventions, compared to traditional teaching and learning approaches (Fonseca, Zacarias, and Figueiredo 2021; Gebru, Phelps, and Wulfsberg 2012; Jeno, Dettweiler, and Grytnes 2020; Jeno, Grytnes, and Vandvik 2017; Roman, Delgado, and García-Morales 2021; Thomas and Fellowes 2017; Wang et al. 2020; Wang, Chen, and Zhang 2015). For example, Thomas and Fellowes (2017) found that student participants felt optimistic about their use of apps to offer greater portability and accessibility to information, even though there was no difference between groups using traditional books and mobile apps to identify bird species.

Insert Table 6 about here

4.3.2 Accentuation of positive outcomes

All but one of the final set of 24 studies provided evidence that the use of mobile technologies had a positive impact on students' learning experiences, with only one study (Lackovic et al. 2017) reporting on negative outcomes. For example, Chen, Xin and Chen (2017) showed that visitors in the m-learning group and traditional group accomplished relatively similar learning performances in a museum setting. However, visitors in the m-learning group stayed for a significantly longer time and had more frequent interactions with the museum artefacts. The only negative outcome was reported by Lackovic et al. (2017), with respect to students' perception of using Twitter for academic purposes. These researchers found that students needed their tutors' ongoing support and guidance in building a Twitter 'learning habit' to support their science learning and community participation.

5. Discussion

This SLR study draws on the synthesis of relevant, high quality research studies over the past decade to provide fresh insights into m-learning practices in university science education, as well as contemporary trends in research designs.

5.1 M-learning practices in university science education

The most commonly studied settings in the selected studies were teacher-imposed formal spaces, such as traditional science lecture theatres, tutorial and laboratory classrooms. A similar emphasis on formal, schteeduled contexts has been identified in other m-learning reviews at school (Bano et al. 2018) and higher education levels (Crompton and Burke 2018). This SLR revealed a low frequency of m-learning studies of more student-controlled, informal contexts in science higher education. Given the commonly espoused rhetoric of portability, ease of access and ubiquity of mobile devices, there is evidently a need for university science education researchers to expand their investigations of m-learning approaches beyond traditional classroom settings, to include more informal, learner-generated contexts. Similarly, there was a lack of student agency evident in the selection of educational apps. More research is needed to explore ways of increasing university learners' agency and control over their choice of apps to learn science.

Given the well-established links between passive learning and traditional, didactic approaches in science education (e.g. see Schneider and Renner 1980), there was a surprisingly high proportion (25%) of papers focusing on teacher-directed, instructionist m-learning approaches (see Table 5). This trend contrasts with the results of similar SLRs in school-based contexts (e.g., Bano et al. 2018) that revealed far less emphasis on didactic approaches. The trend may be aligned with the tendency for university science educators to favour a conventional lecturing style of teaching (Stains et al. 2018). It may also be influenced by the proliferation of education apps available in app repositories with designs that have underpinning assumptions of learning through drill and practice (Liu et al. 2020).

Nevertheless, the approach that was most emphasised in the selected studies was mobile-technology-supported collaborative learning, a well-reported and distinctive mobile digital pedagogy (Kearney et al. 2012). This emphasis on student collaboration is a similar finding to other m-learning SLRs (see Table 1). The use of mobile technologies is evidently connecting university science learners to peer learning opportunities and new possibilities in the science community. Students are using their devices and associated apps to mediate face-to-face and online interactions and for enhancing peer learning and groupwork in their science activities. This is a positive trend, given the expansive evidence-base around the benefits of mobile technology-enhanced peer learning (e.g. Kearney et al. 2012; Kirkwood and Price 2014). A related and emerging area of research identified in this SLR is the adoption of networked (or connectivist) science learning approaches to support students' interactions with the science community and resources. Further studies are needed to explore the potential of connectivist m-learning approaches, such as the use of social media apps for science teaching and learning, and to provide guidance to university science educators and their students.

Inquiry-based m-learning approaches were emphasised in the SLR, though typically these were teacher-controlled and structured. This trend was somewhat unexpected, given the well documented benefits of more student-controlled *open inquiry* in science education, whereby learners enjoy high degrees of agency (Banchi and Bell 2008). This SLR result again contrasts with school science m-learning studies where there is a greater emphasis on guided and open inquiry (Liu et al. 2020). It was also surprising that other student-centred, contemporary approaches such as problem- and field-based learning, did not feature more strongly in the selected studies of this SLR, given the similarly positive research around these approaches in science education (e.g., Akçay 2009; Kamarainen et al. 2013). Further studies are needed to explore in more detail how contemporary pedagogical approaches are adopted in the various science sub-disciplines such as geology and physics education.

This m-learning SLR uncovers a concerning gulf between contemporary digital pedagogies adopted in university and school level science education. It is recommended that future m-learning research in university science education focuses less on traditional transmissive pedagogies that are known to be less effective for student engagement and learning, and more on the examination of participative digital approaches such as technology mediated open inquiry and field-based pedagogies that foster science students' agency and learning (Banchi and Bell 2008).

From a socio-cultural perspective, the findings highlight the use of mobile devices to support peer collaboration in university science education. However, given the broader commentary espousing the benefits of mobile digital pedagogies for authentic and personalised learning (e.g. Kearney et al. 2012), there was surprisingly limited emphasis on rich contextualised and individually tailored science learning. These areas need to be the focus of future educational technology studies in university science education. Additionally, given students' experience of mobile digital pedagogies can be affected by how they utilise an increasing range of m-learning contexts (Kearney, Burden, and Schuck 2020a), it is important for researchers to move beyond the previously mentioned emphasis on formal spaces and schedules to investigate a wider variety of science learning environments.

5.2 M-learning study designs in university science education

Studies under scrutiny in this SLR mostly adopted quantitative methods in their designs, with only one study adopting qualitative methods. This trend again sharply contrasts with m-learning research in school science education, where the majority of studies are qualitative in nature (Bano et al. 2018). There is clearly a need for more qualitative m-learning studies in university science education, to explore related phenomena at a more nuanced, 'thick descriptive' (Lincoln and Guba 1985) level, exploiting multiple data sources and leading to deeper insights (Creswell and Creswell 2018).

Another noticeable trend in this SLR was the number of studies that collected views from both teacher and student participants (seven studies by Baldock et al. (2021), Chang, Chen and Chang (2016), Ernst, Harrison, and Griffin (2013), Lee et al. (2021), Powel and Mason (2013), Wang et al. (2020) and Wang, Chen and Zhang (2015) used both of these participant types). To effectively examine m-learning and provide multiple perspectives on experiences, it is important to elicit students' views (Burke et al. 2021) to triangulate with data elicited from other stakeholders such as teachers. It is therefore important for future qualitative m-learning studies in university science education to consider the views of multiple participants, including teachers and students.

Finally, the dominance of positive outcomes from the m-learning studies analysed in this SLR is a trend that has been identified in other m-learning reviews across a range of educational levels and disciplines (Alrasheedi, Capretz, and Raza 2015; Crompton and Burke 2018; Crompton et al. 2016; Kaliisa and Picard 2017). Although this trend suggests numerous benefits of using mobile technologies for teaching and learning science at universities, it also highlights the need for further research to provide more balanced critique and exploration of potential barriers and constraints. Increased adoption of qualitative studies, including studies privileging multiple stakeholder voices will assist in this endeavour.

5.3 Limitations

Although we have followed a rigorous search and selection strategy using the PRISMA guidelines for our systematic review, there is a small chance of not including all relevant papers in our data collection process. Only electronic resources in English were selected from a number of online databases, as suggested from previous SLR authors. Hence, there could be some papers in other languages and databases, not included in our search results. Future review studies could also expand their scope by including doctoral theses and peer-reviewed scholarly conference proceedings.

6. Conclusion

This review offers insights for practitioners and researchers into contemporary m-learning trends emerging from a robust synthesis of carefully selected studies conducted from 2011 to 2021 in university science education. Unlike other m-learning SLRs in the past decade, this study focuses exclusively on university science education contexts. Disparities between m-learning trends in school and university science education were identified, most notably with respect to adopted pedagogies. Findings emerged from an analysis of predominantly quantitative studies that highlighted the benefits of using mobile devices to support collaborative and networked learning, and teacher-controlled inquiry-based approaches for university science students’ learning. However, there was a surprising emphasis on teacher-imposed formal university settings and schedules, and the use of mobile devices to support traditional teacher-directed, instructionist pedagogies. It is imperative that future m-learning research in this area focuses more on socio-cultural approaches driven by student agency, including use of rich and varied learner-generated contexts and self-paced, participative approaches such as open inquiry. More qualitative research is needed to provide deeper insights into mobile technology-mediated teaching and learning in university science education, especially studies drawing on multiple perspectives.

Data Availability Statement:

The data in the findings of this study is available from the corresponding author with reasonable request.

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Appendix

Appendix: The list of 24 selected papers in this SLR

Study IDs	Citations
S1	Powell, Cynthia B., and Diana S. Mason. 2013. "Effectiveness of podcasts delivered on mobile devices as a support for student learning during general chemistry laboratories." *Journal of Science Education and Technology* 22 (2):148-70. doi: 10.1007/s10956-012-9383-y.
S2	Winter, Julia, Michael Wentzel, and Sonia Ahluwalia. 2016. "Chairs!: A mobile game for organic chemistry students to learn the ring flip of cyclohexane." *Journal of Chemical Education* 93 (9):1657-9. doi: 10.1021/acs.jchemed.5b00872.
S3	Jones, Oliver A. H., Maria Spichkova, and Michelle J. S. Spencer. 2018. "Chirality-2: Development of a multilevel mobile gaming app to support the teaching of introductory undergraduate-level organic chemistry." *Journal of Chemical Education* 95 (7):1216-20. doi: 10.1021/acs.jchemed.7b00856.
S4	Tan, Emelyn Sue Qing, and Yuen Jien Soo. 2017. "Creating apps: A non-IT educator's journey within a higher education landscape." In *Mobile Learning in Higher Education in the Asia-Pacific Region. Education in the Asia-Pacific Region: Issues, Concerns and Prospects*, edited by Angela Murphy, Helen Farley and Laurel Evelyn Dyson, 213-38. Springer Singapore.

S5	Wang, Chih-Chiang, Chia-Lun Lo, Ming-Ching Hsu, Chih-Yung Tsai, and Chun-Ming Tsai. 2020. "Implementation a context-aware plant ecology mobile learning system." *SAGE Open* 10 (2). doi: 10.1177/2158244020920701.
S6	Escamilla-Fajardo, Paloma, Mario Alguacil, and Samuel López-Carril. 2021. "Incorporating TikTok in higher education: Pedagogical perspectives from a corporal expression sport sciences course." *Journal of Hospitality, Leisure, Sport and Tourism Education* 28. doi: 10.1016/j.jhlste.2021.100302.
S7	Chen, Guang, Youlong Xin, and Nian-Shing Chen. 2017. "Informal learning in science museum: development and evaluation of a mobile exhibit label system with iBeacon technology." *Educational Technology Research and Development* 65 (3):719-41. doi: 10.1007/s11423-016-9506-x.
S8	Laurens Arredondo, Luis A., and Hugo Valdés Riquelme. 2021. "M-learning adapted to the ARCS model of motivation and applied to a kinematics course." *Computer Applications in Engineering Education*. doi: 10.1002/cae.22443.
S9	Fonseca, Custódia S. C., Marielba Zacarias, and Mauro Figueiredo. 2021. "MILAGE LEARN+: A mobile learning app to aid the students in the study of organic chemistry." *Journal of Chemical Education* 98 (3):1017-23. doi: 10.1021/acs.jchemed.0c01313.
S10	Roman, Claudia, Miguel A. Delgado, and Moisés García-Morales. 2021. "Socrative, a powerful digital tool for enriching the teaching–learning process and promoting interactive learning in Chemistry and Chemical Engineering studies." *Computer Applications in Engineering Education* 29 (6). doi: 10.1002/cae.22408.
S11	Jeno, Lucas M., Ulrich Dettweiler, and John Arvid Grytnes. 2020. "The effects of a goal-framing and need-supportive app on undergraduates' intentions, effort, and achievement in mobile science learning." *Computers and Education* 159. doi: 10.1016/j.compedu.2020.104022.
S12	Gebru, Misganaw T., Amy J. Phelps, and Gary Wulfsberg. 2012. "Effect of clickers versus online homework on students' long-term retention of general chemistry course material." *Chemistry Education Research and Practice* 13 (3):325-9. doi: 10.1039/c2rp20033c.
S13	Baldock, Brandi L., Anthony L. Fernandez, Jimmy Franco, Brian A. Provencher, and Mark R. McCoy. 2021. "Overcoming the challenges of remote instruction: Using mobile technology to promote active learning." *Journal of Chemical Education* 98 (3):833-42. doi: 10.1021/acs.jchemed.0c00992.
S14	Bidarra, José, and Nuno Sousa. 2020. "Implementing mobile learning within personal learning environments: A study of two online courses." *International review of*

	research in open and distance learning 21 (4):181-. doi: 10.19173/irrodl.v21i4.4891.
S15	Chakraborty, Tandra R., and Deborah F. Cooperstein. 2018. "Exploring anatomy and physiology using iPad applications." *Anatomical Sciences Education* 11 (4):336-45. doi: 10.1002/ase.1747.
S16	Lee, Chwee Beng, Jose Hanham, Kamali Kannangara, and Jing Qi. 2021. "Exploring user experience of digital pen and tablet technology for learning chemistry: applying an activity theory lens." *Heliyon* 7 (1). doi: 10.1016/j.heliyon.2021.e06020.
S17	Chang, Chun-Yen, Chia-Li Debra Chen, and Yueh-Hsia Chang. 2016. "Smart Classroom 2.0 for the Next Generation of Science Learning in Taiwan." In *State-of-the-Art and Future Directions of Smart Learning*, edited by Yanyan Li, Maiga Chang, Milos Kravcik, Elvira Popescu, Ronghuai Huang, Kinshuk and Nian-Shing Chen, 61-7. Springer Singapore.
S18	Fernandez, Anthony L. 2020. "Using iPads and Apple pencils to enhance the student learning experience in inorganic chemistry." In *Advances in Teaching Inorganic Chemistry Volume 2: Laboratory Enrichment and Faculty Community*, 7-79. American Chemical Society.
S19	Jeno, Lucas M., John Arvid Grytnes, and Vigdis Vandvik. 2017. "The effect of a mobile-application tool on biology students' motivation and achievement in species identification: A self-determination theory perspective." *Computers and Education* 107:1-12. doi: 10.1016/j.compedu.2016.12.011.
S20	Lackovic, Natasa, Roger Kerry, Rachael Lowe, and Tony Lowe. 2017. "Being knowledge, power and profession subordinates: Students' perceptions of Twitter for learning." *Internet and Higher Education* 33:41-8. doi: 10.1016/j.iheduc.2016.12.002.
S21	Wang, Shu-Lin, Chia-Chen Chen, and Zhe George Zhang. 2015. "A context-aware knowledge map to support ubiquitous learning activities for a u-Botanical museum." *Australasian Journal of Educational Technology* 31(4). doi: 10.14742/ajet.1205.
S22	Morris, N. P., J. Lambe, J. Ciccone, and B. Swinnerton. 2016. "Mobile technology: students perceived benefits of apps for learning neuroanatomy." *Journal of Computer Assisted Learning* 32(5):430-42. doi: 10.1111/jcal.12144.
S23	Thomas, Rebecca L., and Mark D. E. Fellowes. 2017. "Effectiveness of mobile apps in teaching field-based identification skills." *Journal of Biological Education* 51 (2):136-43. doi: 10.1080/00219266.2016.1177573.
S24	Ernst, Hardy, John Harrison, and David Griffin. 2013. "Anywhere, anytime, with any device: scenario-based mobile learning in biomedical sciences." *International*

	Journal of Mobile Learning and Organisation 7 (2):99-112. doi: 10.1504/IJMLO.2013.055617.

List of tables

Table 1: Summary of existing systematic reviews on mobile learning across different educational levels and disciplines (including science)

Educational levels	Disciplines	Citation	Timeline	Number of studies
Higher education (HE)	any disciplines	(Sophonhiranrak 2021)	2006-2018	78
	any disciplines	(Crompton and Burke 2018)	2010-2016	72
	did not mention disciplines	(Kaliisa and Picard 2017)	2010-2016	31
	any disciplines	(Krull and Duart 2017)	2011-2015	233
	any disciplines	(Pimmer, Mateescu, and Gröhbiel 2016)	2000-2013	36
	did not mention disciplines	(Alrasheedi, Capretz, and Raza 2015)	2005-2013	30
School levels	any disciplines	(Crompton and Burke 2020)	2014-2019	186
		(Burden et al. 2019)	2010-2017	57
		(Crompton, Burke, and Lin 2019)	2010-2016	101
		(Crompton , Burke and Gregory 2017)	2010-2015	113
		(Liu et al. 2014)	2007-2014	63
	science and math	(Bano et al. 2018)	2003-2016	49
	science (inquiry-based learning)	(Liu et al. 2020)	2000-2019	31
All educational levels	any disciplines	(Pishtari et al. 2020)	2008-2019	54
		(Lai 2020)	2000-2016	100
		(Fu and Hwang 2018)	2007-2016	90
		(Suárez et al. 2018)	2006-2016	62
		(Chee et al. 2017)	2010-2015	144
		(Sung, Chang, and Liu 2016)	1993-2013	110
		(Hwang and Wu 2014)	2008-2012	214
	STEM (game-based learning)	(Gao, Li, and Sun 2020)	2010-2019	30
	science	(Crompton et al. 2016)	2000-2015	49
		(Zydney and Warner 2016)	2007-2014	37

Table 2: Major and minor search terms

Mobile learning	Science	University
mlearning	science*	universit*
m-learning	astronomy	college
mobile pedagogy	biology	higher education
mobile technology	chemistry	post-secondary
context aware	geology	tertiary education
seamless learning	physics	
mobile technology enhanced teaching		
mobile technology enhanced learning		
mobile technology supported teaching		
mobile technology supported learning		
mobile technology enabled teaching		
mobile technology enabled learning		
mobile technology mediated teaching		
mobile technology mediated learning		

Table 3: Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
• Published between Jan 2011 and Dec 2021 • Student use of mobile devices for learning science • Science education at university • Peer-reviewed journal articles or book chapters • In the top two quartiles of Scimago journal rankings • Rigorous, empirical research methodology • Must be in English language	• PhD dissertations • Conference papers • School level • Teacher education

Table 4: Frequency of settings

Settings	Frequency	Study IDs
Formal (37.5%)	9	S1, S2, S8, S9, S10, S15, S16, S17, S22
Semi formal (17%)	4	S5, S11, S19, S23
Informal (12.5%)	3	S7, S13, S14
Multiple (33%)	8	S3, S4, S6, S12, S18, S20, S21, S24

Table 5: Pedagogical approaches (as reported or inferred in the selected studies)

Pedagogical approaches supporting:	Frequency	Study IDs
Collaborative learning	11	S1, S2, S6, S9, S11, S13, S15, S16, S18, S22, S23
Inquiry-based learning	8	S1 (structured, guided inquiry); S5, S7, S10, S11, S19, S23 (structured); S8 (guided).
Connectivist learning	6	S3, S6, S9, S13, S14, S20
Instructionist learning	6	S6, S10, S16, S17, S18, S20
Context-aware/ubiquitous learning	5	S4, S5, S7, S14, S21
Problem-based learning	4	S8, S21, S22, S24
Field-based learning	4	S5, S11, S19, S23
Flipped learning	4	S2, S8, S13, S24
Blended learning	2	S9, S22
Constructivist learning	1	S12

Table 6: Study designs

Research Designs		Study IDs
Qualitative (4%)	Exploratory case study	S16
Quantitative (67%)	Experimental	S5, S11, S19, S21
	Quasi-experimental	S12
	Questionnaires	S2, S3, S8, S9, S10, S14, S23
	Survey	S4, S15, S18, S22
Mixed method (29%)		S1, S6, S7, S13, S17, S20, S24

Figure 1

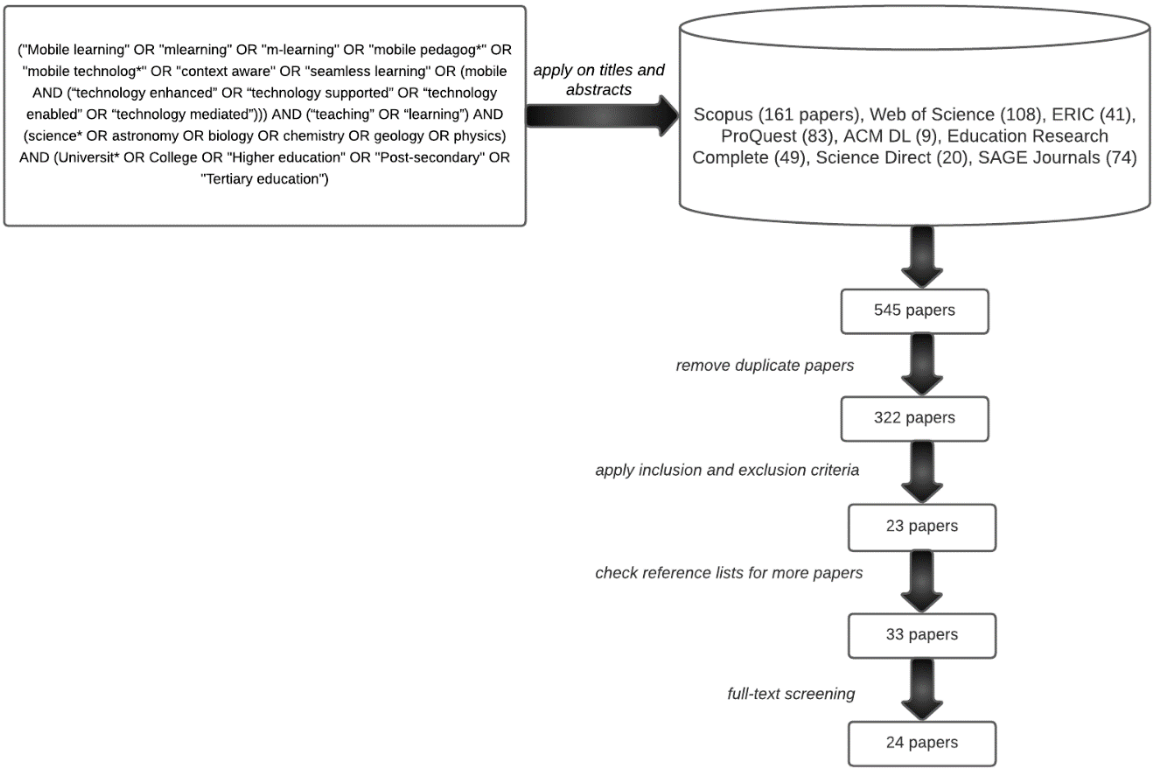

Figure 1. Search and selection process in this SLR.