The Impact of Mobile Learning on Undergraduate Students' Cognitive Learning Outcomes: A Meta-Analytic Review

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Abstract—The objective of this research was to identify the overall effectiveness of mobile-based interventions on the learning performance of tertiary education students. Besides, the paper sought to contour common variables across eligible studies that might have favoured learning achievement. A meta-analysis of the impacts of ubiquitous learning interventions on academic outcomes over 12 years (2010–2021) was carried out, in which 12 experimental and quasi-experimental studies were analysed. A random-effects model yielded the overall standardised mean difference of .52 [.37 to .67] in favour of mobile learning environment, which is a moderate effect size. Common facilitators of achievement as distinguished by experimenters and participants were commendable multimedia design, diversified content, the opportunity for relevant interaction with teachers and peers, as well as flexibility and accessibility of learning activities due to handheld devices. These findings suggest the potential of mobile-assisted interventions in contributing to student educational outcomes. This study summarises the extant literature to some degree thus advancing the investigation into the effectiveness and expediency of mobile technologies in higher education.

Keywords—higher education, learning performance, ubiquitous learning

1 Introduction

1.1 Background

Mobile information and communication technologies are now widespread internationally [1]. In many countries of the world, the majority of the population uses portable computers and/or cell phones with wireless Internet access. This is viewed ambivalently with regard to teaching and learning. The flexibly usable mobile devices are seen as an opportunity to update teaching and learning models, which is referred to as mobile learning (m-learning) or ubiquitous learning [2]. This term should be defined not only from the point of applying portable devices. Rather, individual and personal interests are at the centre of what is happening [3]. Learning is then an omnipresent process that takes place both informally and formally in various contexts [4], including virtual activities [5]. This conforms the new realities in education that imply attention shift towards distance learning modalities [6].

Tertiary education graduates are usually supposed to address challenges systematically, as well as demonstrate critical thinking and creativity. Perhaps the conventional instructional approach may not be a really adequate remedy for bolstering those crucial thinking skills. Given the meteoric rise to the ubiquity of information technology [7], the establishment of enabling environment for developing practical skills and simulating real work experiences is a pressing concern [8]. Since the use of personal electronic devices has been growing globally, attempts to escalate their implementation for pedagogical purposes is a logical consequence. It is believed that mobile learning may make learning individualised due to its adaptability to the capacities and preferences of students [9]. More importantly, mobile technology is considered a tool allowing learners to explore and afford collaboration, which is inestimable since a number of investigations have proven that boosting collaboration and effective regulation can lead to diversified learning and improved learning performance in parallel with enhanced skills improving students' employability [10]. As a developing learning frame, ubiquitous education allows for a more expanded learning environment. Results of a research [11] demonstrate that a friendly and productive learning space constituted by m-learning renders positive effects on individuals' readiness to utilise it.

Having carried out a scoping review based on relevant literature, Pimmer and co-authors [12] concluded that most ubiquitous learning interventions employ instructionist approaches and thus can hardly be deemed transformative, but it does not preclude the agenda to promote mobile learning in order to enrich and extend more traditional forms of tertiary education.

1.2 Research relevance

International research on mobile learning started around the year 2000. Since then, the number of publications on mobile learning has been growing year by year. Diverse research syntheses exist, in the form of handbooks, systematic reviews, and meta-analyses. When considered separately, multiple studies point to promising effectiveness of various ubiquitous learning experiences in higher education contexts [13]. However, there is actually no plethora of researchers' efforts to quantify the weighted average effectiveness of integrating today's ubiquitous technologies with varying educational practices in higher education settings. Yet, those reviews that the literature identifies were conducted five years ago and more (e.g., [14]), probe into the relationship between cell phone usage for non-educational purposes and student academic achievement (e.g., [15]), target a particular domain such as nursing education (e.g., [16]), or represent descriptive analysis rather than meta-analysis (e.g., [17]). Despite Talan [18] undertook a scrupulous meta-analytic review, it relies on grey literature predominantly, while the rest sources do not meet the criteria of eligibility designated in the present paper.

1.3 Research goal

To fill the gap specified above, this meta-analysis aims to identify the overall effectiveness of mobile-based interventions on cognitive domain learning outcomes of tertiary education students by synthesizing empirical data from relevant experimental and quasi-experimental studies published over the past twelve years. In addition, the research attempts to contour common variables across eligible studies that might have favoured learning achievement.

2 Methods

2.1 Eligibility

To be included in the present meta-analysis, studies had to:

1) Be published as a journal article in a peer-reviewed prestigious professional scientific journal between 2010 (since mobile technology adequate for ubiquitous learning merely could be applied earlier) and 2022.
2) Clearly state tertiary education students as the target population.
3) Use a quasi-experimental or experimental research design to compare an m-learning intervention to a non-ubiquitous one. Papers juxtaposing different mobile learning regimens employed in both treatment and control groups (such as [2]) were excluded from the analysis.
4) Involve methodologically sound empirical research evaluating the effects of various handheld devices adoption for facilitating learning. Actually ubiquitous activities (*id est*, those in line with the paradigm of anytime and anywhere learning) were considered rather than those used in specific settings as in the case of iPod Touches handed out to students in the classroom [19] or an electronic medical record application which students could access at patients' bedsides only and no other way but through the local network [20]. In this manner, studies involving podcasting of lectures had to be excluded as it would be hard to infer that learning took place in a really ubiquitous manner. For instance, in the research [21] the authors report that as few as 20% of the participants listened to educational podcasts via mobile devices while the remainder utilised computers. For the same reason, studies implementing educational platforms accessible through such electronic devices like a personal computer (e.g., [22]) were deemed ineligible.
5) Report students' cognitive learning outcomes gauged by standardised or researcher-designed instruments (not self-reported).
6) Report the data required for calculating an effect size (Hedge's g), namely means, standard deviations, and the number of subjects in each group.
7) Be written in English.

2.2 Literature search and selection

To identify papers relevant for inclusion in the analysis, the literature search was undertaken over the period from November 2021 to January 2022, by inspecting titles and abstracts of the papers. For search terms, 'students' and 'learners' were defined as subjects, 'mobile,' 'handheld,' 'ubiquitous,' 'smartphone,' and 'm-learning' as intervention, whereas keywords related to intervention effect were 'learning outcome,' 'achievement,' and 'performance.' Combinations of the terms were applied in ScienceDirect, Pubmed, Australian Education Index, and Google Scholar databases. The search for grey literature was carried out through ProQuest and EASY, but no records meeting the inclusion criteria were found. On top of that, the reference lists of relevant systematic reviews on the topic were screened. In the retrieval process, 226 records were collected. Following the assessment of full-text documents for eligibility, 12 papers with a total sample size of 1,176 and the publication date from 2015 to 2021 satisfied the inclusion criteria.

2.3 Data analysis

This meta-analysis was conducted through R programming environment using a random-effects model, which was chosen to minimize Type I error occurrence and pick up the generalisability of results from this investigation [23]. A pooled standardised mean difference (SMD) was estimated using each study post-test value, as well as corresponding standard deviation and group size. SMD is a summary statistic to explore the same outcome measured differently in a variety of studies. If a study reported more than one outcome measure related to learning performance, then an average score was computed. The magnitude of heterogeneity between studies was examined by means of I^2 classified as low if $25 \leq I^2 < 50\%$ and high if $I^2 \geq 75\%$. A trim-and-fill funnel plot was operated as a publication bias tool to detect missing publications. Study design was assessed as a potential construct moderating the effect size results.

3 Results

Of the included studies, four were carried out in Taiwan [24]–[27], three in South Korea [28]–[30], one in Norway [31], one in Nigeria [32], one in Hong Kong [33], one in Thailand [34] and one in China [35]. Six research projects [25], [26], [29], [31], [34], [35] were experimental in nature, whereas the other six [24], [27], [28], [30], [32], [33] had a pre-post-test design. The intervention time interval ranged from one week to six months and was not mentioned in two of the studies.

The forest plot depicted in Figure 1 indicates that m-learning interventions could contribute to better learning achievement as compared to conventional learning activities, with the overall effect size being medium in accordance with Cohen's rule of thumb (SMD = .52). This effect size was statistically significant at $p < .01$, so the null hypothesis that the true effect size is identical in all of the selected studies can be rejected.

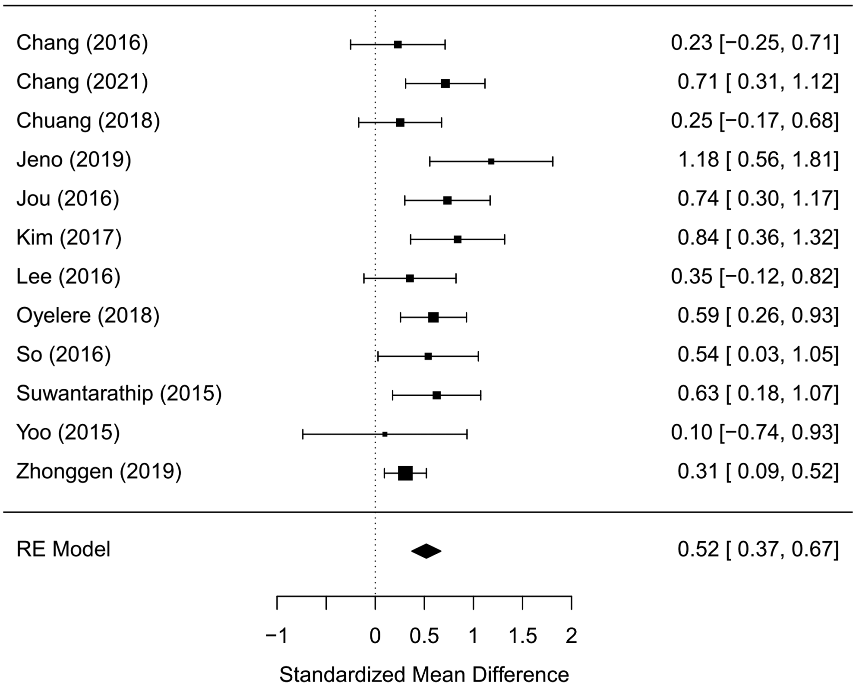

Fig. 1. Forest plot showing individual and overall effect sizes of mobile learning interventions

The I^2 is equal to 29.25%, which suggests a low level of heterogeneity and may inform us that the proportion of the observed variance is likely to account for sampling error rather than differences in the effect sizes [36]. Further, there were no missing studies as can be judged from Figure 2, since no open circles can be observed on the right side of the funnel plot. Therefore, it is safe to claim the lack of publication bias in these data.

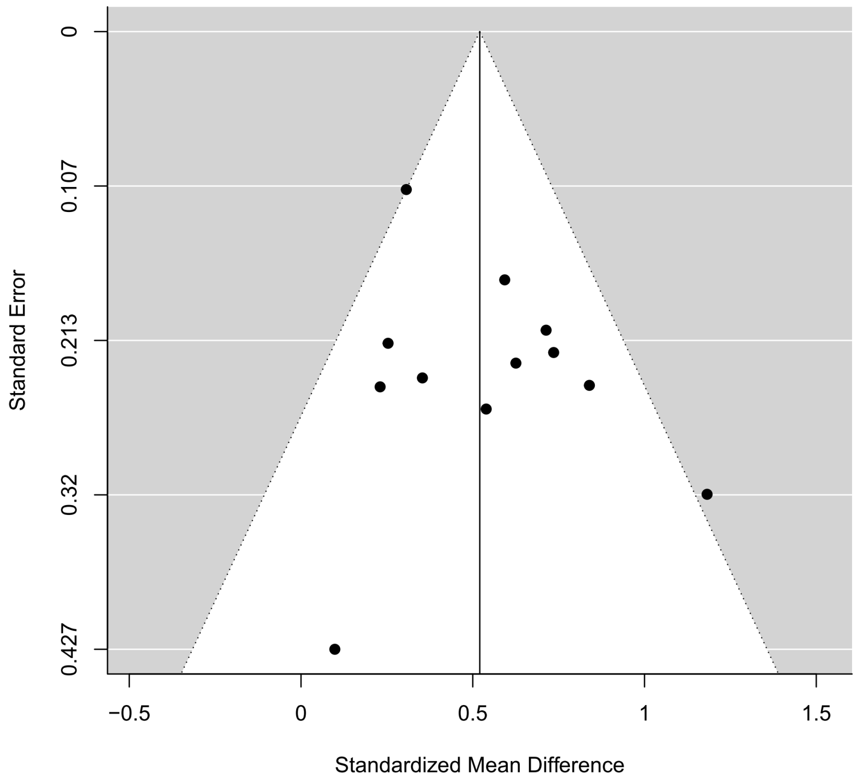

Fig. 2. Results of a publication bias analysis using the funnel plot

As regards moderators (i.e., study features), the categorical moderator analysis showed that the pooled effect size of mobile learning interventions on learning performance is .50 for experimental studies and .56 for non-randomised ones. These effects are insignificant (> .05), which tells us that student learning performance is not moderated by study design. However, it does not seem advisable to rely entirely on this evidence taking into account the small number of included studies and no need to explore possible moderators due to low heterogeneity.

4 Discussion

Given that the moderator analysis yielded no meaningful results, looking at individual studies included in this review could bring about a better understanding of the reasons why the mobile learning projects were fruitful or not. Chang and co-authors [24] evaluated the use of mobile inquiry-based learning centred on a field-trip activity designed to advance students' English and help them delve into some topics pertaining to the Taiwan Confucius Temple. Although participants that utilised mobile devices in this inquiry-based learning to scan QR-codes and so forth eventually showed better scores for a comprehension test, the difference was not statistically significant.

The research team maintains that the failure was caused by the short duration of the experiment as six weeks are not enough for the learning task.

Another research team [25] introduced a simulation-based mobile learning application developed for nursing students to enable them to obtain certain nursing skills and gain corresponding knowledge. At the end of the study, m-learning students' focal knowledge and performance were found to be significantly superior to those of controls involved in a traditional simulation-based paper learning. The authors argue that their simulation application provided a conceptual link from theory to a virtual clinical setting so that participants could transform the learned content into a nursing practice, which contributes to the effectiveness obtained, along with the fact that certain tasks were allocated to scenes available in the app thus encouraging students' engagement.

In a research by Chuang et al. [26], nursing students were invited to download a skill demonstration video to their smartphones for watching in order to refine nursing skill competency and confidence. At post-test, participants that had access to the video significantly outperformed their counterparts in terms of urinary catheterization knowledge and skills. The authors explain it by the opportunity for learners to use the material recurrently, which ensured flexibility and better memorization. A similar intervention is reported in [29] with a mobile-based video clip group overscoring standard practice students in terms of nursing competency. According to students' feedback, catalytic elements were loose access and frequency of viewing, visualised learning effect, as well as reduced anxiety concerning making mistakes when performing the skill.

Yoo and Lee [30] compared the learning performance between a group of nursing students that completed practical exercises on heart sound and lung assessment using a human patient simulator and another group doing the same through a special mobile application. Eventually, neither students' basic knowledge of cardiopulmonary assessment nor the clinical lung and heart assessment skills were significantly different between the groups. The authors failed to discover the root causes for these findings and recommended combining the simulation practices.

Jeno and co-authors [31] describe their study in which biology students identified plant species consulting a traditional textbook, its digital version, or a researcher-designed mobile application providing digital pictures and explanations on species' traits. There was a significantly higher learning achievement level in mobile device users when compared to textbook and e-book conditions after the intervention. From the authors' point of view, this stems from the fact that the mobile application could offer pedagogically important visualisations and user-friendliness.

Jou et al. [27] elaborated and experimentally implemented a theme-based mobile learning application that allowed engineering students to go through the synthesis of materials course, make self-assessment via a test item bank, and interact with a virtual expert agent to run experiments on material synthesis. The intervention resulted in significantly higher post-test scores for learners' basic knowledge and skills as opposed to a conventional learning group. The authors believe that the finding is grounded with the application usability.

Kim and co-authors [28] nursing students were requested to utilise a thematic mobile application delivering instructional content pertaining to emergency care for infant airway obstruction. It is reported that ubiquitous program participants' skills and confidence in performance significantly surpassed those of controls upon completion of the experiment. The authors suppose this is due to the opportunity to gain knowledge and skills repeatedly coupled with using familiar technology.

In an attempt to facilitate the learning of computer science courses, Oyelere [32] examined a self-designed mobile learning application among university students. As stated in the paper, mobile education proved to improve students' learning performance significantly relative to non-mobile learners. Post-intervention interviews revealed that apart from the flexibility of usage participants enjoyed enhancement of teamwork by dint of group chat with classmates.

In turn, So [33] investigated the effectiveness of a mobile instant messaging environment. The experimental group participants received some bite-sized learning materials in the form of key points and supporting multimedia through WhatsApp outside classroom hours in order to consolidate the concepts addressed in class. Besides, the teacher used WhatsApp to answer students' queries and post questions trying to encourage the participants to respond. Learners in the control group could employ WhatsApp for administrative support only. After the intervention, the experimental group demonstrated significantly higher learning achievement than subjects with no access to the teacher-student interaction via the web platform. Regarding strengths of the experimental approach, the participants pointed out not only the convenience of handheld devices and WhatsApp for the learning process, but also the fact that the applied mode might evoke productive communication, enable relevant feedback, provide informal and formal learning opportunities, and maintain collaborative learning.

Suwantarathip and Orawiwatnakul [34] found that language course students who performed mobile-assisted (Short Message Service) vocabulary exercises on vocabulary acquisition attained and applied new words significantly better as compared to learners that received in-class paper-based exercises. The authors suggest the outcome is thanks to the possibility for learners to practice and work on vocabulary they had learned.

In a study published by Zhonggen et al. [35], some English as a foreign language learners attained traditional lectures while others installed a mobile learning platform in their smartphone to obtain requisite learning resources. A post-intervention test determined that mobile students' proficiency of English as a foreign language was significantly superior relative to the conventional approach group. Among the merits of the mobile learning system, participants indicated that it could elicit online interaction with peers and teachers, facilitate knowledge distribution, and offer captivating content representing a wide spectrum of English as a foreign language topics easily accessed through smartphones.

On the whole, it should be inferred that mobile learning attributes that could conduce to improvements in tertiary students' learning outcomes are flexibility and accessibility of learning process ensured by handhelds, diversity of quality content, good visualisations, effective feedback, and favourable conditions for collaboration. A short research span has been mentioned as a weak point that would ruin an m-learning program. Notwithstanding, studies with the highest effect sizes herein [28], [31] lasted no more than four weeks. Thus, the results of this review are somewhat in keeping with the findings outlined in the research synthesis undertaken by Sung and co-authors [14] who discovered a moderate (.599) overall effect size of ubiquitous learning environment on college students' learning performance. The authors concluded from the moderator analysis that variables propelling learning achievement are the use of handheld devices, inquiry-oriented learning, informal educational environments, and medium- and short-term interventions. Moreover, a systematic review by Crompton and Burke [17] emphasizes the need to shift research focus towards the assessment of mobile-mediated learning in informal settings.

As for limitations of this review, not only does it observe a small sample of studies, but it also is restricted to English language sources, so it could not represent works published in other languages. Further research in this area is definitely warranted so that a homogenous corpus of research could be pooled and extended moderator analyses could be performed. Nonetheless, this study summarises the extant literature to some degree thus advancing the investigation into the effectiveness and expediency of mobile technologies in post-compulsory education. Also, it highlights how poorly the topic has been investigated despite being often-trumpeted.

5 Conclusions

This study provides a necessary overview of the literature surrounding practice-based research in the field. The results indicated a significant, medium positive effect of implementing mobile learning programs in tertiary education settings on students' learning performance. Common facilitators of achievement as distinguished by experimenters and participants were commendable multimedia design, diversified content, the opportunity for relevant interaction with teachers and peers, as well as flexibility and accessibility of learning activities due to handheld devices. These findings suggest the potential of mobile-based interventions in contributing to student cognitive educational outcomes. However, this meta-analysis also highlights the shortage of robust research conducted in this area as could be judged from the inclusion of only twelve records, which undermines the generalisation of outlined findings. We therefore call on scholars to carry out more rigorous experimental research so that replicating this review on a more cogent body of evidence will be possible.

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