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The effects of integrating mobile devices with teaching and learning on students' learning performance: A meta-analysis and research synthesis

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ABSTRACT

Mobile devices such as laptops, personal digital assistants, and mobile phones have become a learning tool with great potential in both classrooms and outdoor learning. Although there have been qualitative analyses of the use of mobile devices in education, systematic quantitative analyses of the effects of mobile-integrated education are lacking. This study performed a meta-analysis and research synthesis of the effects of integrated mobile devices in teaching and learning, in which 110 experimental and quasiexperimental journal articles published during the period 1993–2013 were coded and analyzed. Overall, there was a moderate mean effect size of 0.523 for the application of mobile devices to education. The effect sizes of moderator variables were analyzed and the advantages and disadvantages of mobile learning in different levels of moderator variables were synthesized based on content analyses of individual studies. The results of this study and their implications for both research and practice are discussed.

1. Introduction

1.1. Integrating mobile devices with learning and instruction

Mobile computers have gradually been introduced into educational contexts over the past 2 decades. Mobile technology has led to most people to carry their own individual small computers that contain exceptional computing power, such as laptops, personal digital assistants (PDAs), tablet personal computers (PCs), cell phones, and e-book readers. This large amount of computing power and portability, combined with the wireless communication and context sensitivity tools, makes one-to-one computing a learning tool of great potential in both traditional classrooms and outdoor informal learning.

With regard to access to computers, large-scale one-to-one computing programs have been implemented in many countries globally (Bebell & O'Dwyer, 2010; Fleischer, 2012; Zucker & Light, 2009), such that elementary- and middle-school students and their teachers have their own mobile devices. In addition, in terms of promoting innovation in education via information technology, not only does mobile computing support traditional lecture-style teaching, but through convenient

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information gathering and sharing it can also promote innovative teaching methods such as cooperative learning (Lan, Sung, & Chang, 2007; Roschelle et al., 2010), exploratory learning outside the classroom (Liu, Lin, Tsai, & Paas, 2012), and game-based learning (Klopfer, Sheldon, Perry, & Chen, 2012). Therefore, mobile technologies have great potential for facilitating more innovative educational methods. Simultaneously, these patterns in educational methods will likely not only help subject content learning, but may also facilitate the development of communication, problem-solving, creativity, and other high-level skills among students (Warschauer, 2007).

However, despite the proposed advantages of using mobile computing devices for increasing computer accessibility, diverse teaching styles, and academic performance, currently researchers found mixed results regarding the effects of mobile-devices (e.g., Warschauer, Zheng, Niiya, Cotten, & Farkas, 2014), and very few studies have addressed how best to use mobile devices, and the effectiveness of doing so.

1.2. Review of the research into integrating mobile devices with teaching and learning

There are seven studies which reviewed the research into integrating mobile devices with teaching and learning and can be divided into two types according to the devices they focused on: (1) those focused on how laptops are used in schools and (2) those focused on the applications of various types of mobile device in education (see Appendix A).

Regarding the review of laptop-based programs, Zucker and Light (2009) believed that school programs integrating laptops into schools have a positive impact on student learning. However, they also believed that laptop use did not achieve the goals of increasing higher-level thinking and transformation of classroom teaching methods. Penuel (2006) reviewed 30 studies that examined the usage of laptops with wireless connectivity in one-to-one computer programs. Those studies found that students most often used the laptops to do homework, take notes, and finish assignments. General-purpose software such as word processors, web browsers, and presentation software were relatively common. Bebell and O'Dwyer (2010) examined four different empirical studies of laptop programs in schools. They discovered that in most schools participating in one-to-one programs there were significant increases in grade-point averages or standardized tests of student achievement, relative to schools that did not provide such programs. In addition, they found that most students used their laptops to write, browse the Internet, make presentations, do homework, or take tests. Furthermore, teachers made more changes to their teaching methods when they had increased opportunities to use laptops. Students participating in one-to-one programs also had a deeper engagement with what they were learning when compared to control groups.

Fleischer (2012) conducted a narrative research review of 18 different empirical studies on the usage of laptops. These studies found a large range in the number of hours that students used laptops, from a few days to as little as 1 h per week. The most frequently used computer functions were searches, followed by expression and communication. In most studies it was found that students had a positive attitude toward laptops, and felt that they were more motivated and engaged in their learning, and it was further believed that teachers conducted more student-centered learning activities. Moreover, considerable differences in classroom educational practices arose from the diversity of teachers' beliefs about the usefulness of laptops. Fleischer (2012) also found several challenges regarding the use of laptops in classrooms, such as encouraging teachers to change their previous beliefs and teaching methods (e.g., teacher-centered lectures) in response to their students' greater flexibility and autonomy; how to reconcile the conflict between the students' desire for independent study and the need for teachers' guidance; and how to facilitate teachers' competence by designing an appropriate curriculum and teaching models for laptop usage programs.

With respect to the research on the use of mobile technology in education, Hwang and Tsai (2011) provided a broad discussion of studies on mobile and ubiquitous learning published in six journals between 2001 and 2010. In their review of 154 articles, they discovered that the use of mobile and ubiquitous learning accelerated markedly during 2008; researchers mostly studied students of higher education, and the fields most often researched were language arts, engineering, and computer technology. Frohberg, Goth, and Schwabe (2009) categorized 102 mobile-learning projects, and discovered that most mobile-learning activities occurred across different settings, and took place within a physical context and an official environment, such as a classroom or workplace. Regarding the pedagogical roles that mobile devices play in education, most research has used mobile devices primarily as a sort of reinforcement tool to stimulate motivation and strengthen engagement, and secondarily as a content-delivery tool. Few projects have used mobile devices to assist with constructive thinking or reflection. Furthermore, most learning activities using mobile devices have been controlled by the teacher, with there being only a handful of learner-centered projects in existence. Concerning the communication functions, very few projects have made any use of cooperative or team communication. Moreover, the vast majority of studies have made use of novice participants; little research has involved experienced participants. When sorted according to educational goals, it was found that the vast majority of research has focused on lower-level knowledge and skills, and ignored higher-level tasks such as analysis and evaluation. Wong and Looi (2011) investigated the influence of mobile devices on seamless learning. Seamless learning refers to a learning model that students can learn whenever they want to learn in a variety of scenarios and that they can switch from one scenario or one context to another easily and quickly (Chan et al., 2006; Wong & Looi, 2011). Wong and Looi (2011) selected and analyzed a sample of 54 articles on the use of mobile devices to facilitate seamless learning, and found that all 54 articles contained 10 features, including formal and informal learning, personalized and social learning, and learning across multiple durations and locations.

1.3. Purposes of this study

While analyzing the overall effectiveness of using mobile devices in education, the review research described above has two major limitations. First, all of the reviews adopted a qualitative approach, which may be able to describe and summarize how related studies were conducted and the problems encountered during their execution, but this makes it difficult to evaluate the effects actually produced by the mobile devices in general and the specific moderator variables. Second, much of the previous review research has focused on the usage of laptop computers as the subject of their investigation (e.g., Penuel, 2006), and most of the research participants in those reviewed articles were in primary and secondary schools. However, the many new developments in mobile hardware have meant that diverse age groups now use different devices. Therefore, many different moderators need to be accounted for when attempting to determine whether or not intervening variables have an effect.

In the context of this background, the primary goal of this study was to perform a meta-analysis and research synthesis of the research on the usage of mobile devices in education published in the last 2 decades. Specifically, the purposes of this study were as follows:

1. To provide an overview of the status of the use of mobile devices in educational experimental studies, including who is using them, which domain subjects are being taught, what kinds of mobile device and software are being used, where such programs take place, how the devices are used in teaching, and the duration of the interventions.
2. To quantify the overall effectiveness of integrating mobile technologies into education on student learning achievement.
3. To determine how the moderator variables influence the effects of mobile devices on learning achievement.
4. To synthesize the advantages and disadvantages of mobile learning in levels of moderator variables based on the content analysis of articles related with moderator variables.

2. Method

2.1. Data sources and search strategy

Journal articles published during the period 1993–2013 were searched electronically and manually, and via reference-list checking to retrieve the relevant literature. For electronic searches, the main databases were the Education Resources Information Center (ERIC) and the Social Sciences Citation Index database of the Institute of Science Index (ISI). Two sets of keywords were searched: (1) mobile-device related keywords, including mobile, wireless, ubiquitous, wearable, portable, handheld, cell phone, personal digital assistant, PDA, palmtop, pad, web pad, tablet PC, tablet computer, laptop, e-book, digital pen, pocket dictionary, and classroom response system; and (2) learning-related keywords, including teaching, learning, training, and lectures. The two sets of keywords were combined when searching the electronic databases. Manual searches included the major journals in educational technology and e-learning, such as the Australian Journal of Educational Technology, British Journal of Educational Technology, Computers & Education, Computer Assisted Language Learning, Educational Technology Research and Development, Journal of Computer Assisted Learning, Language Learning & Technology, and ReCall.

After collating all of the related literature, another round of searches was conducted using the reference lists found in the literature yielded by the electronic search to find any omitted but relevant works.

2.2. Search results

2.2.1. Initial screening

The initial search yielded 4121 abstracts published between 1993 and 2013 (1718 in ERIC and 2403 in ISI) that were related to mobile learning. Two authors read each abstract of the article and judged whether or not the article was related to teaching and learning with a mobile device, which resulted in the selection of 925 articles.

2.2.2. Screening for experimental and quasiexperimental research

In the second stage, the studies were screened according to the research method. Experimental studies (including the pretest-posttest equivalent-group, posttest-only equivalent-groups, and randomized matched subjects and posttest-only control-group designs) and quasi-experimental studies (including the pretest-posttest nonequivalent-groups and counterbalanced designs; see Ary, Jacobs, & Razavieh, 2002; Best & Kahn, 1998, for a reference) were included. Conceptual analysis or research reviews, case studies and qualitative research, survey research, and pre-experimental studies were all excluded at this stage. At the completion of this stage there remained 182 articles.

2.2.3. Application of inclusion and exclusion criteria for the meta-analysis

Studies were eligible for inclusion in the meta-analysis if they conformed with the following three criteria:

1. The application of mobile devices was the key variable of the study. The experimental group had an intervention that used mobile devices, and was compared with a control group that used traditional learning. If both the experimental and control groups used mobile-device interventions, and only the teaching methods were compared, then the study was excluded (e.g., Hsu, Hwang, Chang, & Chang, 2013; Jeong & Hong, 2013; Li, Chen, & Yang, 2013; Ryu & Parsons, 2012).
2. Sufficient information was presented to calculate effect sizes, such as means, standard deviations, t, F, or χ^2 values, or the number of people in each group. Articles in which the sample sizes of each group were not cited, lacked any inferential statistical results, or had inferential statistical results but were still inadequate for calculating an effect size according to Lipsey and Wilson (2000) were excluded (e.g., Gleaves, Walker, & Grey, 2007; Langman & Fies, 2010; Purrazzella & Mechling, 2013; Yang et al., 2013).
3. Experimental results were presented with learning achievement as a major dependent variable measured by standardized or researcher-constructed tests. Studies for which the results were related to affective variables (e.g., learning attitude or learning motivation) or interaction between peers but without learning achievement were excluded (e.g., Jian, Sandnes, Law, Huang, & Huang, 2009; Lan et al., 2007; Mouza, 2008; Siozos, Palaigeorgiou, Triantafyllakos, & Despotakis, 2009).

Application of these criteria yielded 110 articles that were acceptable for inclusion in the meta-analysis. For a complete list of these references, please see our online supplemental archive.

2.3. Selection and coding of the outcome variables

One of the most used framework for representing the research content and dimensions is the activity theory (AT), which uses activity as a unit for analyzing human practices (Bakhurst, 2009). Recently, several researchers have used the AT as a theoretical basis for analyzing mobile learning studies (e.g., Frohberg et al., 2009; Sharples, Taylor, & Vavoula, 2007) or for designing mobile learning scenarios (e.g., Zurita & Nussbaum, 2007). This study used six major components of AT to select moderator variables and analyze mobile learning: (a) Subjects: which involve all the people who may be involved in learning curriculums through mobile devices, such as students of different age levels or teachers of different levels of teaching expertise. (b) Objects (or objectives) of the mobile learning, which focus on the goal such as acquiring cognitive skills or enhancing learning motivation through mobile devices. (c) Tools/instruments in the mobile learning, which may be artifacts (e.g., hardware and software) or learning resources (e.g., tutors). (d) Rules/control for the activity, which are norms or regulations that circumscribe the mobile activities, such as the procedure in teaching scenarios designed for the learning pace or styles designated. (e) Context of the activity, which refers to the physical (e.g., classroom or museum) or social (e.g., ambience of learning in a group) environments for conducting mobile learning. (f) Communication/interaction, which refers to the method of interaction between users and mobile technologies (such as the process teachers' adaption to mobile devices) or the communications styles among learners.

2.3.1. Research name

This refers to the first author's name, the year of publication, and the article title.

2.3.2. Research participants

In this review, for all the reviewed articles, the research participant corresponded to the “subject” of the AT framework, and was coded by their learning stages, including kindergarten, elementary school, middle school, (senior) high school, university, graduate school, teachers, adults, and mixed.

2.3.3. Treatments

The treatments of the reviewed articles corresponded to the “tools” component (e.g., the hardware and software), the “rules/control” component (e.g., the teaching methods and domain subjects), and the “context” component (e.g., intervention settings, intervention duration). The description for each of these treatment variables are as follows:

1. *Hardware*: Different types of mobile hardware, which comprised PDAs, laptops, tablet PCs, cell phones, iPods, MP3 players, e-book readers, pads, digital pens, pocket dictionaries, and classroom response systems (CRSs), or any mixture of thereof.
2. *Software*: Different types of software, which encompassed general-purpose software and learning-oriented software (Sung & Lesgold, 2007), the former referring to commercial software currently in circulation that was not designed especially for teaching and learning (e.g., word processors or spreadsheets), and the latter having been designed specifically for educational programs or goals.
3. *Teaching method*: Different teaching methods, including lectures, cooperative learning (students were divided into groups and completed learning tasks collaboratively, e.g., Chang, Lan, Chang, & Sung, 2010; Huang, Liang, Su, & Chen, 2012), inquiry-oriented learning (using problem-, project-, or inquiry-based methods with mobile devices for learning, e.g., Chen, 2010; Lowther, Ross, & Marrison, 2003), self-directed study (teachers/researchers did not designate or implement specific teaching scenarios for students to follow, students use mobile devices for self-paced learning, e.g., Chen & Li, 2010; Chen,

Tan, & Lo, 2013), computer-assisted testing/assessment (using mobile devices for formative assessment or quizzes in classroom or outdoors, e.g., Agbatogun, 2012), and mixed methods thereof.

4. *Domain subject:* Domain subjects were analyzed to establish the relative effectiveness of mobile devices for teaching different subjects, including language arts, social studies, science, mathematics, multidisciplinary (if the mobile devices were used in several subjects, but measurement of the achievement was presented as a whole instead of separately, this was coded as multidisciplinary), specific abilities (e.g., spatial ability or creativity), health-care programs, education, psychology, and computer and information technology.
5. *Implementation setting:* Implementation settings were included to establish whether the impact of mobile devices on learning differed according to the environment in which they were used, which included classrooms, outdoors (e.g., zoo or campus gardens), museum, laboratory, workplaces, and unrestricted settings (devices may be used anywhere).
6. *Intervention duration*: Different periods of time for the intervention, including periods no more than four hours ($\leq$4 h), between five and 24 h (>4 and $\leq$24 h), between one day and seven days (>1 day and $\leq$7 days), between one week and four weeks (>1 week and $\leq$4 weeks), between one month and six months (>1 month and $\leq$6 months), and more than six months (>6 months).

2.3.4. Dependent variables

The dependent variables corresponded to the "Objective" of the AT model, including two categories: the learning achievement dependent variables refer to measurement of cognitive outcomes such as knowledge application, retention, problem solving…etc. The affective variables refer to measurement of motivation, interest, participation…etc.

2.4. Data analysis

2.4.1. Calculating the effect size

The following meta-analysis steps recommended by Borenstein, Hedges, Higgins, and Rothstein (2009) were employed in this study: (a) determine the effect sizes of each article, (b) determine the weighted mean effect size across articles, (c) calculate the confidence interval for the average effect size, and (d) determine whether the effect size of any particular group was influenced by a moderator variable based on a heterogeneity analysis (Q_B).

Two formulae were used to calculate the effect sizes of the studies. Cohen's *d* formula (Cohen, 1988) was used to determine the effect size for the experimental research with random assignment and without a pretest:

$$d = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{\frac{(n_1-1)s_1^2+(n_2-1)s_2^2}{(n_1+n_2-2)}}} \tag{1}$$

where $\overline{X}_1$ and $\overline{X}_2$ represent the mean scores, n_1 and n_2 represent the sample sizes, and s_1^2 and s_2^2 represent the variances of the experiment and control groups, respectively.

For experimental or quasiexperimental research with pretests, it was proposed that the pretest should be taken into consideration instead of using the posttest in order to mitigate possible selection bias (Furtak, Seidel, Iverson, & Briggs, 2012; Morris, 2008). Hence, the formula developed in Comprehensive Meta Analysis (version 2.0) was used to obtain effect sizes for research with pre- and posttests:

$$ES_{\text{Pre/Post Test Two Groups}} = \frac{\left(\overline{X}_{1\_\text{Post}} - \overline{X}_{1\_\text{Pre}}\right) - \left(\overline{X}_{2\_\text{Post}} - \overline{X}_{2\_\text{Pre}}\right)}{SD_{\text{Post}}} \tag{2}$$

where $\overline{X}_{1\_\text{Pre}}$ and $\overline{X}_{1\_\text{Post}}$ represent the mean scores of the experimental group for the pretest and posttest, respectively, and $\overline{X}_{2\_\text{Pre}}$ and $\overline{X}_{2\_\text{Post}}$ represent the mean scores of the control group for the pretest and posttest, respectively. SD_{Post} can be calculated as follows:

$$SD_{\text{Post}} = \sqrt{\frac{\left(n_{2\_\text{Post}} - 1\right)s^2_{2\_\text{Post}} + \left(n_{1\_\text{Post}} - 1\right)s^2_{1\_\text{Post}}}{\left(n_{2\_\text{Post}} + n_{1\_\text{Post}} - 2\right)}} \tag{3}$$

where n_{1_Post} and n_{2_Post} represent the sample sizes of the experimental and control groups, respectively, for the posttest, while $s^2_{1\_\text{Post}}$ and $s^2_{2\_\text{Post}}$ represent the variances of the experimental and control groups, respectively.

The two types of effect sizes were calibrated using the sample weights to calculate a Hedges' *g* according to

$$g = \left(1 - \frac{3}{4df - 1}\right) \times d \tag{4}$$

2.4.2. Evaluating publication bias

The fail-safe N (i.e., classic fail-safe N) of Rosenthal (1979) was used to estimate how many insignificant effect sizes (unpublished data) would be necessary to reduce the overall effect size to an insignificant level. The comparison criterion was $5n+10$, where n is the number of studies included in the meta-analysis. If the fail-safe N is larger than $5n+10$, it means that the estimated effect size of unpublished research is unlikely to influence the effect size of the meta-analysis. Moreover, the present study also adopted Orwin's fail-safe N (Orwin, 1983) to estimate the number of missing null studies that would be required to bring the mean effect size to a trivial level.

3. Results and discussion

3.1. Descriptive statistics information

Table 1 presents the distribution of moderator variables and their corresponding effect sizes (g). In total there were 110 articles, 419 effect sizes, and 18 749 participants. The largest proportion of studies involved the college-student-level learning stage (38.4%); the next largest group was elementary-school students (33.9%). More studies used learning-oriented software (62.7%) than general-purpose software (34.5%). Handheld devices (including PDA, cell phone, iPod, MP3 player, digital pen, pocket dictionary, and classroom response system) were the most widely studied of the hardware (72.7%), followed by laptops (21.8%, including laptop, pad, tablet PC, and e-book reader). The largest proportion of studies were set in the classroom (50.0%), followed by outdoors (15.5%) and unrestricted settings (16.4%). For teaching methods, self-directed study (30.9%) was the most frequently researched, and the most frequently studied intervention duration was >1 month and ≤6 months (32.7%), followed by > 1 week and ≤4 weeks (25.5%) and ≤4 h (20.9%). Finally, language arts were the most often studied domain subject (34.7%), followed by science (22.9%).

In addition, among those moderating variables, the evolution of hardware used, implementation setting, and domain subjects may have seen the greatest amount of change during 1993–2013. The trends of those moderating variables during the two decades are shown in Figs. 1–3. Fig. 1 shows the evolution of the use of different mobile devices. Compared with laptop and mixed categories, handheld devices (e.g., cell phone) had been used more since 2009–2013 and showing an obviously rising trend. Moreover, Fig. 2 shows the evolution of the use of different implementation settings. Compared with informal settings (e.g., museums; outdoors) and unrestricted categories, formal settings (e.g., classroom; laboratories) had been set more since 2004–2008 and showing an obviously rising trend. Finally, Fig. 3 shows the evolution of the domain subject. Compared with other domain subjects, language arts had been studied more since 2009–2013 and showing an obviously rising trend.

3.2. Overall effect size for learning achievement

The distribution of the effect sizes of the 110 articles is shown in Fig. 4. The forest plot of effect sizes and the 95% confidence interval of the 110 articles are shown in Appendix B. There were two unusually large effect sizes, $g = 4.045$ (Hsu & Lee, 2011) and $g = 3.050$ (Wu, Sung, Huang, Yang, & Yang, 2011), which were larger than the average effect size for the entire collection of 110 articles ($g = 0.628$) more than three standard deviations, and so these were not included in further analyses (Lipsey & Wilson, 2000). Using the procedure of Lipsey and Wilson (2000) with a random-effects model to integrate the effect sizes of the 108 articles, there was an overall moderate mean effect size of 0.523, with a 95% confidence interval of 0.432–0.613. Researchers (e.g., McMillan, Venable, & Varier, 2013; Van der Kleij, Feskens, & Eggen, 2015) have proposed that Hattie's (2009) criterion is appropriate for evaluating the effect sizes in educational contexts. Therefore, we adopt Hattie's (2009) criterion to interpret the effect size of our research, in which an effect size of ≥0.60 is high, around 0.40 is medium, around 0.20 is low, and <0.20 is with little significant meaning. In this study it was found that using mobile devices in education had a medium effect size for learning achievement; in other words, 69.95% of learners using a mobile device performed significantly better in dependent variables related with cognitive achievement than those not using mobile devices.

The Q statistics show that the effect sizes in the meta-analysis were heterogeneous ($Q_{total} = 626.302$, $z = 11.315$, $p < .001$), which indicates that there are differences among the effect sizes resulting from factors other than subject-level sampling error, such as the diversity of the learning stage, the hardware used, and the teaching methods.

Furthermore, we also conducted an analysis for the studies related to the affective variables (such as motivation, engagement, attitude, satisfaction, preference). The overall mean effect size of the 22 articles was 0.433 ($z = 6.148$, $p = .001$), with a 95% confidence interval of 0.295–0.570. According to Hattie's criterion, there is a medium effect size for affective variables when using mobile devices in educational context.

The overall mean effect size for learning achievement in this meta-analysis was 0.523, meaning that learning with mobiles is significantly more effective than traditional teaching methods that only use pen-and-paper or desktop computers. Compared to past comparisons of effects between using computers and not using computers in education, the effect size of using mobile devices reported herein seems larger than those found in meta-analysis into desktop-computer-based instruction, such as in the studies of Kulik and Kulik (1991) and Tamim, Bernard, Borokhovski, Abrami, and Schmid (2011), who found mean effect sizes for computer-based instruction of 0.30 and 0.35, respectively. One of the reasons for the different effect sizes may be differences in the features of desktops and mobile devices; however, there are alternative

Table 1
Categories and learning achievement effect sizes for 110 articles.

Variable	Category	Number of studies (k)	Number of effect sizes	Proportion of studies	Proportion of effect size	Effect size (g)
Learning stage	1. Kindergarten	1	2	0.009	0.005	0.103
	2. Elementary school	38	97	0.339	0.232	0.654
	3. Middle school	10	47	0.089	0.112	0.512
	4. High school	10	47	0.089	0.112	0.390
	5. College	43	128	0.384	0.305	0.599
	6. Adults	2	4	0.018	0.010	2.474
	7. Mixed	8	94	0.071	0.224	0.084
Intervention duration	1. Not mentioned	7	23	0.064	0.055	0.782
	2. ≤4 h	23	86	0.209	0.205	0.521
	3. > 4, ≤24 h	2	18	0.018	0.043	0.385
	4. >1, ≤7 days	5	9	0.045	0.021	0.369
	5. >1 week, ≤4 weeks	28	95	0.255	0.227	0.643
	6. >1 month, ≤6 months	36	100	0.327	0.239	0.630
	7. >6 months	9	88	0.082	0.210	0.290
Hardware used	1. Not mentioned	2	8	0.018	0.019	1.421
	2. Handhelds	40	87	0.364	0.208	0.743
	3. Laptop	14	109	0.127	0.260	0.276
	4. Tablet PC	8	19	0.073	0.045	0.615
	5. Cell phone	24	84	0.218	0.200	0.676
	6. iPod or MP3 player	5	16	0.045	0.038	0.524
	7. E-book reader	2	41	0.018	0.098	−0.693
	8. Digital pen	1	1	0.009	0.002	0.217
	9. Pocket dictionary	2	11	0.018	0.026	−0.160
	10. Classroom response systems	8	31	0.073	0.074	0.369
	11. Mixed	4	12	0.036	0.029	0.273
Software used	1. Not mentioned	3	29	0.027	0.069	0.355
	2. General purpose	38	223	0.345	0.532	0.494
	3. Learning-oriented	69	167	0.627	0.399	0.626
Implementation setting	0. Not mentioned	2	3	0.018	0.007	0.700
	1. Classroom	55	242	0.500	0.578	0.487
	2. Museum	4	13	0.036	0.031	0.833
	3. Laboratory	3	12	0.027	0.029	0.329
	4. Outdoors	17	27	0.155	0.064	0.760
	5. Unrestricted	18	94	0.164	0.224	0.480
	6. Workplaces	3	14	0.027	0.033	0.247
	7. Mixed	8	14	0.073	0.033	1.032
Teaching method	1. Not mentioned	9	84	0.082	0.200	0.186
	2. Lectures	13	45	0.118	0.107	0.556
	3. Discovery and exploration	13	25	0.118	0.060	0.920
	4. Cooperative learning	9	60	0.082	0.143	0.261
	5. Problem-solving	10	32	0.091	0.076	0.572
	6. Game-based learning	4	7	0.036	0.017	0.404
	7. Self-directed study	34	122	0.309	0.291	0.521
	8. Podcasting	1	6	0.009	0.014	0.153
	9. Computer-assisted testing	6	8	0.055	0.019	0.660
	10. Project-based learning	1	7	0.009	0.017	2.551
	11. Mixed	10	23	0.091	0.055	0.847
Domain subject	1. Language arts	41	169	0.347	0.403	0.593
	2. Social studies	5	10	0.042	0.024	0.776
	3. Science	27	78	0.229	0.186	0.578
	4. Mathematics	12	41	0.102	0.098	0.338
	5. Multidisciplinary	1	6	0.008	0.014	0.333
	6. Specific abilities	5	24	0.042	0.057	0.103
	7. Health-care programs	7	18	0.059	0.043	0.535
	8. Education	3	6	0.025	0.014	0.381
	9. Psychology	3	7	0.025	0.017	0.467
	10. Computer and information technology	14	60	0.119	0.143	0.716

explanations, including differences in the meta-analysis methodology, dependent variable measurements, or software employed. Whether computer-based instruction would be able to enhance students' learning motivation remained equivocal (e.g., Jabbar & Felicia, 2015; Wouters, van Nimwegen, van Oostendorp, & van der Spek, 2013). Our study found that mobile learning was able to facilitate students' affective learning outcomes, which provides more convergent evidence for the effects of using computers in learning and teaching. Possible reasons may include that mobile learning integrated

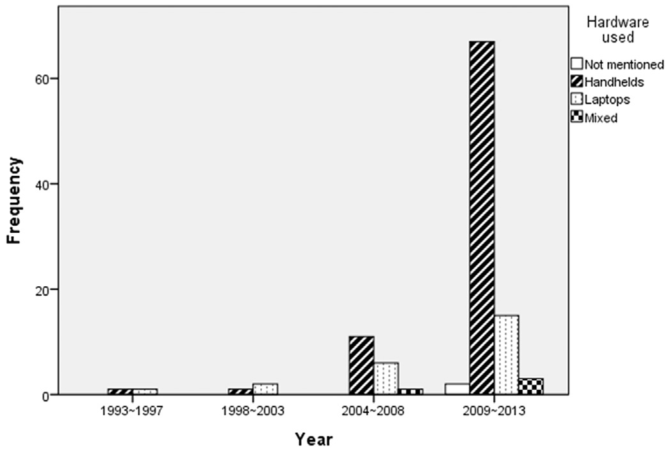

Fig. 1. Histogram of the hardware used in mobile devices assisted learning across time.

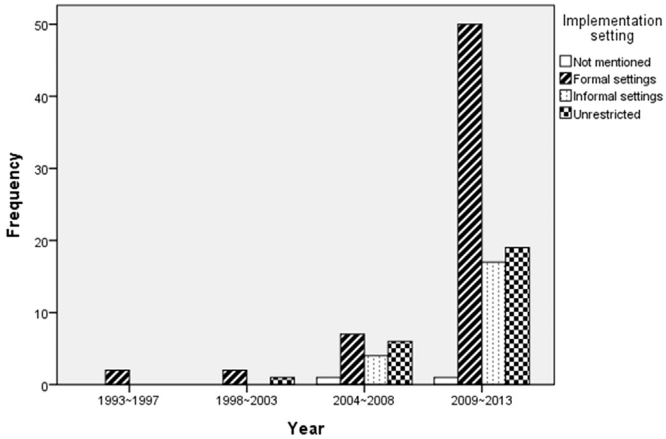

Fig. 2. Histogram of the implementation setting in mobile devices assisted learning across time.

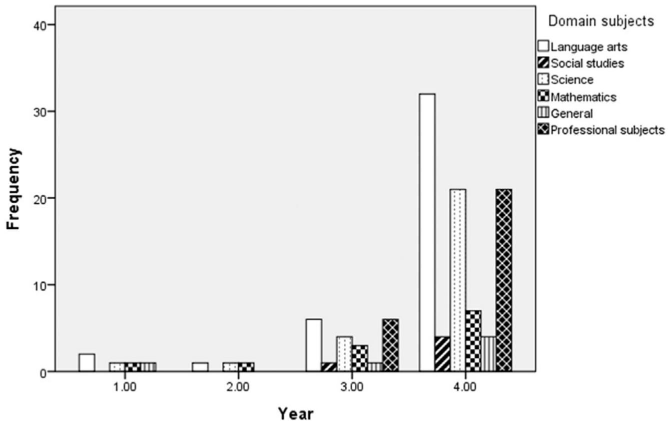

Fig. 3. Histogram of the domain subjects in mobile devices assisted learning across time.

more diverse type of teaching/learning strategies and involved more different learning scenarios in different situations (see next section for more descriptions). However, because many of the articles included in our study used teaching programs lasted for very short-term durations (see next section), the effect of novelty for technology should be taken into consideration.

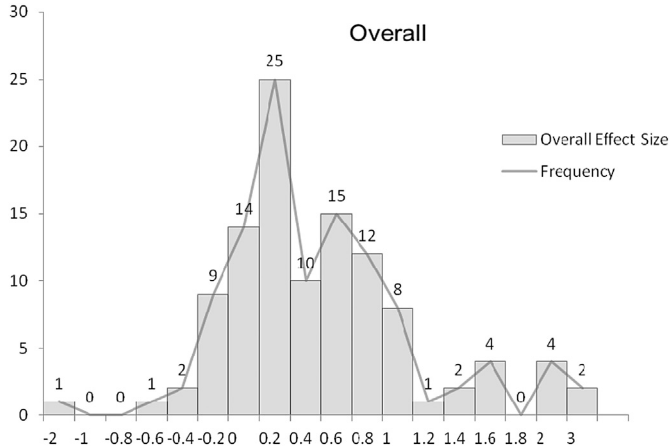

Fig. 4. Histogram of the effect sizes of the 110 articles.

3.3. Effect sizes of learning achievement for moderator variables

To learn more about the effects of moderating variables on mobile devices with teaching and learning, this study conducted analyses for the effects of learning achievement with moderator variables. Because there were only 22 studies which related to affective dependent variables can calculate effect size, which is not comprehensive enough to cover different levels of moderating variables, the moderator analyses did not include the affective effects.

As indicated in Table 1, some levels of the moderator variables included small samples, and so a few of the levels were merged within some moderator variables. For the learning stage, kindergarten and elementary school were combined into a “young-children” category; middle schools and high schools were combined into “secondary-schoolers;” and college and graduate students, teachers, and working adults were combined into “adult users.” With respect to the hardware, laptops, tablet PCs, and e-book readers were combined into a “laptops” category, while PDAs, iPods, MP3 players, cell phones, digital pens, dictionaries, and classroom response systems were bundled together to form one “handheld” category. In terms of function, digital pen is different from other handheld devices, such as iPod, PDA, and smart phone. Also, there was only one study on digital pen. Therefore, it was excluded in our moderator analysis. In terms of the settings, classrooms, laboratories, and workplaces were combined into “formal learning environments,” while museums and outdoors were combined into “informal learning environments” (Dierking, Falk, Rennie, Anderson, & Ellenbogen, 2003). Intervention durations were also combined, with $\leq$4 h, > 4 and $\leq$24 h, and >1 day and $\leq$7 days becoming “$\leq$ 1 week.” For domain subjects, specific abilities and multidisciplinary were combined into “domain-general subjects.” In addition, health-care programs, education, psychology, and computer and information technology were combined into “professional subjects.” For teaching methods, discovery and exploration, problem-solving, and project-based learning were combined into “inquiry-oriented learning.” Moreover, the learning methods of self-directed study and podcasting were combined into “self-directed study.” Table 2 list the effect sizes for the moderator variables.

3.3.1. Learning stage

Table 2 indicate that young children had a high effect size on learning achievement ($g = 0.636$, $z = 8.000$, $p < .001$), while adults ($g = 0.552$, $z = 7.360$, $p < .001$) and secondary-schools ($g = 0.451$, $z = 4.274$, $p < .001$) had medium effect sizes. However, Mixed ($g = 0.086$, $z = 0.503$, $p = .615$) did not show significant effect sizes. The Q_B achieved significance ($Q_B = 9.226$, $p = .026$), meaning that the mean effect size different significantly between the categories.

The results indicated that mobile-assisted learning/instructions were not effective for groups with mixed-age students. The possible reason may be that it is difficult to design appropriate teaching method or material for students with different needs and competence in the same group.

3.3.2. Hardware used

Table 2 gives the effect sizes for the usage of different types of hardware in mobile learning. While ignoring the “not mentioned” category, handheld devices ($g = 0.591$, $z = 10.992$, $p < .001$) were associated with a medium effect size, while laptops ($g = 0.309$, z = 3.350, $p = .001$) were associated with a low effect size. The Q_B was significant ($Q_B = 18.426$, $p < .001$), indicating that the effect sizes differed significantly among the various categories. The R^2 was 7%, meaning that 7% of total between-study variance in effects can be explained by hardware used.

The positive learning outcomes of implementing handhelds could be attributed to their features. For example, to make use of the portability and communication functionality of cell phones, the short message service were used to help teach foreign language vocabulary (e.g., Başoğlu & Akdemir, 2010; Lu, 2008; Saran, Seferoğlu, & Cağıltay, 2012), and because the messages

Table 2
The learning-achievement effect sizes of categories and their related moderator variables.

Category	k	g	z	95% CI	Q_B	R^2
Learning stage					9.226*	0%
1. Young children	39	0.636	8.000***	[0.480–0.791]		
2. Secondary-schoolers	20	0.451	4.274***	[0.244–0.658]		
3. Adults	43	0.552	7.360***	[0.405–0.700]		
4. Mixed	8	0.086	0.503	[−0.248 to 0.419]		
Hardware used					18.426***	7%
1. Not mentioned	2	1.416	4.491***	[0.798–2.033]		
2. Handhelds	78	0.591	10.992***	[0.485–0.696]		
3. Laptops	24	0.309	3.350**	[0.128–0.490]		
4. Mixed	3	0.044	0.173	[−0.460 to 0.548]		
Software used					3.025	0%
1. Not mentioned	3	0.347	1.262	[−0.192 to 0.886]		
2. General purpose	37	0.429	5.407***	[0.273–0.584]		
3. Learning-oriented	68	0.590	9.699***	[0.471–0.709]		
Implementation setting					7.993*	8%
1. Not mentioned	2	0.701	2.069*	[0.037–1.365]		
2. Formal settings (classroom, laboratory, hospital)	60	0.430	7.328***	[0.315–0.545]		
3. Informal settings (museum, outside)	21	0.768	7.096***	[0.556–0.980]		
4. Unrestricted	25	0.550	5.887***	[0.367–0.734]		
Teaching method					26.744***	12%
1. Not mentioned	9	0.186	1.369	[−0.080 to 0.452]		
2. Lectures	12	0.394	3.120**	[0.146–0.641]		
3. Inquiry-oriented learning	24	0.844	8.400***	[0.647–1.041]		
4. Cooperative learning	9	0.261	1.673	[−0.045 to 0.566]		
5. Game-based learning	4	0.407	1.922	[−0.008 to 0.822]		
6. Self-directed learning	34	0.440	5.492***	[0.283–0.597]		
7. Computer-assisted testing	6	0.656	3.661***	[0.305–1.006]		
8. Mixed	10	0.839	5.702***	[0.550–1.127]		
Intervention duration					4.924	0%
1. Not mentioned	7	0.770	4.181***	[0.409–1.130]		
2. ≤1 week	30	0.479	5.175***	[0.298–0.661]		
3. >1, ≤4 weeks	27	0.552	5.644***	[0.360–0.743]		
4. >1 month, ≤6 months	35	0.566	6.870***	[0.405–0.728]		
5. >6 months	9	0.287	1.942	[−0.003 to 0.577]		
Domain subjects					9.108	0%
1. Language arts	39	0.473	6.352***	[0.327–0.619]		
2. Social studies	5	0.768	3.682***	[0.359–1.177]		
3. Science	27	0.565	6.397***	[0.392–0.738]		
4. Mathematics	12	0.337	2.628**	[0.086–0.588]		
5. General	6	0.151	0.868	[−0.190 to 0.491]		
6. Professional subjects	27	0.592	6.808***	[0.422–0.763]		

Note. CI = confidence interval.
*$p < .05$; **$p < .01$; ***$p < .001$.

were short, students could efficiently use their short periods of spare time to take small "bites" out of the material. Another example is the use of cell phones to communicate, make records, and give and receive feedback. These functions can remind students about their learning schedule, and promote self-awareness (Liu, Tao, & Nee, 2008; Runyan et al., 2013) and self-regulation (Kondo et al., 2012). The aforementioned advantages of the handhelds created the environment for seamless learning, which should be able to prompt better learning outcomes.

According to the analysis result, the implementation of handhelds induced higher learning outcomes than the implementation of laptops. It is perhaps due to the fact that studies with handhelds tend to integrate innovative teaching methods (Lu, 2012). Among the handheld research, there was 31.6% employing teaching methods, such as inquiry-oriented and cooperative learning (Table C1 of Appendix C). In contrast, in a large portion of the laptop-related studies (50.0%, Table C1 of Appendix C), the computers were placed into the classroom and used simply for lectures, self-directed study, or with no specific teaching methods.

It is important to note here that most of the research on handhelds in education has involved only short-term interventions, with 29.1% (Table C2 of Appendix C) testing their effectiveness within 1 week. These users of handhelds also probably experienced a transient effect because of their novelty (Kulik & Kulik, 1991). In contrast, most of the research on laptops involved long-term use, with 25.0% (Table C2 of Appendix C) being used for > 6 months. Long-term laptop use without appropriate supporting logistics may reduce both the students' level of commitment and the teachers' willingness to use computers to integrate their teaching with the students' learning (Drayton, Falk, Stroud, Hobbs, & Hammerman, 2010; Inan & Lowther, 2010; Penuel, 2006).

3.3.3. Software used

The data given in Table 2 indicated that the effect sizes for learning-oriented software ($g = 0.590$, $z = 9.699$, $p < .001$) approached high effect size, and general-purpose software ($g = 0.429$, $z = 5.407$, $p < .001$) had medium effect size. The Q_B did not achieve significance at the $p < .05$ level ($Q_B = 3.025$, $p = .220$), which means that the average effect size did not differ significantly between the two categories.

According to the survey results, after 1990 most of the software that the teachers used was actually made for general purposes (e.g., word processors, spreadsheets, and web browsers) (Becker, 1991, 2001; Drayton et al., 2010), instead of learning-oriented software tailored for teaching and learning tasks. This made it difficult for most teachers to achieve the goal of greater efficiency and effectiveness in education using the technology-adapted instruction that they applied (Sung & Lesgold, 2007; Weston & Bain, 2010). The present study indicates that the aforementioned shortage of learning-oriented software has improved, with software specifically designed for teaching and learning goals or activities being used in 62.7% of the research, and only 34.5% of the studies using general-purpose software.

Even though there was no significant difference between learning oriented software and general-purpose software in our research, learning oriented software showed interesting features in mobile based learning. First, the software and the curriculum were closely integrated. As an example, Looi and colleagues (Looi et al., 2011; Zhang et al., 2010) combined educational software with cell phones to make a mobilized curriculum for elementary-level natural science, which was able to implement seamless learning in classrooms, outdoors, and in the home. Their designs were not only based on the pedagogy of inquiry learning, but also promoted formative assessment, cooperative learning, and social interaction in teaching tasks. The second feature of learning-oriented software is that it provides diverse educational activities. Within the studies included in this research, those in which learning-oriented software was used implemented various educational methods, most of which were related to inquiry, cooperation, game-based learning, problem-solving, and formative assessment. On the other hand, for those studies using general-purpose software, lectures and self-directed study were implemented. Moreover, among the 37 studies with the general-purpose software, 6 of them did not mention the teaching methods (Table C1 of Appendix C). The third feature of learning-oriented software is its ability to enable elaborate and efficient designs for teaching strategies and learning scenarios. The steps and procedures of the aforementioned teaching strategies, such as inquiry, cooperation, game-based learning, and problem-solving, were all fairly complex. Learning-oriented software allowed teachers with no programming skills to flexibly and efficiently implement mobile-assisted education. For example, Lan et al. (2007, Lan, Sung, & Chang, 2009) designed an English foreign-language learning model based on cooperative learning and reciprocal teaching. Procedures related to reciprocal teaching, such as reading text, questioning and probing, answering and feedback, were all designed for specific modules that could be further arranged according to the needs of different teaching situations. Teachers could substitute their own material, or even completely customize their program. In addition, the research of Roschelle et al. (2010) on cooperative learning set out three stages of design and implementation for modules, modules for experiments and classroom tryouts, and modules for classroom implementation. After 2 years of designs, tryouts, and revisions, their PDA-based cooperative learning modules were able to integrate the mathematics content, cooperative learning procedures, and teacher-training programs for efficient use in the classroom.

3.3.4. Implementation settings

As indicated in Table 2, when the "not-mentioned" category is ignored, informal settings had a high effect size ($g = 0.768$, $z = 7.096$, $p < .001$), while unrestricted settings ($g = 0.550$, $z = 5.887$, $p < .001$) and formal settings ($g = 0.430$, $z = 7.328$, $p < .001$) had medium effect sizes. The effect size of informal setting was larger than that of the formal setting, as the 95% of confidence intervals of the two effect sizes did not overlap. The Q_B was significant ($Q_B = 7.993$, $p = .046$), showing that the average effect size differed significantly with the category. The R^2 was 8%, meaning that 8% of total between-study variance in effects can be explained by implementation settings.

As found in the present study, the effect size was larger for using mobile devices in the outdoors and informal locations than for using them in more formal places. Some observations on the use of mobile devices in informal places may be helpful for explaining this phenomenon. First, this could be due to the motivation induced by the novelty of the technology and activities. Students are keen to go outside or to museums to learn, and combining this with the use of novel learning tools can facilitate learners' motivation (e.g., Zhang, Sung, Hou, & Chang, 2014). The second is that most of the informal educational models, software functionality, and hardware characteristics were closely integrated in the included research, and this probably improved the learning effects. In the present study, 77.9% of informal learning-oriented software was specially designed for specific learning scenarios in specific settings (Table C3 of Appendix C). These more elaborately designed teaching procedures allow educational effects to become more apparent. For instance, when learning in museums, one of the important issues is how to guide learners' attention to exhibitions through an appropriate learning process, and informative and interesting activities to promote interaction among visitors, computers, and the historical contexts (e.g., Hsi, 2003; Sung, Hou, Liu, & Chang, 2010). Several of the studies included in our research combined the models of role-playing games and problem-solving to immerse learners in the historical events, engaging them to observe and learn target exhibits more deeply (e.g., Huizenga, Admiraal, Akkerman, & ten Dam, 2009; Sung, Chang, Hou, & Chen, 2010). Similarly, researchers are also concerned with how to make the fieldwork involved in the natural and social sciences structuralized, focused, and efficient, rather than loose, absent-minded, and ineffective. In several studies (e.g., Hwang, Chu, Lin, & Tsai, 2011; Liu, Tan, & Chu, 2009), the researchers tried to make observations, note-taking, problem-solving, information exchanges, and discussion more structured, and to sharply focus the students' learning process by integrating mobile devices with other peripheral devices such as camcorders, positioning functions, and measuring facilities.

3.3.5. Teaching methods

The data regarding the effect size for different teaching methods are given in Table 2. Three high effect sizes were found for inquiry-oriented ($g = 0.844$, $z = 8.400$, $p < .001$), mixed methods ($g = 0.839$, $z = 5.702$, $p < .001$), and computer-assisted testing ($g = 0.656$, $z = 3.661$, $p < .001$). Lectures ($g = 0.394$, $z = 3.120$, $p = .002$) and self-directed study ($g = 0.440$, $z = 5.492$, $p < .001$) were around medium effect sizes. However, cooperative learning ($g = 0.261$, $z = 1.673$, $p = .094$) and game-based learning ($g = 0.407$, $z = 1.922$, $p = .055$) did not show significant effect sizes. The Q_B achieved statistical significance ($Q_B = 26.744$, $p < .001$), indicating that the average effect sizes differed significantly among the various categories. The R^2 was 12%, meaning that 12% of total between-study variance in effects can be explained by teaching methods.

The unique features of mobile devices can enhance the essential functionalities of certain specific teaching methods, and thus promote educational outcomes. Because each student has his own mobile device, this "individuality" combined with wireless communication enabled more accessible self-paced and self-directed study. Combining the features of individuality and instant message delivery resolves the past difficulties of putting instant formative assessment into the classroom (e.g., Chen & Chen, 2009), such that these assessments can even be performed outdoors with equal ease (e.g., Shih, Kuo, & Liu, 2012). Another feature that empowers the teaching and learning process is the portability and context awareness of mobile devices. These two features allow learners to exploit the information in the environments in which they are situated, and to retrieve, record, and react to the data needed to resolve their learning issues by traversing multiple learning environments, such as fieldwork and museums (e.g., Tan, Liu, & Chang, 2007).

It is note-worthy that although researchers (Kukulska-Hulme & Shield, 2008; Roschelle & Pea, 2002) have proposed that conveying information and giving feedback via mobile devices can help to keep learners in touch with their peers, promote discussions, and to facilitate the effects of cooperative learning, our study found that in general theses features did not help enhance cooperative learning outcomes. The researchers of cooperative learning used mobile devices' features of individuality and sharing coupled with mechanisms for enhancing social interaction, such as co-constructing concept maps (Lai & Wu, 2006), peer evaluation (Lan et al., 2007; Roschelle et al., 2010), and building consensus (Zurita & Nussbaum, 2004). Interestingly, perhaps these methods had facilitated the positive interactive relationships among team members (e.g., Lan et al., 2007; Zurita & Nussbaum, 2004), however, these teaching methods did not enhance the learning outcomes compared with the cooperative scenarios without using mobile devices. There are at least two possible reasons for the results. Firstly, the cooperative learning tasks in those studies, when coupled with mobile devices, may be helpful for increasing the interactive behaviors and social cohesions among team members. However, the increased social cohesion may not be powerful enough to enhance learning achievement. As Slavin (2012) proposed, whether higher social cohesion is related with higher learning achievement is not conclusive. Those methods used in the above-noted research may be insufficient to empower the cognitive elaboration processes imperative for enhancing students' learning. In those studies students in both the control and treatment groups received cooperative treatments: The only difference was mobile-device usage. Thus, the inherent effects of mobile devices may not go much beyond sharing, communicating, and consensus building. Therefore, elaborate design of learning scenarios, such as mechanisms for prompting questioning and explanatory strategies (Byun, Lee, & Cerreto, 2014; Gillies & Haynes, 2011) specifically related with the learning content, may be needed to be incorporated into the mobile-device based activities in order to enhance students' cognitive elaboration processes and outcomes. The second possible reason is that the intervention durations of the mobile-based cooperative learning programs were not long enough to produce positive effects. Researchers have proposed that several weeks of duration is helpful for producing positive learning outcomes in cooperative learning (Slavin, 1993), as sufficient time is important for learners to get familiar with team members, tasks, and required procedure (Slavin, 1977). Time for familiarization may be even more important for mobile-devices based cooperative learning because learners need time to get familiar not only with members, tasks, and procedure, but also with the hardware and software. Most of the research included in our study lasted for less than one month, which may be too short for the programs to produce sound effects.

Another note-worthy finding is that game-based learning did not achieve a significant overall effect in mobile learning, either. The major reason may be that most of the studies (e.g., Ketamo, 2003; Kim et al., 2011; Riconscente, 2013) focused on using the mobile devices to provide learners with a handy and individualized game-based environment to enhance their motivation and engagement. However, the relationships between the concepts to be learned and the content of the game may not have been closely integrated, and therefore the effects of learning might not have been illustrated.

Researchers have pointed out that computer interventions in education have not yet led to practical implementations of innovative educational methods (Ertmer & Ottenbreit-Leftwich, 2010; Gerard, Varma, Corliss, & Linn, 2011). Contrarily, it was found in the present study that mobile devices seemed to elicit much more diverse and innovative educational methods from researchers.

3.3.6. Intervention duration

When the "not-mentioned" category is ignored, interventions of >1 month and ≤6 months duration ($g = 0.566$, $z = 6.870$, $p < .001$), those of >1 week and ≤4 weeks duration ($g = 0.552$, $z = 5.644$, $p < .001$), and those ≤ 1 week had medium effect sizes ($g = 0.479$, $z = 5.175$, $p < .001$). Interestingly, interventions conducted for durations of >6 months had a non-significant effect size ($g = 0.287$, $z = 1.942$, $p = .052$). The Q_B was not significant ($Q_B = 4.924$, $p = .295$), which suggests that the effect size did not differ significantly between these categories.

The non-significance of the effect size in long-term duration (>6 months) is counterintuitive, but consistent with those of Kulik and Kulik (1991), who found that computer-based instruction had a greater effect when the duration was shorter. Kulik and Kulik (1991) and Cheung and Slavin (2013) proposed three reasons for why short-term treatments have better effects: high novelty value, stronger interventional supports, and different measurement tools for the dependent variables. These explanations are also applicable to the present findings. In most studies with intervention durations less than 6 months, the use of mobile devices and the applied teaching methods were both novel, so the students were more easily engaged in the activity. Cross-analysis of intervention duration with other moderator variables provides data that supports these arguments. For example, most research that took place over a 6-month period used general-purpose software (66.7%; Table C2 of Appendix C), which did not necessarily match the needs of the learning scenarios in specific learning topics. Furthermore, around half of the studies (44.4%; Table C2 of Appendix C) with durations of >6 months placed the computers directly in the classroom and did not specify the teaching methods to be used to achieve specific educational goals. Conversely, 57.1% of the studies lasting for >1 month and ≤6 months used learning-oriented software for specific teaching and learning goals, and 94.3% specified a specific teaching strategy instead of simply using computers for some unspecified purpose in the classroom (Table C2 of Appendix C).

In terms of the interventional supports, in most short-term studies, researchers could gather all of their resources for one shot, so they chose the most appropriate hardware and software with more diverse functionality, prepared more elaborate learning activities, and made every effort to control confounding factors. However, in studies lasting >6 months, the longer duration made it more difficult to support the use of diverse resources, finding logistic assistance for technological problems, and maintaining the enthusiasm associated with using new technologies. For example, Shapley, Sheehan, Maloney, and Caranikas-Walker (2010) found that in laptop immersion schools, after four years of implementation, only 6 of 21 schools reached a substantial level of immersion, and the level of student access and use of laptops in classrooms declined during the period of implementation because of insufficient support.

Research in the field of education mostly advocates that long-term teaching interventions are important for obtaining reliable results (Hsieh et al., 2005; Pressley & Harris, 1994), but in the present study it was found that long-term interventions with mobile devices in classrooms did not necessarily lead to better effects. Such findings echo comments made by many researchers about the use of laptops in the classroom: If computers are simply given to teachers and students to use for a long time without any positive guidance, it will not necessarily produce satisfactory educational outcomes (Holcomb, 2009; Zucker & Light, 2009), especially for higher levels learning skills such as reasoning and problem solving (Drayton et al., 2010). In order for there to be abundant effects, long-term interventions need logistical support to integrate advanced technologies with innovative and elaborate educational methods. Information technology applications in the classroom must first go through adoption and adaptation before they can proceed to innovation. These processes are also likely to take longer than 1 year (Gerard et al., 2011), or even up to 3 years (Bebell & O'Dwyer, 2010). During such a long-term process, if the main support provided to teachers and students is enthusiasm rather than appropriate support such as hardware, software, and instructional designs, computer use in the classroom will ultimately be merely superficial.

3.3.7. Domain subjects

The data in Table 2 indicate the effect sizes for different domain subjects. Social studies ($g = 0.768$, $z = 3.682$, $p < .001$) had a high effect size, while professional subjects ($g = 0.592$, $z = 6.808$, $p < .001$), science ($g = 0.565$, $z = 6.397$, $p < .001$), language arts ($g = 0.473$, $z = 6.352$, $p < .001$) and mathematics ($g = 0.337$, $z = 2.628$, $p = .009$) had medium effect sizes. No significant effect size was obtained for using mobile devices for domain-general abilities ($g = 0.151$, $z = 0.868$, $p = .386$). The Q_B did not achieve statistical significance ($Q_B = 9.108$, $p = .105$), which shows that the average effect size did not differ significantly among these categories.

3.4. Evaluation of publication bias

The classic fail-safe N and Orwin's fail-safe N were adopted to demonstrate the publication bias for the 108 selected studies. As suggested by the data in Table 3, the classic fail-safe N test determined that a total of 4144 studies with null results would be needed in order to nullify the effect size. Moreover, the results of Orwin's fail-safe N test (see Table 4) show that the

Table 3
Results of the classic fail-safe N.

Z value for observed studies	22.51
p value for observed studies	0.00
Alpha	0.05
Tail	2.00
Z for alpha	1.96
Number of observed studies	108.00
Number of missing studies that would bring the p value to >alpha	4144.00

Table 4
Results of Orwin's fail-safe N.

Hedges' g in observed studies (fixed effect)	0.33
Criterion for a 'trivial' Hedges' g	0.01
Mean Hedges' g in missing studies	0.00
Number of missing studies needed to bring Hedge's g to under 0.01	3423.00

number of missing null studies required to bring the existing overall mean effect size to a trivial level ($g = 0.01$) was 3423. Both tests suggest that publication bias could not explain the significant positive effects observed across all studies.

4. Conclusions and implications

Analysis of the empirical research on the use of mobile devices as tools in educational interventions that were published in peer-reviewed journals has revealed that the overall effect of using mobile devices in education is better than when using desktop computers or not using mobile devices as an intervention, with a moderate effect size of 0.523. Through the analysis of moderator variables, we found that many different combinations of hardware, software, and intervention durations for mobile devices have been applied to various ages of users, implementation settings, teaching methods, and domain subjects. The effect of such usage was greater for handhelds than for laptops; usage in inquiry-oriented learning was more effective than usage along with lectures, self-directed study, cooperative learning, and game-based learning; informal educational environments were more effective than their formal counterparts, and medium- and short-duration interventions were superior to long-term interventions. These findings will contribute to a better understanding of where, for whom, and in which way the use of mobile devices in the learning environment will best highlight the effects of particular educational methods, and reveal the limitations of mobile devices in education.

Based on the findings of this study, it is proposed that more elaborate instructional design developments are needed to more thoroughly exploit the educational benefits possible by utilizing mobile devices. We believe that the three implications proposed below will be helpful for facilitating and achieving these goals.

4.1. Leveraging the pedagogical effects of mobile devices through elaborate designs of learning/teaching scenarios

Mobile devices have various distinctive features such as individualized interfaces, real-time access to information, context sensitivity, instant communication, and feedback. These features may be able enhance the effects of certain pedagogies, such as self-directed learning, inquiry learning, or formative assessment. However, it is note-worthy that the features of mobile devices are not sufficient conditions for positive learning effects. The minor effects of mobile-device-based cooperative and game-based learning in our study illustrated this fact. Instructional strategies are important for effective learning with information technology (Lan, 2014; Lan, Sung, Cheng, & Chang, 2015; Liu, Lin, & Paas, 2014). Researchers must find the "key" to integrating mobile devices with instructional strategies and ingeniously match the unique features of mobile devices to the resolution of specific pedagogic challenges. Doing so will maximize the impact of those features on learning outcomes.

Some examples include using the instant-feedback functions to solve the difficulty of efficiently executing and managing formative assessment in a class with many students (Penuel, Roschelle, & Shechtman, 2007) and, for cooperative groups, using wireless communication to facilitate between-group scaffoldings and to avoid idling (Lan et al., 2007). As one of the most used strategies in mobile learning/teaching, self-directed study is an example of a method that deserves more attention paid to pairing specific features to specific challenges to yield improved results. In addition, most of the studies in our research utilized mobile devices' features of individuality and wireless communication capacity for self-directed learning, such as learning vocabularies through messaging services or using word processors for writing. However, few studies in our research provided their mechanisms for using the instant feedback to facilitate the interaction between mobile devices and users (e.g., Oberg & Daniels, 2013; Ozcelik & Acarturk, 2011), which is an important element of effective self-directed learning with computers. Therefore, more elaborate methods of implementation, such as a monitoring mechanisms for learning EFL vocabularies through the message services of cell phones, an annotation system for reading e-books (e.g., Hwang, Shadiev, & Huang, 2011), speech recognition for providing feedback to students' oral practices (e.g., Tanner & Landon, 2009), etc., should be considered to enhance the interaction between learner and computers and the effects of self-directed learning.

4.2. Enhancing the quality of the experimental design for mobile intervention

While it was found in this study that mobile devices can enhance educational effects, the actual impact of mobile learning programs needs to be enhanced by longer intervention durations, closer integration of technology and the curriculum, and further assessment of higher-level skills.

The intervention duration will affect the reliability and ecological validity of mobile learning programs. Of all of the included interventions in this study, those with durations of >6 months constituted only about 8.3% of the research, and more than 27.2% took place within 1 week. With short programs, and especially those that last for only hours, it is difficult to prove that any effects are produced by the features of mobile-integrated instruction rather than by the experience of technology novelty. Moreover, short-term projects may adapt poorly to regular classroom practices that may last for several months. Another issue related to teaching duration is the closeness of the integration between mobile devices and the curriculum. Most of the short programs included in our study involved only one or two units of teaching materials in the curriculum of a whole semester. Although it is not necessary for a teacher to use mobile devices in every class, different units or topics may involve different instructional designs when such devices are being used, and hence an iterative trial process is likely to be needed to determine the optimal procedure for the best effects. Therefore, an abundance of mobile learning units will help to provide exemplar models for teachers and enhance the possibility of transferring practices to different lessons. Furthermore, in terms of research, it can improve the reliability and ecological validity of mobile programs in education. Based on the above considerations, researchers may consider appropriate intervention durations according to the skills or teaching methods to be developed with mobile devices. For example, for vocabulary-learning, bite-size materials and short-term durations may be appropriate for learners, but for more complex skills or methods such as inquiry or cooperative learning, longer interventions may be needed to warrant the effect of mobile programs.

Another effect of mobile usage that could be strengthened is the expansion of measurements of dependent variables. Most of the studies in our research currently still placed the interests on achievement in content knowledge (e.g., Liu, 2009; Wang & Wu, 2011), and methods for measuring higher-level skills were scarce. Mobile devices were expected to encourage innovation in education and increase high-level abilities (Frohberg et al., 2009; Sung, Chang, & Yang, 2015; Zucker & Light, 2009). Yet most of the research collected for this study focused on increasing content learning, and even though the designed educational activities involve explorative, communication, and cooperative skills, the dependent variables had almost no connection with these skills. For example, in the database of our research, only 5 of the 9 experimental/quasi experimental studies explored the interactive behaviors of students during their mobile learning; furthermore, none of the 24 inquiry-oriented learning recorded and investigated process-related skills such as hypothesis-formation and hypothesis-testing. Therefore, including dependent variables besides content knowledge—such as problem-solving, critical thinking, interactive communication, or creative innovation skills—in the measurements will make the persuasiveness of the educational effects of mobile devices much more convincing.

4.3. Empowering educational practitioners through the orchestration of mobile devices, software, and pedagogical design

Scholars (e.g., Gao, Liu, & Paas, in press; Liu et al., 2012) have gradually reached a consensus that exerting the maximum effect of information technology in the educational field requires reconciliation of the connection among the components of technology (hardware and software), educational context and missions (e.g., learning and teaching processes in different settings), and users (teachers and students) in order to overcome many of the limitations present in the field. Scholars (Dillenbourg, Nussbaum, Dimitriadis, & Roschelle, 2013; Dimitriadis, Prieto, & Asensio-Pérez, 2013) came to agree that the efforts of building harmonious relationships among those components to enable compatible, efficient, and effective technology-enhanced teaching and learning environments may be called orchestration. To achieve orchestration in mobile-integrated education requires the pursuit of at least two directions for research and practices. The first is strengthening the functions and expanding the applicability and breadth of learning-oriented software. For example, the research analyzed in this study paired many different learning-oriented software programs with educational activities (e.g., reciprocal teaching, inquiry learning, and formative assessment) that have already proven effective. That software may be modified to provide the functionality of authoring tools that allow teachers to flexibly arrange their own teaching and learning flows in the classroom.

The second direction is strengthening professional teacher-development programs for mobile-enhanced instruction. Most review research into the use of mobile devices for education has emphasized that one of the largest obstacles to implementing effective mobile learning programs is insufficient preparation of the teachers (Frohberg et al., 2009; Penuel, 2006). The essence of effective professional development for technology-enhanced inquiry proposed by Gerard et al. (2011) is also applicable to mobile learning programs. Teachers should be encouraged to modify already developed mobile-integrated education programs, and to gradually customize them into their own personalized program rather than simply designing their own program around the use of technology. The latter approach implicitly leads teachers to technology-adapted instruction, which means that the educational practices of the teachers may be restricted by the functions of technology, and may make it difficult for teachers to change their existing beliefs and habits. In contrast, customizing existing research-based mobile learning programs not only transfers researchers' visions and experiences for the use of technology to teachers, but also minimizes the time teachers spend on formulating new ideas and performing trial-and-error iterative procedures (Gerard et al., 2011; Penuel et al., 2007). To facilitate the transition of researchers' vision, experiences, and skills to school teachers, it is also helpful to involve university-level researchers as mentors or collaborators. Diverse functions and types of hardware and software are available for mobile devices, but conversely the complexity is also high, and hence designing and using them can readily impose additional overhead on teachers. The plethora of technological knowledge and resources that are available to researchers for educational technology means that their participation in a program can result in their knowledge and experience greatly assisting the teachers' autonomy in implementation.

Another note-worthy fact is that, despite the importance of teachers' professional development during their adoption of and adaptation to mobile-device based teaching (Newhouse, Williams, & Pearson, 2006; Penuel & Yarnall, 2005), the investigations into increasing the education of teachers regarding the use of mobile devices have been extremely limited. Therefore, more in-depth experimental research is needed into how teachers reconcile mobile hardware and software, lesson content, teaching methods, and educational goals.

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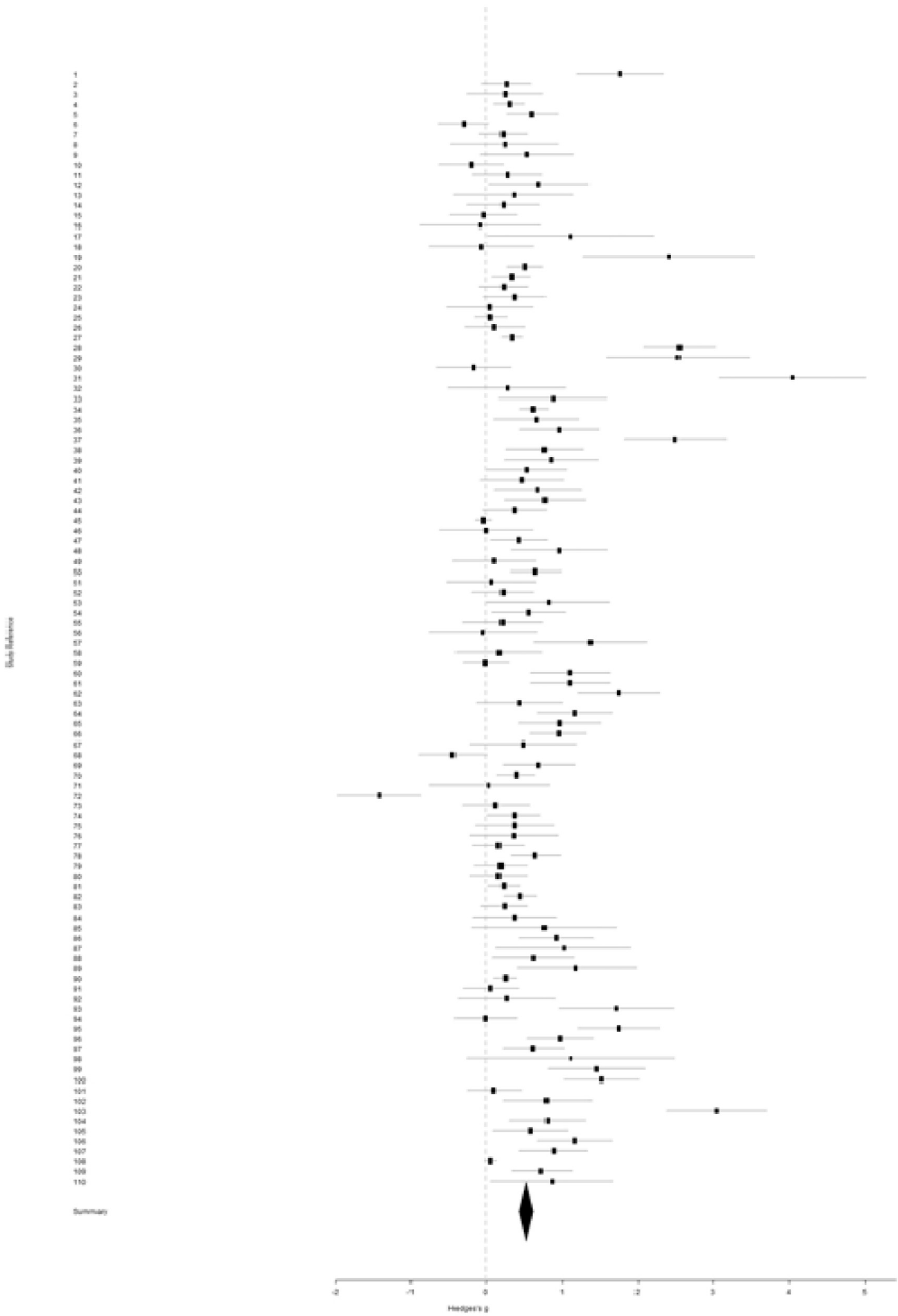
Appendix A. Related review of the research into Integrating Mobile Devices with Teaching and Learning.

Study	Devices are focused on	Method	Number of studies	Result
Penuel (2006)	Laptops	Narrative review	30(not provided publication list)	Penuel (2006) synthesized findings from research and evaluation studies that analyzed implementation and effects of one-to-one initiatives from a range of countries. Factors related to successful implementation reported in the research include extensive teacher professional development, access to technical support, and positive teacher attitudes toward student technology use. Penuel (2006) found that outcome studies with rigorous designs are few, but those studies that did measure outcomes consistently reported positive effects on technology use, technology literacy, and writing skills.
Frohberg et al. (2009)	Laptops	Narrative review	102 (mobile learning projects)	Frohberg et al. (2009) used a mobile learning framework to evaluate and categorize 102 mobile learning projects, and to briefly introduce exemplary projects for each category. Despite the fact that mobile phones initially started as a communication device, communication and collaboration play a surprisingly small role in Mobile Learning projects.
Zucker and Light (2009)	Laptops	Narrative review	31(not provided publication list)	Zucker and Light (2009) found research in many nations suggests that laptop programs will be most successful as part of balanced, comprehensive initiatives that address changes in education goals, curricula, teacher training, and assessment.
Bebell and O'Dwyer (2010)	Laptops	Narrative review	5	Bebell and O'Dwyer (2010) summarized evidence that participation in the 1:1 computer programs was associated with increased student and teacher technology use, increased student engagement and interest level, and modest increases in student achievement.
Hwang and Tsai (2011)	Various types of mobile device	Content analysis	154(not provided publication list)	Hwang and Tsai (2011) examined the mobile or ubiquitous learning papers published in the Social Science Citation Index (SSCI) database from 2001 to 2010. Hwang and Tsai (2011) found that the number of articles has significantly increased during the past 10 years; moreover, researchers from the different countries have contributed to the related field in recent years.
Wong and Looi (2011)	Laptops	Narrative review	54	Wong and Looi (2011) aimed to further investigate the meaning of seamless learning and the potential ways to put it in practice. Through a thorough review of recent academic papers on mobile-assisted seamless learning (MSL), Wong and Looi (2011) identify ten dimensions that characterize MSL.
Fleischer (2012)	Narrative review	Narrative review	18	Fleischer (2012) reviewed cross-disciplinary accumulated empirical research on one-to-one computer projects in school settings as published in peer-reviewed journals between 2005 and 2010, particularly the results of teacher- and pupil-oriented studies. The results of Fleischer (2012) show that the research field has not developed substantially since the previously published reviews. One the other hand, Fleischer (2012) discussed the reasons for this lack of development, as well as the need for political, scholarly and epistemological awareness when researching questions of one-to-one computer projects.

Appendix B. Forest plot of the effect sizes and 95% CI of the 110 articles.



Note. The research papers were numbered from 1 to 110. Please see the further reading section.

Appendix C. Cross analyses of moderator variables.

Table C1
Cross-analysis of teaching methods, domain subjects, and hardware used.

		Teaching method								
		Not mentioned	Lectures	Inquiry-oriented learning	Cooperative learning	Game-based learning	Self-directed study	Mixed	Computer-assisted testing	Total
Domain subjects	Language arts	6 (15.4%)	1 (2.6%)	2 (5.1%)	5 (12.8%)	0 (0.0%)	20 (51.2%)	4 (10.3%)	1 (2.6%)	39 (100%)
	Social studies	0 (0.0%)	0 (0.0%)	3 (60.0%)	0 (0.0%)	1 (20%)	0 (0.0%)	0 (0.0%)	1 (20%)	5 (100%)
	Science	2 (7.4%)	5 (18.5%)	11 (40.7%)	1 (3.7%)	0 (0.0%)	2 (7.4%)	5 (18.5%)	1 (3.7%)	27 (100%)
	Mathematics	2 (16.7%)	0 (0.0%)	2 (16.7%)	2 (16.7%)	3 (25.0%)	1 (8.3%)	1 (8.3%)	1 (8.3%)	12 (100%)
	General	3 (50.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	3 (50.0%)	0 (0.0%)	0 (0.0%)	6 (100%)
	Professional subjects	1 (3.7%)	6 (22.2%)	6 (22.2%)	2 (7.4%)	0 (0.0%)	8 (29.6%)	0 (0.0%)	4 (14.8%)	27 (100%)
Total		14 (12.1%)	12 (10.3%)	24 (20.7%)	10 (8.6%)	4 (3.4%)	34 (29.3%)	10 (8.6%)	8 (6.9%)	116 (100%)
Hardware used	Not mentioned	0 (0.0%)	0 (0.0%)	1 (50.0%)	0 (0.0%)	0 (0.0%)	1 (50.0%)	0 (0.0%)	0 (0.0%)	2 (100%)
	Handhelds	2 (2.5%)	10 (12.7%)	18 (22.8%)	7 (8.9%)	3 (3.8%)	27 (34.2%)	6 (7.6%)	6 (7.6%)	79 (100%)
	Laptops	6 (25.0%)	2 (8.3%)	5 (20.8%)	2 (8.3%)	1 (4.2%)	4 (16.7%)	4 (16.7%)	0 (0.0%)	24 (100%)
	Mixed	1 (33.3%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	2 (66.7%)	0 (0.0%)	0 (0.0%)	3 (100%)
Total		9 (8.3%)	12 (11.1%)	24 (22.2%)	9 (8.3%)	4 (3.7%)	34 (31.5%)	10 (9.3%)	6 (5.5%)	108 (100%)
Software used	Not mentioned	1 (33.3%)	0 (0.0%)	0 (0.0%)	1 (33.3%)	0 (0.0%)	1 (33.3%)	0 (0.0%)	0 (0.0%)	3 (100%)
	General purpose	6 (16.2%)	9 (24.3%)	5 (13.5%)	1 (2.7%)	0 (0.0%)	13 (35.1%)	2 (5.4%)	1 (2.7%)	37 (100%)
	Learning-oriented	2 (2.9%)	3 (4.4%)	19 (27.9%)	7 (10.2%)	4 (5.9%)	20 (29.4%)	8 (11.8%)	5 (7.4%)	68 (100%)
Total		9 (8.3%)	12 (11.1%)	24 (22.2%)	9 (8.3%)	4 (3.7%)	34 (31.5%)	10 (9.3%)	6 (5.6%)	108 (100%)

Table C2
Cross-analysis for intervention durations, hardware used, software used, and teaching methods.

		Intervention duration					
		Not mentioned	≤1 week	>1, ≤4 weeks	>1 month, ≤6 months	>6 months	Total
Hardware used	Not mentioned	0 (0.0%)	0 (0.0%)	0 (0.0%)	2 (100.0%)	0 (0.0%)	2 (100.0%)
	Handhelds	4 (5.1%)	23 (29.1%)	20 (25.3%)	29 (36.7%)	3 (3.8%)	79 (100.0%)
	Laptops	3 (12.5%)	5 (20.8%)	6 (25.0%)	4 (16.7%)	6 (25.0%)	24 (100.0%)
	Mixed	0 (0.0%)	2 (66.7%)	1 (33.3%)	0 (0.0%)	0 (0.0%)	3 (100.0%)
	Total	7 (6.5%)	30 (27.8%)	27 (25.0%)	35 (32.4%)	9 (8.3%)	108 (100.0%)
Software used	Not mentioned	1 (33.3%)	0 (0.0%)	2 (66.7%)	0 (0.0%)	0 (0.0%)	3 (100.0%)
	General purpose	2 (5.4%)	7 (18.9%)	7 (18.9%)	15 (40.5%)	6 (16.2%)	37 (100.0%)
	Learning-oriented	4 (5.9%)	23 (33.8%)	18 (26.5%)	20 (29.4%)	3 (4.4%)	68 (100.0%)
	Total	7 (6.5%)	30 (27.8%)	27 (25.0%)	35 (32.4%)	9 (8.3%)	108 (100.0%)
Teaching method	Not mentioned	1 (11.1%)	1 (11.1%)	1 (11.1%)	2 (22.2%)	4 (44.4%)	9 (100.0%)
	Lecture	1 (8.3%)	5 (41.7%)	0 (0.0%)	5 (41.7%)	1 (8.3%)	12 (100.0%)
	Inquiry-oriented	3 (12.5%)	9 (37.5%)	5 (20.8%)	7 (29.2%)	0 (0.0%)	24 (100.0%)
	Cooperative learning	0 (0.0%)	2 (22.2%)	4 (44.4%)	2 (22.2%)	1 (11.1%)	9 (100.0%)
	Game-based learning	0 (0.0%)	2 (50.0%)	2 (50.0%)	0 (0.0%)	0 (0.0%)	4 (100.0%)
	Self-directed study	1 (2.9%)	9 (26.5%)	13 (38.2%)	11 (32.4%)	0 (0.0%)	34 (100.0%)
	Mixed	0 (0.0%)	0 (0.0%)	1 (10.0%)	6 (60.0%)	3 (30.0%)	10 (100.0%)
	Computer-assisted testing	1 (16.7%)	2 (33.3%)	1 (16.7%)	2 (33.3%)	0 (0.0%)	6 (100.0%)
	Total	7 (6.5%)	30 (27.8%)	27 (25.0%)	35 (32.4%)	9 (8.3%)	108 (100.0%)

Table C3
Cross-analysis for implementation settings and software used.

		Software used			
		Not mentioned	General purpose	Learning-oriented	Total
Implementation setting	Not mentioned	0 (0.0%)	1 (50.0%)	1 (50.0%)	2 (100.0%)
	Formal settings	2 (3.3%)	22 (36.7%)	36 (60.0%)	60 (100.0%)
	Informal settings	0 (0.0%)	4 (19.0%)	17 (81.0%)	21 (100.0%)
	Unrestricted	1 (4.0%)	10 (40.0%)	14 (56.0%)	25 (100.0%)
Total		3 (2.8%)	37 (34.3%)	68 (63.0%)	108 (100.0%)

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