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Tablets for Teaching and Learning

A Systematic Review and Meta-Analysis

Rana M. Tamim, Eugene Borokhovski, David Pickup, Robert M. Bernard and Lina El Saadi

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Commonwealth of Learning

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ABSTRACT

Tablets and smart mobile devices are the most recent addition to the long list of technological innovations believed to support and enhance the teaching process and learning process. This review aimed at going beyond the general hype around tablets and smart mobile devices to investigate the evidence supporting their use in educational contexts. To achieve this purpose, a systematic review of quantitative and qualitative research studies published since 2010 was completed. A rigorous review process resulted in the inclusion of 27 quantitative studies that were subjected to a full-scale meta-analytic procedure, and 41 qualitative research studies that were reviewed for substantive study characteristics. A significant average effect size was found for studies comparing tablet use contexts with no tablet use contexts ($g+ = 0.23$, $k = 28$). For studies comparing two different uses of tablets by students, the average effect size ($g+ = 0.68$, $k = 12$) showed a significant favouring of more student-centred pedagogical use of technology. Although not statistically tested, the findings also indicate that higher effect sizes are achieved when the devices are used with a student-centred approach rather than within teacher-led environments. Similarly, the qualitative literature review revealed that tablets and smart mobile devices are garnering positive perceptions within educational contexts, with the strongest support showing for the technologies' effectiveness in particular tasks and when used within more student-active contexts. Finally, the review provides an overview of the Turkish Fatih Project as a case study and highlights the lessons learned.

INTRODUCTION

Long gone are the days when the debate among educators focused on the validity of the claim that computer technology will have an impact on teaching and learning and will enhance the educational environment to make it more conducive for meaningful learning (Clark, 1983, 1994; Ferdig, 2006; Ross, Morrison, & Lowther, 2010; Wurst, Smarkola, & Gaffney, 2008). Research has provided supportive evidence for the overall claim that technology is beneficial for students' performance (Tamim, Bernard, Borokhovski, Abrami, & Schmid, 2011), while offering strong indications that it is not about the technological device itself but about how it is used and for what purpose (Bethel, Bernard, Abrami, & Wade, 2007; Schmid et al., 2014; Wurst et al., 2008). Research findings have consistently indicated that stronger effect sizes are achieved when technology is used for cognitive support rather than for presentation purposes (Schmid et al., 2014) and when technology is used to support instruction rather than to deliver material (Tamim et al., 2011).

Nevertheless, the general perception about the role of technological devices in educational contexts has not moved much beyond the naïve assumption that the introduction of the devices will automatically lead to higher levels of interactivity and effective learning. Although it is currently taken for granted that technologies are among the primary tools to be considered by teachers when designing instruction, limited attention is given to best practices or lessons learned from previous initiatives. Many policy-makers and academic administrators are jumping on the technological bandwagon to secure a more contemporary image for their educational systems and schools. Yet, while they are providing the needed technical infrastructure, they are paying little attention to pedagogical variables and considerations. This is highly evident in the latest innovations to hit the educational scene: tablets and smart mobile devices.

Tablets seem to have replaced laptops that were hailed in the 1990s as the cutting-edge innovation to support students in the learning process through one-to-one laptop initiatives. Unfortunately, the perception still prevails that providing students with contemporary technologies will resolve educational access issues and transform the educational context. Over the last few years in particular, the tablets' promise has seemed so rewarding and worthwhile that a number of countries have embarked on large-scale, government-led initiatives to distribute tablets to students in the K–12 schooling sector. This is described in the report *Large-Scale, Government-Supported Educational Tablet Initiatives* (Tamim, Borokhovski, Pickup, & Bernard, 2015), published by the Commonwealth of Learning.

The purpose of the research project presented in this current report was to go beyond the general hype around tablets and smart mobile devices to investigate the evidence supporting their use in educational contexts, through a systematic review and meta-analysis of available empirical research studies.

TECHNOLOGY FOR TEACHING AND LEARNING

No one can deny the importance of digital and smart technologies and the level to which they have pervaded our society. Their impact on every aspect of our daily lives is escalating exponentially and is being sensed more than ever before. Already obsolete is the 2008 comment, "They say one of a baby's first non-verbal forms of communication is pointing. Clicking must be somewhere just after that." Today, it is understood that swiping would be what comes soon after pointing.

Research addressing the use of smart devices and tablets for teaching and learning is still in relatively early stages. Nevertheless, the argument that technology per se is beneficial for students' performance has been supported by numerous research studies. An extensive second-order meta-analysis revealed a positive moderate effect size in favour of technology-enhanced instruction when compared with traditional non-technology enhanced settings (Tamim et al., 2011). That analysis synthesised effect sizes from 25 meta-analyses, encompassing 1,055 primary studies that compared technology-enhanced settings with settings using more traditional practices. An average effect size of 0.35 was determined. Such results indicate that the performance of an average student in technology-enhanced contexts tends to be 12 percentile points higher than the performance of an average student in a technology-limited context.

Laptops have been found to increase in-class academic and collaborative tasks, note-taking activities, resource accessibility, communication and information sharing, and organisation (Kay, 2012; Kay & Lauricella, 2011a). As well, a systematic review of one-on-one laptop initiatives (Bethel et al., 2007) found that laptops might increase technology integration in learning while improving students' attitudes toward technology and slightly increasing their engagement and motivation. However, other research indicates that individual laptops do not always lead to better performance or satisfaction with courses (Wurst et al., 2008); and, used in class, may even distract students and their classmates (Fried, 2008; Kay, 2012; Sana, Weston, & Cepeda, 2012) — although when laptop use is properly structured, it seems that the distracting influence can be minimised (Kay & Lauricella, 2011b).

TABLETS AND SMART MOBILE DEVICE INITIATIVES

As would be expected with anything technology-related in this time and age, yesterday's cool gadget soon becomes old news. So it is with laptops. They are not the centre of attention anymore; tablets and smart mobile devices are the new kids on the block. This is clearly apparent in the current financial investments being allocated to furnishing classrooms and schools with such technologies.

A growing number of countries around the world have launched large-scale, government-supported initiatives to distribute tablet-computing devices to students in the K–12 schooling sector. Most of these initiatives were launched with strong enthusiasm and optimism but little critical thought and planning to allow for successful implementation. In reality, most of the projects were initiated with many of the unchecked assumptions that the One Laptop per Child (OLPC) initiative was based on.

The COL report *Large-Scale, Government-Supported Educational Tablet Initiatives* (Tamim et al., 2015) presented the findings of a systematic review of publicly available documents on government-supported tablet initiatives and related policies around the world. Among the major findings of the review:

- Increasing attention has been paid to the use of information and communication technology (ICT) around the world.
- Large-scale, government-supported tablet initiatives have been launched in 11 countries around the world: Antigua & Barbuda, Australia, Brazil, India, Iran, Jamaica, Kazakhstan, Pakistan, Russia, Turkey and the United Arab Emirates.
- The magnitude of the financial investment is significant. Investments are being made with the goal of reforming educational systems, the hope of making K–12 classrooms more motivating and engaging, and the dream of bringing literacy to children in rural areas and breaking their isolation.
- Except for a few skeptical voices, most of the 142 retrieved source documents focused on the advantages of technology for teaching and learning, and the need to use the power of ICT for the advancement of education. However, none of the identified initiatives was supported by a particular rationale or evidence for why tablets in general are expected to help achieve the articulated objectives.
- In addition to the 11 countries noted above, others are very interested in mobile learning, for reasons other than merely device distribution. Some countries, for example, are establishing stronger policies, procedures and infrastructure for enhancing the educational process for students; and providing the needed content for various mobile- and technology-enhanced initiatives to be successful.
- As for the financial and organisational models that were used while planning for the initiatives, the documents provided limited information. General reference was often made to tablets providing an overall inexpensive option for teaching use. However, there were no indications of any real cost comparison analyses for any of the projects, and no reference to procurement issues.
- Finally, the review indicated that little attention was given to educational factors that are of the greatest relevance for academics and researchers — namely, pedagogical and theoretical frameworks, accessibility of content, and teacher preparation. Content was the only one mentioned on more than one occasion within the context of tablet initiatives and other forms of educational reforms. Reference was limited to the need to digitise available content or to provide content in the official language of the country, but there was no reference to interactive content or to the need for more active involvement of students in the production of content.

Although the review was limited by the nature of the documents that were retrieved and the shortage of publicly available information, it did confirm the original assumption that most of the initiatives were launched in a hasty and uncalculated manner, similar to the uncritical enthusiasm that surrounded the One Laptop per Child initiative. In its conclusion, the report stressed the need for a more focused systematic review of the academic literature addressing tablet use in educational contexts. Such a review would allow for a better understanding about tablet effectiveness and a clearer idea about best practices.

The project described in this report presents the findings of a systematic review and meta-analysis of research studies addressing the use of tablets and smart mobile devices in educational contexts.

SYSTEMATIC REVIEWS AND META-ANALYSES

> *"Scientists have known for centuries that a single study will not resolve a major issue. Indeed, a small sample study will not even resolve a minor issue. Thus, the foundation of a science is the culmination of knowledge from the results of many studies."*
>
> (Hunter, Schmidt, & Jackson, 1982, p. 10)

As no single study can ever give conclusive evidence, there is a strong need for research syntheses that offer greater coverage of the population to be studied. Narrative reviews and vote counts are neither scientifically sound (Kline, 2004) nor adequate for yielding information that can be reliably extracted, organised, analysed and presented (Glass, 1977). Furthermore:

- They do not account for different sample sizes and the varying strength of results in different studies, they are not statistically rigorous and they do not address the size of the effect in a given study (Abrami, Cohen, & D'Appollonia, 1988; Hunt, 1997).
- They are highly subjective (Bernard & Naidu, 1990; Slavin, 1984).
- They rely heavily on statistical test outcomes, namely the p value, which is subject to all the null hypothesis testing limitations emphasised by many researchers, including Cohen (1990), Glass (1976) and Meehl (1967).

For all these reasons, systematic review methodologies started garnering more attention as a stronger alternative to narrative reviews and vote counts.

Systematic Review

Systematic reviews are literature reviews characterised by their adherence to a set of scientific methods and the objective of limiting systematic error and bias by identifying, appraising and synthesising all relevant studies (of different designs) in order to answer a particular question (Petticrew & Roberts, 2008). According to Petticrew and Roberts, a systematic review depends on seven important steps:

- Clearly define the research question to be answered by the review.
- Decide on the types of studies to be located in order to answer the question.
- Conduct a comprehensive literature search to locate studies of interest.
- Screen the search results and decide which ones meet the inclusion criteria and thus need more in-depth examination.
- Critically evaluate the included studies.
- Synthesise the findings from the studies.
- Disseminate the findings of the review.

Meta-Analysis

A meta-analysis is a particular form of systematic review in which quantitative data from multiple primary research studies is summarised in order to answer a specific research question or set of research questions. The research literature in a particular area of interest is systematically collected, coded/categorised and analysed. The research question, usually of some applied value (e.g., whether a particular treatment is effective), should be fairly well defined a priori. This informs search terms and parameters, determines inclusion criteria and guides the review process (study selection; effect-size extraction and aggregation, and analyses; and interpretation and presentation of the findings).

Most meta-analyses follow a general set of steps or procedures. The investigation undertaken and reported here follows the meta-analysis approach described in Cooper (2010) (see text box on next page).

See Appendix A: Quantification in Meta-Analysis and Calculation of Effect Sizes, for details about meta-analysis methodology.

The approach below to meta-analysis, as described in Cooper (2010), was followed by the investigation reported here:

1. Formulate the problem and state the research question (i.e., articulate review objectives, definitions, inclusion and exclusion criteria, etc.).

2. Search the literature (i.e., identify appropriate search terms and parameters, including the relevant databases, indices and journals to search, and the time frame and types of publication). The results of the searches are collected and organised, usually with some bibliographic record management system (e.g., EndNote).

3. Gather information from identified studies (i.e., make inclusion/exclusion decisions, extract effect sizes, code for methodological, substantive, demographic and other relevant study characteristics). Considerations of reliability (i.e., independent double coding) and thorough documentation of all review decisions (including reasons for exclusion and statistical precision of effect-size extraction procedures) are of particular importance at this stage of a meta-analysis.

4. Evaluate the quality of admitted primary research (i.e., recognise and assess threats to all types of validity — internal, external, construct and statistical — of included studies [as outlined, for instance, in Valentine & Cooper, 2008]).

5. Analyse and integrate the outcomes of research (i.e., conduct publication bias and sensitivity analyses; synthesise individual effect sizes to produce the weighted average effect–population estimate; evaluate and explain variability by means of moderator variable analyses).

6. Interpret the evidence (i.e., integrate findings to draw main conclusions, identify and describe the best practices, address limitations, offer recommendations for research and practice, etc.).

7. Present the results (i.e., integrate outcomes of the previous step in a comprehensive report, devise and implement knowledge transfer strategy and activities, tailor presentation for various target audiences, etc.).

OBJECTIVES

The current research project is a follow-up to the systematic review of large-scale government-supported educational tablet initiatives around the world (Tamim et al., 2015). As noted earlier, that review concluded with the recommendation for an in-depth investigation into the effect of tablets and smart mobile devices on students' performance in educational contexts.

The overall purpose of the current review was therefore to identify, collect and summarise available empirical evidence of the effects of the educational use of tablets and smart devices on student learning.

Given the relatively recent introduction of tablets and smart devices into the classroom context, and the likely lack of experimental research in the area, the decision was made to systematically review both quantitative and qualitative research studies.

Meta-Analysis

To synthesise the quantitative literature, the meta-analytical approach was used. The preliminary review of relevant literature identified two types of studies, leading to two complementary but distinct research questions:

1. What is the effectiveness of using tablets and smart mobile devices for educational purposes (i.e., experimental condition) versus using more traditional means of instruction (i.e., control condition), including the use of laptops and stationary computers, as assessed by measures of student learning achievements?
2. What is the effectiveness (i.e., added value) of using, for educational purposes, tablets with additional technological features/applications or pedagogical modifications (i.e., experimental condition) versus using tablets without these features or modifications (i.e., control condition)?

Qualitative Research Review

For the qualitative research studies, the review focused on identifying relevant case studies that would offer an answer to the following research question:

1. Considering different qualitative case studies, what are some of the characteristics of effective tablet and smart mobile device use as perceived by students?

METHODOLOGY

Given the specified research questions, there were no limitations for including studies in terms of their subject matter, participants' population or geographical location. However, because of time restrictions and the composition of the research team, only studies in English were considered.

From that starting point, a set of inclusion criteria was established to determine which primary studies to include in the meta-analysis. To be admitted, each study had to:

- have been published no earlier than 2010;
- feature educational use of tablets and smart mobile devices but not laptops or smartphones;
- allow for comparison between two instructional conditions – These comparisons could be of two types: 1) with versus without educational use of tablet computers (Research Question 1); or 2) ameliorated (technologically or pedagogically) use of tablet computers versus their use without such modifications (Research Question 2).
- represent all types of research designs (except for "one group pre-to-post-test" pre-experimental design) – In the latter category of study design, comparison is made not between two instructional conditions but between student learning outcomes before and after the tablet-based educational intervention. This is incompatible with the rest of the research (even post-test-only non-equivalent groups pre-experimental design) admitted to the meta-analysis. However, when sufficiently described, these studies could contribute to our understanding of tablet-based instructional interventions. As such, studies of this particular research design were considered for possible inclusion in the category of qualitative research to contribute to the pool for drawing case studies to exemplify the intervention in question.
- describe primary empirical research (i.e., excluding "description" or "opinion" articles and reviews of research);
- be conducted in a formal educational setting (i.e., schools and universities, excluding workplace professional development courses or informational sessions for patients in healthcare facilities), in the field of general education (so, excluding medical education, military training, etc.);
- address a general population of students (i.e., excluding students with special needs, such as "at-risk" students and students with learning disabilities);
- report measures of student achievement outcomes associated with the above-designated comparisons (e.g., exams, course grades, composite scores of various assignments/projects, and standardised and non-standardised achievement tests); and
- contain sufficient statistical information to enable effect-size extraction.

Failure to meet any of these criteria resulted in discarding the study from further analyses.

Search Strategy and Outcomes

A fairly broad search strategy was developed, but was still targeted at educational use of tablet-type mobile devices. The aim was to locate recently published research into the effectiveness of classroom tablet interventions within the education literature. The following keywords were used, with some variation to account for the particularities and controlled vocabulary of specific databases:

Subject/Domain: Tablet* OR Phablet* OR "mobile device" OR ipad

Outcomes: Achieve* OR Learn*

To exclude the large number of non-experimental publications in this topic area, a further group of keywords was used:

Methods: Experiment* OR Study OR "Control Group" OR Evaluation OR Effective* OR Comparison OR "Post Test"

Where available, additional search filters such as Date Limit (2010 onwards) and Publication Type were employed. Furthermore, most searches employed the NOT operator to remove results that had been assigned a controlled vocabulary term indicating that the research addressed special needs students (e.g., NOT DE "Special Needs Students" in the Education Resource Information Center [ERIC] database). The text box here shows a sample search.

SAMPLE SEARCH OF THE EDUCATION RESOURCE INFORMATION CENTER (ERIC) DATABASE:

(tablet* OR phablet* OR "mobile device" OR ipad) AND (achieve* OR learn*) AND (experiment* OR study OR "control group" OR evaluation OR effective* OR comparison OR "post test")

Limiters - Date Published: 20100101-20151231; Publication Type: Reports - Descriptive, Reports - Evaluative, Reports - Research

Results: 162
NOT DE "Special Needs Students" = 158

The following databases were searched: ERIC; Education Full Text (Wilson); Education Source; EdITLib; and ProQuest Dissertations & Theses.

After removal of duplicates (same studies located in different databases or same data used in different publications [e.g., a dissertation and a journal article based on it]), a total of 1,010 unique records were retrieved at the abstract level. After abstract screening, 233 studies were retained for the full-text review.

Coding Study Characteristics

To guide the review of identified primary studies that met inclusion criteria, a code book of categories for important study features (characteristics) was developed.

- *Methodological study features* describe research design, outcome measures, and statistical procedures for effect-size extraction
- *Demographic study features* address age of learners, country of the study, subject matter, and duration of the treatment
- *Substantive technological study features* address the effect of particular types of mobile devices and their technological characteristics and applications used in instruction, as well as technology presence and type in control conditions
- *Substantive pedagogical study features* account for the influence of various pedagogical frameworks and approaches on the effects of tablet computers use

RESULTS

Meta-Analysis Results

The initial literature searches produced 1,010 hits. Abstract screening and full-text review (see Appendix B) reduced that original set of documents to a final 27 primary empirical research studies to be included in the meta-analysis.

These studies yielded 40 independent effect sizes related to student achievement outcomes that informed the two research questions:

1. What is the effectiveness of using tablet computers for educational purposes versus using more traditional means of instruction as assessed by measures of student learning achievements?
2. What is the effectiveness of using, for educational purposes, tablet computers with additional technological features/applications or pedagogical modifications versus using tablet computers without these features or modifications?

From the 40 independent effect sizes, 28 were relevant to Research Question 1 and 12 were relevant to Research Question 2. A summary of the basic information of the included studies addressing each of the two questions is provided in Tables 1 and 2, respectively.

Table 1: Basic information for included quantitative research studies addressing Research Question 1

STUDY AUTHORS	YEAR	COUNTRY	DEVICES	SUBJECT MATTER	GRADE LEVEL	OUTCOME MEASURE	N	ES	OVERVIEW
Amick & Cross	2014	USA	iP	S	PS	T	72	0.214	Students in the experimental group were provided with iPads during lectures and lab sessions (using Notability for note taking, and Dropbox and Google drive for sharing files) while students in the control group were not given iPads.
Austin	2012	USA	T-PC	S	ES	T	102	-0.215	Students in the experimental group used the Dell Streak Android device while the students in the control group were restricted from using it until after the testing period was over.
Carr	2012	USA	iP	M	ES	T	104	-0.002	Students in the experimental group used iPads as 1:1 computing devices on a daily bases during Mathematics class while students in the control group did not use them.
Conley	2013	USA	iP	NS	PS	T	252	0.162	Students in the experimental group were provided with a high-augmented reality experience (3D images coupled with movement through a physical space) while students in the control group were not exposed to any augmented reality experience.
Dundar & Akcayir	2012	Turkey	T-PC	L	ES	T	20	0.430	Students in the experimental group read e-textbooks on an electronic tablet PC display while students in the control group read ordinary printed books.
Empirical Education Inc.	2012	USA	iP	M	SS	E	1,204	0.026	Students in the experimental group used the Houghton Mifflin Harcourt's Fuse: Algebra 1 application, which includes interactive lessons, explanations, quizzes and problem solving, while students in the control group did not use any iPad application.
Enriquez	2010	USA	T-PC	E	PS	T	69	0.166	Students in the experimental group used an Interactive Learning Network (ILN) with tablet PC when taking a Circuits class, while students in the control group did not use it.
Feltman	2013	USA	iP	S	SS	T	61	-0.063	Students in the experimental group were exposed to interactive iPad-based environments while students in the control group received textbook-based instructional format.
Hawkes & Hategekimana	2010	USA	T-PC	L	PS	T	145	-0.160	The achievement of students who were using tablet PCs was compared with that of those who were not, without any specifications of the particulars of the tablet PCs' use.

STUDY AUTHORS	YEAR	COUNTRY	DEVICES	SUBJECT MATTER	GRADE LEVEL	OUTCOME MEASURE	N	ES	OVERVIEW
Lan et al.	2010	Taipei	T-PC	M	ES	O, T	28	-0.048	Students in the experimental group were exposed to problem-based estimation instruction using mobile devices while students in the control group were offered problem-based estimation instruction without mobile devices.
Liao et al.	2013	Taiwan	T-PC	L	ES	T	116	0.721	Students in the experimental group used a drawing and writing system on tablet PC mobile devices for their language learning while students in the control group were provided with conventional language instruction with no tablet PCs.
Liu & Lee	2013	Taiwan	iP	M	ES	T	316	0.257	Students in the experimental group were taught geometry in a multi-phase teaching procedure that included information, guided orientation, cooperative learning, integration and deduction phases, while using the Smartboard, iPad and Cbri3D software. Instruction in the control group was delivered with the help of regular textbooks and worksheets.
Martin & Ertzberger	2013	USA	Cs	ID	PS	T	109	-0.364	Students in the experimental group were given maps and iPads with QR Readers installed and asked to scan the QR codes when they were at subject paintings (in real time) and to read information about them. Students in the control group viewed paintings and came back to class, where they read information about the paintings from a computer.
McCollum. et al	2014	Canada	iP	S	PS	T	102	0.718	Students in the experimental group were provided with manipulable projections of 3D molecular structures on an iPad while control students used printed 2D ball-and-stick images of molecules.
Oh et al.	2014	Korea	T-PC	L	M	T	161	0.149	Students in the experimental group were offered English language instruction while using tablet PCs; students in the control group were provided traditional paper-based instruction.
Probst	2014	USA	T-PC	M	PS	T	119	0.225	Students in the experimental group used a technology-enhanced tablet PC learning environment, enabling them to use a virtual pen and take notes on pre-prepared instructional material and collaborate through a discussion area with each slide. Students in the control group were provided with non-technology, lecture-based instruction.

STUDY AUTHORS	YEAR	COUNTRY	DEVICES	SUBJECT MATTER	GRADE LEVEL	OUTCOME MEASURE	N	ES	OVERVIEW
Simoni	2011	USA	T-PC	E	PS	T	69	0.384	Students in the experimental group used tablet PCs with interactive course software in Integrated Circuit courses while students in the control group did not have access to tablet PCs.
Wierson	2013	USA	iP	L	ES	T	44	-0.103	Students in the experimental group used the Vocabulary Central Grade 6 iPad application while students in the control group did not have access to iPads.
Wilson et al.	2013	USA	P	M	ES	RC	131	0.125	The math achievement of students who were using iPads was compared with that of students who were not using them, without any specifications of the particulars of the iPad use.
Yixin	2011	USA	T-PC	M	ES	T	93	0.303	Students in the experimental group were offered instruction with the use of handheld tablet PCs while students in the control group were not offered instruction.
Zapatero et al.	2012	USA	T-PC	IA	PS	T	NS	0.075	Students in the experimental group received collaborative instruction using tablet PCs in a hybrid format (face-to-face and online components) while students in the control group received traditional lecture-based instruction.

GRADE LEVEL
ES = Elementary school
SS = Secondary school
PS = Post-secondary
M = Mixed

DEVICES
T-PC = Tablet PC
iP = iPad
Cs = Combination

SUBJECT MATTER
L= Language
M = Math, including statistics
S = Science
E = Engineering
ID = Instructional design
IA = Information analysis

OUTCOME MEASURE
T = Test
RC = Report card
O = Observation
E = Experiment

Table 2: Basic information for included quantitative research studies addressing Research Question 2

STUDY AUTHORS	YEAR	COUNTRY	DEVICES	SUBJECT MATTER	GRADE LEVEL	OUTCOME MEASURE	N	ES	OVERVIEW
Huang et al.	2014	Taiwan	T-PC	S	PS	T	63	2.066	Students in the experimental condition used Google+ platform on tablet PCs with a jigsaw-based collaborative learning approach, while students in the control condition used the Google+ platform on tablet PCs individually and without the opportunity for collaboration among them.
Lehtinen & Viiri	2014	Finland	T-PC	S	SS	E	36	0.862	Students in the experimental condition used tablets as tools for learner-generated drawings in the context of teaching the kinetic theory of gases while being assisted with another drawing to compare theirs with. Students in the control condition used tablet PCs for the same purpose without the provision of drawing assistance.
Lin et al.	2011	NS	T-PC	SS	ES	E	64	-0.040	Students in the experimental condition worked collaboratively in groups using a tablet PC to create concept maps while students in the control condition used the tablet PCs individually to create the concept maps.
Liu et al.	2012	Taiwan	PDA	S	ES	E	81	-0.600	Students in the experimental condition used texts with pictures embedded in the PDA and real objects outside the PDA. Students in the control condition used the texts with pictures embedded in the PDA and no real objects provided.
Liu et al.	2013	Taiwan	T-PC	S	ES	T	74	0.858	Students in the experimental condition used tablet PCs with cued text with pictures while students in the control condition used tablet PC with un-cued text with pictures.
Tutty	2013	USA	Cs	ED	PS	T	151	1.319	Students in the experimental conditions were offered aligned practice or reflective practice with tablet devices while students in the control condition were not offered any level of tablet device practice.

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Inter-rater reliability for the effect-size calculations (i.e., identification of conditions for comparison, accuracy of data extraction, and selection and application of formulas) was 89.5% (Cohen's $\kappa = 0.79$). The following sections report the findings of the meta-analysis organised by the research questions.

All statistical analyses were performed using the BioStat CMA 2.2. software package (Borenstein, Hedges, Higgins, & Rothstein, 2005).

Publication Bias and Outlier Analysis

Publication bias analysis is used to determine if there might have been studies overlooked in searches and therefore not included in a meta-analysis that would substantially affect its findings (Rothstein, Sutton, & Borenstein, 2005). Publication bias analysis employs several complementary statistical procedures, each addressing a slightly modified applied question.

- Visual examination of a funnel plot (effect size by standard error) allows researchers to evaluate the symmetry of the distribution of weighted effect sizes and recognise positions of potentially missing studies that would balance this distribution.
- Classic Fail-Safe Analysis (Rosenthal, 1979) determines how many null-effect studies it would take to bring the probability of the average effect to the predetermined α (e.g., 0.05).
- Orwin's (1983) Fail-Safe Procedure specifies the number of null-effect studies that may be needed to bring the average effect size to some trivial value (e.g., $g+ = 0.10$).
- Duval and Tweedie's (2004) Trim and Fill Procedure seeks to specify the number of potentially missing effect sizes that would allow achieving symmetry between effect sizes below and above the mean. It recalculates the average effect sizes that would result if these missing studies were added (imputed).

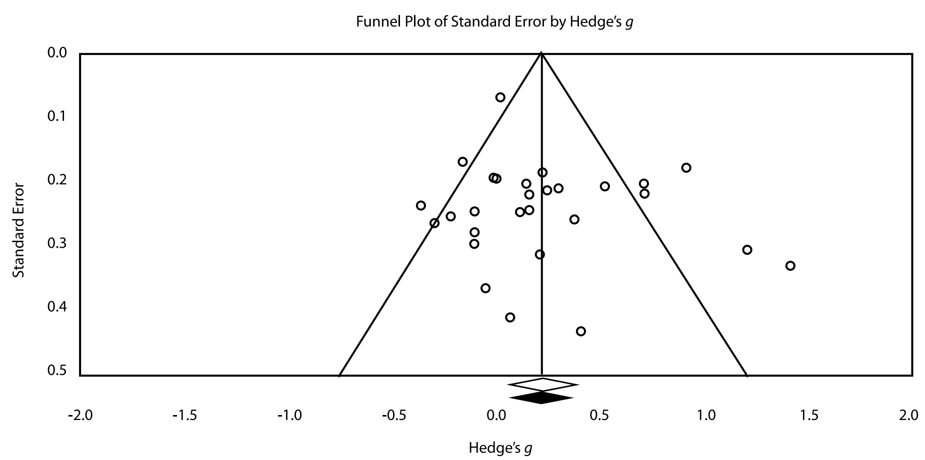
Outliers (effects of atypical magnitude) can substantially distort the overall average weighted effect size and variability that surrounds it. In the fixed-effects model, this distortion is more influential because of the study-weighting procedure described earlier (Viechtbauer & Cheung, 2010). The random-effects model is better protected from the distortion because it incorporates average between-study variance into the respective study weights. Regardless, special attention should be paid to ensure that "high-leverage" studies (large magnitude effects combined with large sample sizes) do not over-influence findings in meta-analysis.

In addition to visual examination of the distribution of effect sizes, a procedure known as "one study removed" is used to assess the influence of each individual effect size on the entire collection of effects by routinely removing one effect size in turn and recalculating the overall average weighted effect size accordingly (Borenstein et al., 2005).

Results of publication bias analysis for Research Question 1

The funnel plot for the first research question (k = 28) is presented in Figure 1. It depicts a fairly balanced distribution of effect sizes both inside and outside of the funnel of standard errors.

Figure 1. Funnel plot for achievement outcomes (k = 28) for Research Question 1 with no imputed values.

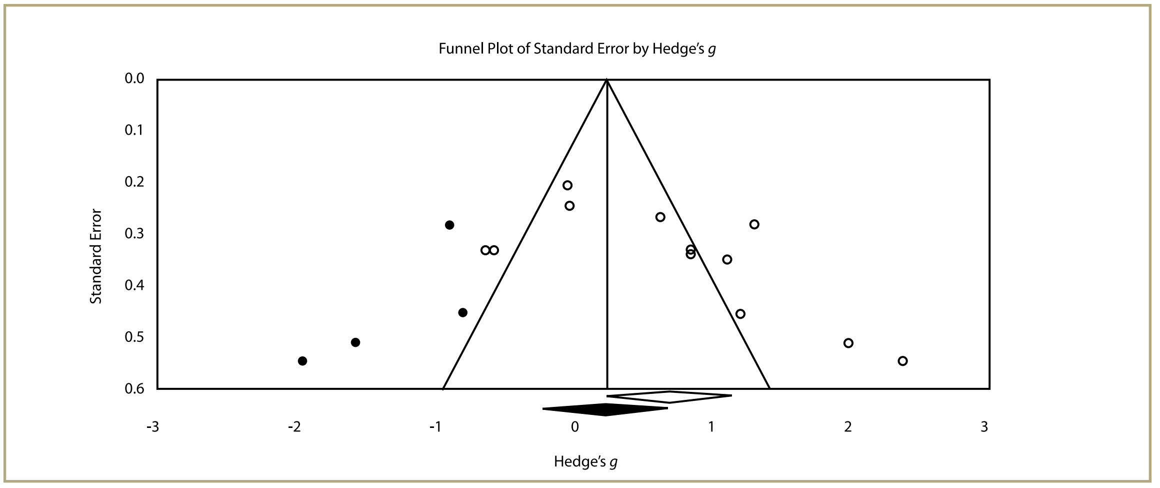


According to the results of the Classic Fail-Safe Analysis for the achievement data informing Research Question 1, a total of 166 additional null-effect studies would be required to "nullify" the observed average weighted effect size of $g+ = 0.226$ (i.e., to make the overall probability exceed $\alpha = .05$). In addition, the results of Orwin's Fail-Safe Procedure indicate that 20 additional null-effect studies would be necessary to trivialise $g+$ (i.e., to bring it down to the level of 0.10). Duval and Tweedie's Trim and Fill Procedure found that no studies should be added to the negative side of the distribution to achieve symmetry, either in the fixed- or random-effects models. Overall, these results suggest that there is no evident publication bias in this particular dataset.

Results of publication bias analysis for Research Question 2

The funnel plot for the second research question ($k = 12$) shows some misbalance in favour of positive effects, so that imputation of additional studies is needed to achieve symmetry in the distribution (Figure 2).

Figure 2. Funnel plot for achievement outcomes (k = 12) for Research Question 2 with four imputed values (in black).



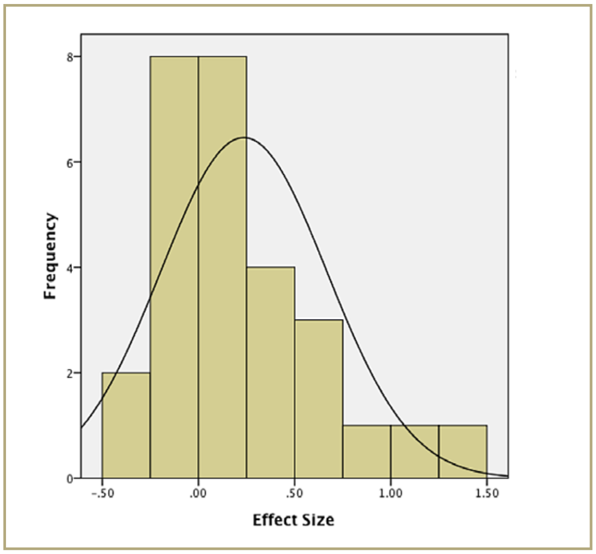
The same set of publication bias analyses were applied to Research Question 2 achievement outcomes. The results: with the Classic Fail-Safe Analysis, 113 additional null-effect studies would "nullify" the observed $g+ = 0.679$; with Orwin's Fail-Safe Procedure, 45 additional null-effect studies would bring the overall $g+$ to the trivial value of 0.10); and Duval and Tweedie's Trim and Fill Procedure suggested the need of imputing 4 negative-effect studies to balance the current distribution of the effect sizes. With these imputations, $g+$ would assume values of 0.374 and 0.447 — under the fixed- and random-effects models, respectively.

All of the above may indicate the presence of a minor degree of publication bias, probably due to high expectations for the new technology and tendency to focus attention on the research related to the more innovative use of that technology to answer to those promises.

Results of outlier analysis for Research Question 1

Twenty-eight achievement effect sizes pertaining to Research Question 1 ranged in magnitude from -0.36 *sd* to +1.42 *sd*. No obvious outliers (e.g., exceeding 2.05 *sd*) were detected. Subsequently, no adjustments were made to either negative or positive ends of the effect-size distribution shown in Figure 3. The distribution seems slightly skewed (1.22), with the majority of effects clustering around the zero-point with the unweighted average of 0.24 and standard deviation of 0.43. "One study removed" analysis found no overly influential effect sizes that would lead to misrepresentation of the findings (neither overestimations nor underestimation of the overall average weighted effect size).

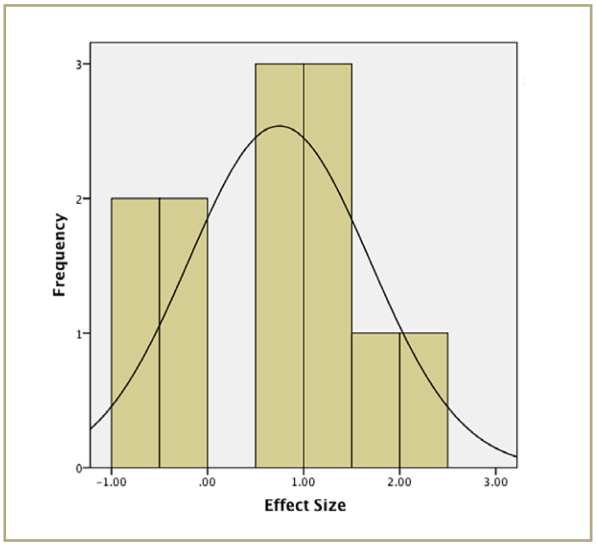
Figure 3. Histogram of achievement effect sizes (*k* = 28) for Research Question 1.



Results of outlier analysis for Research Question 2

Twelve achievement effect sizes informed Research Question 2. They ranged in magnitude from -0.63 *sd* to +2.37 *sd* (a distribution much wider than for Research Question 1). Though no obvious outliers were detected either, there were two relatively distinct clusters — groups of positive and negative effects — in the distribution (Figure 4) with the unweighted average of 0.75 and standard deviation of 0.94. No outliers resulted from "one study removed" analysis.

Figure 4. Histogram of achievement effect sizes (*k* = 12) for Research Question 2.



Overall Effects

Findings were aggregated using the random-effects model to produce the average weighted effect size for each research question. The fixed-effects model produced the corresponding estimates of heterogeneity of findings (i.e., Q_{Total} and I^2 statistics). In case significant heterogeneity in the entire distribution was found, the subsequent moderator variable analyses used the mixed model to further explore and explain variability (i.e., identify sources of systematic variations) in the effect sizes (Borenstein et al., 2009).

Table 3 reports average weighted effect sizes for student achievement outcomes in both fixed- and random-effects models, alongside associated statistics (standard errors, 95% confidence intervals and measures of heterogeneity). All $g+$ are positive and statistically significant (neither 95% *CI* crosses the zero-point).

For Research Question 1 (tablets vs. no tablets), the random-effects model analyses of student achievement outcomes resulted in an average weighted effect size of $g+ = 0.23$ ($k = 28$), low in magnitude according to most conventional classifications for social sciences (Cohen, 1988), but still statistically significant ($p = .002$). That effect size was, however, substantially smaller than the random effects average of achievement outcomes for Research Question 2 (tablets+ vs. tablets): $g+ = 0.68$ ($k = 12$), moderate to high magnitude in Cohen's terms, and statistically significant ($p = .004$). No direct comparison is possible between these two datasets, but the results suggest that specifically designed technology-based instructional interventions have higher potential to support learning than does relying on modern technology per se. This suggestion is fully in line with the findings of previous research in technology integration in education (e.g., Schmid et al., 2014).

The results also suggest that the effects on student achievement outcomes are dichotomised (predominantly positive or predominantly negative, with a sizable gap in between – see Figure 4), implying that additional attention should be paid to how to integrate technology in teaching and learning processes rather than leaving technological advancements (both tools and applications) to work for themselves with little or no pedagogical guidance.

Table 3: Overall achievement effects by research question

	k	*g+*	LOWER 95TH	UPPER 95TH
RESEARCH QUESTION 1: Tablets vs. no tablets				
Random-effects model	28	0.226	0.08	0.37
Fixed-effects model	28	0.171	0.10	0.24
Heterogeneity (fixed-effect model)	$Q_T = 85.74$	$df = 27$	$p < .001$	$I^2 = 68.51$
RESEARCH QUESTION 2: Tablets+ vs. tablets				
Random-effects model	12	0.679	0.22	1.14
Fixed-effects model	12	0.471	0.29	0.65
Heterogeneity (fixed-effects model)	$Q_T = 69.80$	$df = 11$	$p < .001$	$I^2 = 84.24$

The fixed-effects model average weighted effect sizes were $g+ = 0.17$ ($k = 28$) for Research Question 1 and $g+ = 0.47$ ($k = 12$) for Research Question 2. Also, the fixed-effects model analyses established significant heterogeneity of both distributions ($Q_T = 85.74$ and $Q_T = 69.80$, respectively, both $p < 0.001$. The corresponding I^2 values were 68.51 and 84.24.

There are two major implications of these findings. First, the findings denote the differential effects of various instructional interventions that use tablet-type mobile devices. Second, the findings warrant moderator variable analyses to explain systematic variations in effect sizes by comparing the influence on student learning of different levels of coded study characteristics. The next sections report on the results of these moderator variable analyses, separately for Research Question 1 and Research Question 2.

Moderator Variable Analyses for Research Question 1

The set of moderator variable analyses below were carried out to explain under what circumstances (described by the corresponding methodological, substantive and demographic study features) the effects of educational tablet use, as compared to no use (Research Question 1), tend to be more or less evident. The three types of study features were coded for subsequent use in moderator variable analyses.

The mixed model was used throughout the entire set of moderator variable analyses.

Methodological study features

Table 4 summarises the results of methodological study features to inform Research Question 1. The following characteristic were coded and analysed: study research design, precision of the effect-size extraction procedures, and source of outcome measure. The main objective of this set of analyses was to ensure that the meta-analysis findings were unaffected by variations in the methodological quality of included studies and thus would not be questioned on the grounds of admitting unreliable evidence to the review (e.g., Eysenck, 1978).

Table 4: Comparison of levels of methodological study characteristics for Research Question 1 (*k* = 28)

	k	*g+*	LOWER 95TH	UPPER 95TH	Q_B *(df, p)*
RESEARCH DESIGN Experimental (RCT)	4	0.209	-0.33	0.75	
Quasi-experimental (QED)	13	0.233	0.01	0.45	
Pre-experimental (Pre-X)	11	0.216	-0.01	0.44	
Q between					0.02 (2, .99)
METHODS OF EFFECT-SIZE EXTRACTION					
Calculated from descriptive and inferential statistics	21	0.273	0.08	0.47	
Estimated from *p*-values, etc.	7	0.048	-0.06	0.16	
Q between					3.88 (1, .05)
SOURCE OF OUTCOME MEASURE					
Cumulative final assessment	22	0.236	0.05	0.42	
Other means of assessment	6	0.189	-0.04	0.42	
Q between					0.10 (1, .75)

As Table 4 shows, the methodological quality of studies included in the meta-analysis had little influence on the effect sizes. Marginally significant were outcomes of the analysis of two levels of the source of outcome measure moderator variable in favour of effect sizes calculated using reported descriptive and inferential statistics as the variable compares with various forms of effect-size estimation (e.g., *p*-values under or above particular conventional levels): $Q_B = 3.88, p = .05$. This result should not, however, be of concern, being on the edge of statistical significance. Potentially more concerning would be the reversal of the observed tendency when imprecision in calculations might lead to the overestimation of the average weighted effect size.

Substantive study features

As described earlier, an objective of this study was to explore whether the actual educational practice of using tablet-type mobile devices influenced the effectiveness of their use in improving student achievement outcomes. The quality of reporting in the reviewed studies allowed for relatively confident coding of only a few aspects of technology-related aspects of instructional interventions in question: presence/absence of technology (other than mobile devices used by students in experimental groups) in control conditions; type of mobile devices used; and primary objectives of their use (eventually reduced to contrasting predominantly teacher-controlled activities and various forms of learning activities favoured by students).

Findings of this set of moderator variable analyses are summarised in Table 5.

Table 5: Comparison of levels of substantive study characteristics for Research Question 1 (*k* = 28)

	k	*g+*	LOWER 95TH	UPPER 95TH	Q_B (*df, p*)
TECHNOLOGY IN CONTROL CONDITION					
Yes	3	0.411	-0.20	1.02	
No	25	0.208	0.05	0.37	
Q between					0.40 (1, .53)
TYPE OF MOBILE DEVICE*					
iPad	11	0.193	-0.03	0.41	
Tablet PC	16	0.293	0.09	0.50	
Q between					0.43 (1, .51)
OBJECTIVE OF TECHNOLOGY USE					
Teacher-controlled	24	0.257	0.09	0.42	
Various student-centred uses	4	0.062	-0.26	0.38	
Q between					1.14 (1, .29)

* Reduction of cases from *k* = 28 to *k* = 27 because of missing data. The particular mixture of mobile devices in one study was problematic to identify.

None of the analysed substantive study characteristics resulted in statistically significant differences across the levels of each moderator variable. Thus, there was no evidence that these aspects of the educational use of tablet-type mobile devices had any specific influence on the overall student achievement outcomes.

Demographic study features

Moderator variable analyses of demographic study characteristics was intended to address questions of whether population factors — such as who uses mobile technology for learning, and what for, where and for how long — have different effects on student achievement outcomes. In terms of geographical location, studies conducted in North America (U.S. and Canada) were compared with studies conducted in other countries (as one combined set).

The results are presented in Table 6.

Table 6: Comparison of levels of demographic study characteristics for Research Question 1 (*k* = 28)

	k	*g+*	LOWER 95TH	UPPER 95TH	Q_B *(df, p)*
AGE OF LEARNERS					
Elementary school – Grades 1–6	12	0.306	0.0	0.57	
Secondary school –Grades 7–12	2	-0.028	-0.26	0.20	
Post-secondary education	14	0.214	0.02	0.41	
Q between					3.97 (2, .14)
SUBJECT MATTER DOMAIN					
STEM*	18	0.290	0.10	0.48	
Non-STEM	10	0.114	-0.10	0.33	
Q between					1.41 (1, .24)
TREATMENT DURATION**					
Short experiments	7	0.507	0.16	0.86	
Close to one semester	10	0.227	0.02	0.48	
Longer than one semester	7	0.058	-0.05	0.17	
Q between					6.61 (1, .037)
GEOGRAPHICAL REGION					
U.S. and Canada	22	0.167	0.02	0.32	
Other regions	6	0.442	0.12	0.76	
Q between					2.32 (1, .13)

* STEM = STEM education (science, technology, engineering and mathematics).

** Reduction of cases from *k* = 28 to *k* = 24 because of missing data. In four studies, treatment duration was not specified.

There was only one statistically significant finding. It appears that the shorter the duration of the intervention was, the higher effect size it produced: $Q_B = 6.61$, $p = .037$. The most plausible explanation would be to attribute this difference to the well-recognised "novelty effect" (e.g., Clark & Sugrue, 1988), especially with the most recent and fashionable technological gadgets — a novelty that tends to dissipate with passing time (because, for example, use of gadgets becomes habit-forming, and enthusiasm diminishes as inconveniences are discovered).

Moderator Variable Analyses for Research Question 2

The findings of the moderator variable analyses of methodological, substantive and demographic study characteristics pertaining to Research Question 2 (the effects on achievement of augmented tablet use as compared to unmodified tablet use) are discussed below.

Methodological study features

The results of the methodological study features — study research design, precision of effect-size extraction, and source of outcome measure — are shown in Table 7.

As in the case for Research Question 1, the only significant difference in this analysis was found between precisely calculated and estimated effect sizes: $Q_B = 9.01$, $p = .003$. The same explanation, affirming the merits of being more conservative, applies here as well (i.e., not to allow the overestimation of the effect due to incomplete data while relying more on exact figures): there is no reason based on the assessed aspects of methodological quality for doubting the overall findings of the meta-analysis.

Table 7: Comparison of levels of methodological study characteristics for Research Question 2 (*k* = 12)

	k	*g+*	LOWER 95TH	UPPER 95TH	Q_B *(df, p)*
RESEARCH DESIGN					
Experimental (RCT)	5	0.955	0.33	1.58	
Quasi-experimental (QED)	7	0.311	-0.44	1.06	
Q between					1.68 (1, .20)
METHODS OF EFFECT-SIZE EXTRACTION					
Calculated from descriptive and inferential statistics	8	1.081	0.58	1.58	
Estimated from *p*-values, etc.	4	-0.106	-0.70	0.49	
Q between					9.01 (1, .003)
SOURCE OF OUTCOME MEASURE					
Cumulative final assessment	9	0.607	0.02	1.19	
Other means of assessment	3	0.926	0.54	1.31	
Q between					0.80 (1, .37)

Substantive study features

Only two substantive technology-related study characteristics were analysed for Research Question 2: type of mobile devices used and the major objective of their use (in this case, tablets were used by students mostly for communication purposes). By definition, tablets were present in both experimental and control conditions in this collection of primary research studies. Findings are summarised in Table 8.

Table 8: Comparison of levels of substantive study characteristics for Research Question 2 (*k* = 12)

	k	*g+*	LOWER 95TH	UPPER 95TH	Q_B *(df, p)*
TYPE OF THE MOBILE DEVICE					
PDA & iPad	3	0.350	-0.76	0.06	
Tablet PC	7	1.099	0.51	1.68	
Mixture of various mobile devices	2	0.957	0.29	1.63	
Q between					6.76 (2, <.001)
OBJECTIVE OF THE TECHNOLOGY USE					
Teacher-controlled	7	0.372	-0.18	0.93	
Predominantly communication among students	5	1.197	0.32	2.08	
Q between					2.41 (1, .12)

Although the moderator variable analysis detected a highly significant difference among levels of the type of device study feature ($Q_B = 6.76, p < .001$), the number of cases in each level (especially representing an unspecified mixture of various tablet-like mobile devices) was too small for any meaningful interpretation or generalisation of the findings.

Demographic study features

The following demographic study characteristics were coded and analysed: age of learners, subject matter domain, treatment duration, and geographical region (due to multiple regions represented by just a single study, these data were dichotomised to contrast studies conducted in the U.S. and anywhere else around the globe). Results of these moderator variable analyses are summarised in Table 9.

Table 9: Comparison of levels of demographic study characteristics for Research Question 2 (*k* = 12)

	k	*g+*	LOWER 95TH	UPPER 95TH	Q_B (*df, p*)
AGE OF LEARNERS					
Elementary & secondary school combined	6	0.247	-0.34	0.84	
Post-secondary education	6	1.150	0.44	1.86	
Q between					3.68 (1, .055)
SUBJECT MATTER DOMAIN					
STEM*	8	0.837	0.13	1.54	
Non-STEM	4	0.442	-0.17	1.05	
Q between					0.69 (1, .41)
TREATMENT DURATION					
Short experiments	3	0.922	0.50	1.34	
Not specified	9	0.605	0.02	1.19	
Q between					0.75 (1, .39)
GEOGRAPHICAL REGION					
U.S.	3	0.609	-0.18	1.40	
Other regions	9	0.722	0.10	1.34	
Q between					0.05 (1, .82)

* STEM = STEM education (science, technology, engineering and mathematics).

The only outcome approaching (but not reaching) the level of statistical significance was the difference between the combined set of elementary and secondary school students and the learners in post-secondary educational settings: $Q_B = 3.68$, $p = .055$. It could well be that the older student population is more prepared to benefit from the added value of instructional design, pedagogy and specialised applications for mobile devices in their learning than students of younger ages, though this interpretation (as based on the data just approaching statistical significance and representing a limited number of cases) should be considered cautiously and as just a possible tendency.

Qualitative Research Synthesis

As noted earlier, the abstract screening and full-text review resulted in 41 studies being selected for the qualitative research review. An important objective of that review was to identify case studies that would offer an in-depth understanding of the effective use of tablets and smart mobile devices as perceived by the students.

This task proved to be harder than expected. The most fundamental challenges were directly related to the nature of the research studies, namely the narrow scope of the projects and/or limited information provided in the articles, which did not allow for critical analysis and reflection. Nevertheless, substantive study features and characteristics were extracted. These, along with a brief overview and overall findings for each of the studies, are summarised in Table 10.

Table 10: List of basic information for included qualitative research studies

STUDY AUTHORS	YEAR	COUNTRY	DEVICES	SUBJECT MATTER	GRADE LEVEL	N	OVERVIEW	OVERALL
Ahern-Dodson & Comer	2013	USA	iP	L	PS	86	Students from Environmental Sciences, French, Public Policy and Writing courses used various apps (Backboard, Notes…) for journal and essay writing, note taking and communicating.	Students found iPads useful for note taking but not as beneficial for in-depth composing. The tablet seemed to increase distinctions between different phases of the writing process.
Belcher	2014	USA	iP	NS	SS	834	Students were provided with iPads as extra resources to enhance instruction. The majority of students opted to pay a "take- home fee" to extend learning beyond the school day.	Students appreciated the ease of access to technology and noted an improvement in their organisation and note-taking skills. The 24/7 access to iPads seemed to increase student–teacher communication.
Benevides	2013	Canada	iP	L	SS	6	Students took part in reading e-books, taking notes (both in print and audio form), and using educationally relevant apps.	Students' motivation for reading was increased and their reading comprehension seemed to also benefit from working with the iPads.
Boyce et al.	2014	USA	iP	S	ES	55	Students participated in a nature hike during which they were provided with one iPad per pair of students. iPads had a GO app that was paired with the camera and notebook app.	iPads were used as resources (information reference) and data collectors (digital pictures and note taking). The seamless integration and ease of use indicates that tablet technology is supportive of field-based nature learning.
Bryer et al.	2014	UK	iP	L	SS	NS	Students used the iPads to respond creatively, through the medium of film, to a pre-20th-century text.	iPads provided multi-purpose media production tools combined on one device, enabling the students to explore freely and create films without limiting them to pre-specified criteria.

STUDY AUTHORS	YEAR	COUNTRY	DEVICES	SUBJECT MATTER	GRADE LEVEL	N	OVERVIEW	OVERALL
Chou et al.	2012	USA	iP	SS	SS	120	Students were observed using the iPads in their Geography class for learning activities, assignments and group discussions.	Findings indicated more active engagement, increased time for projects, improved digital literacy, and digital citizenship. The most challenging aspect was distraction by abundance of irrelevant apps and websites.
Couse & Chen	2010	USA	T-PC	A	KG	41	Students were introduced to the tablet's drawing features. The final activity was for students to draw a self-portrait.	iPads supported children's independence, with findings indicating higher engagement with older students.
Crichton et al.	2011	Canada	Cs	NS	M	NS	Students were given their own devices (phase 1 iPods; phase 2 iPads) for the completion of their everyday tasks across all courses.	Although the majority of participants used the devices, high-school students seemed more critical of their educational use and felt that access to online textbooks would be the most helpful aspect.
Deaton et al.	2013	USA	iP	S	PS	42	Students used iPad apps for note taking, as well as a stop-motion animation video, in an introductory Biology course.	iPads enabled students to demonstrate their understanding through creative ways, enhanced their communication skills, and provided an alternative means for gathering and sharing resources.
Eichenlaub et al.	2011	Canada	iP	NS	PS	4	Students were given iPads for the academic year and asked to integrate them into their daily academic lives.	Besides the technical advantages and ease of use, iPads allowed students to customize effective time-management strategies.
Ellington et al.	2011	USA	T-PC	M	PS	32	Students were provided with tablets to be used during collaborative math activities.	Findings indicated that tablets enhanced the pedagogical impact of the course and had a positive impact on how students perceived math problem solving.
Encheff	2013	USA	iP	S	ES	NS	Students freely explored and used a variety of apps on their iPads to help design, develop and publish their own iBook.	Students reported increased skills in photo and video recording and editing, and a deeper understanding of cloud computing and word processing.

STUDY AUTHORS	YEAR	COUNTRY	DEVICES	SUBJECT MATTER	GRADE LEVEL	N	OVERVIEW	OVERALL
Falloon & Khoo	2014	New Zealand	iP	NS	ES	19	Students used iPads in pairs for developing numeracy, literacy and problem-solving/decision-making skills.	Results revealed high levels of on-task talk that was mostly of an affirming and non-critical nature and unsupportive of outcome improvement or refinement.
Galligan et al.	2010	Australia	T-PC	M	PS	2,000	Tablet PCs were used to record lectures and tutorials, capture video snippets of difficult concepts, and conduct one-to-one or small group online sessions.	Tablet PCs were easy to use for lecture capture and sharing and allowed revision and post-lecture reflection on difficult points. In addition to technical challenges, clear handwriting was needed, particularly with complex solutions.
Grace & Lee	2014	Singapore	iP	NS	ES	279	Students organised a party using different iPad apps while connecting with teammates, teachers and party participants.	Most students experienced a sense of relatedness (borne out of collaborative problem solving), competence and autonomy.
Hoisch et al.	2010	USA	T-PC	S	PS	32	Students participated in lecture demonstrations during which digital photomicrographs were taken and delivered using tablet PCs.	Most students felt that the tablet PCs helped them with the complex visualisations and for note taking during lectures.
Jaciw et al.	2012	US	iP	M	SS	1,259	Students worked on a tablet-based algebra application. The application provides interactive lessons, explanations, quizzes and problem solving.	Findings did not reflect any particular improvement in performance at end of course or in students' attitudes to math-based problem solving.
Johnson	2013	USA	Cs	L	PS	243	Students used their smart devices to read a chapter of a textbook in digital format as compared to paper format.	Results did not indicate any particular impact on students' comprehension based on their reading of the digital textbook.
Khalid et al.	2014	Denmark	iP	M,L	ES	59	Using iPad apps, students solved problems, stored and shared assignments, and produced creative activities.	Findings indicated that iPads offer added mobility, multimodality, access to information, startup time and differentiated learning environments. Barriers included accessibility, training and economy.

STUDY AUTHORS	YEAR	COUNTRY	DEVICES	SUBJECT MATTER	GRADE LEVEL	N	OVERVIEW	OVERALL
Kucirkova et al.	2014	Spain	iP	L	ES	41	Students were allowed to use various apps during free-choice time and their engagement was observed.	Findings indicated that apps supporting easily accessible open-ended content accomplishments are more likely to have positive educational impact.
Li et al.	2010	Hong Kong	T-PC	NS	ES	NS	Students used tablet PCs to complete activities and assignments during self-study and independent learning time.	Tablet PC use had positive impact on student learning in various dimensions, including cognitive, metacognitive, affective and socio-cultural areas.
Lin et al.	2011	Taiwan	T-PC	M	ES	25	Students worked in groups and took part in two puzzle mode tasks, with each group given equal opportunity to operate the system.	Findings indicated an improvement in students' competency in rotation and space of shapes.
Lindsey	2013	USA	T-PC	M, E	PS	64	Groups of students were provided with tablet PCs or a Pen system for use during Statistics course assignments.	Findings indicated that students preferred the natural and easy-to-use Newton's Tablet system over the Newton's Pen system.
Liu et al.	2014a	USA	iPod	L	SS	NS	Students were given iPods 24/7 as an extra resource to help them in different classes, particularly in English language learning (ELL).	Convenience, individual guidance and educational play encouraged ELL students and helped them access just-in-time support for their learning needs at their particular level when they needed it.
Liu et al.	2014b	USA	iPod	L	M	155	Students were provided iPod touch devices 24/7 for accessing additional educational resources.	The iPod touch supported language and content learning, provided differentiated instructional support, and extended learning time from classroom to home.
Loch et al.	2011	Australia	Netbook PC	M	PS	NS	Students' feedback was sought on the usefulness of Netbook tablet PCs in their academic and daily lives.	Students engaged in tutorial activities reflecting active learning and collaboration. Noted disadvantages included tablet size and processing capabilities.

STUDY AUTHORS	YEAR	COUNTRY	DEVICES	SUBJECT MATTER	GRADE LEVEL	N	OVERVIEW	OVERALL
Lynch & Redpath	2014	Australia	iP	L	KG	20	Students used iPads in the literacy block learning centre to produce audiovisual alphabet books.	iPads were found to be supportive of literacy learning with young learners due to the iPads' portability, "touch" interface, and simple navigation system.
Mancilla	2014	USA	Cs	L	ES	7	Students were provided with a Smartpen tool and digital notebook for use in drawing and journal entry.	Results indicated augmented access to target language through extended input, control over input and vocabulary support. Speaking, reading and writing skills were enhanced through extended audience, models and practice, respectively.
Mango	2015	USA	iP	L	PS	35	Students used iPads in their learning of Arabic according to activities that were pre-designed by the instructor.	Students enjoyed using the iPads and reported that the devices helped them learn by facilitating participation and collaboration in class.
Marrone	2014	USA	iP	L	ES	22	Students were provided with the option to read traditional storybooks, read e-books on the iPad or play selected educational games on the iPad.	The combination of e-books and traditional storybooks seemed most beneficial for increased fluency and comprehension among readers. E-books were more appealing than traditional print books and as equally appealing as educational apps.
Medzini et al.	2015	Israel	Cs	SS	PS	10	Geography students used the devices to plan and carry out field trips.	Students indicated that the devices offered a strong method for learning outside the classroom and that they planned to use these technologies on a regular basis.
Milman et al.	2014	USA	iP	NS	ES	17 St 12 Te	Students used iPads to produce a variety of products, demonstrating their learning according to their personal strengths or abilities.	iPads improved students' ability to demonstrate what they learned, helped them develop a deeper understanding of the subject matter, and improved their engagement and motivation.

STUDY AUTHORS	YEAR	COUNTRY	DEVICES	SUBJECT MATTER	GRADE LEVEL	N	OVERVIEW	OVERALL
Pamuk et al.	2013	Turkey	Cs	NS	M	1,099	Students used their devices in a variety of courses and subject matter areas.	Perceptions were generally positive about using smart devices, while emphasising the role of the teacher.
Redd	2011	USA	iPod	L	SS	25	Students used a vocabulary gaming app on iPods over the course of three weeks.	Findings indicated that electronic gaming offers learners an opportunity to build their vocabulary knowledge at a pace that suits them best.
Reid et al.	2013	Canada	iP	NS	ES	NS	Students used various iPad apps selected by them, their parents and the school district to reinforce basic math and literacy concepts.	Findings indicated that with proper teacher professional development, iPads may allow students to better demonstrate and guide their learning.
Shipman	2014	USA	iP	S	ES	5	iPads were used by students to submit their quiz answers using a Student Response System (SRS).	Results indicated that the SRS increased participation, and accuracy rate did not seem to affect the quiz scores.
Stecklein	2014	USA	T-PC	S	PS	3	All course lecture material was shared with students via DyKnow interactive presentation program, and students could manipulate the "slides" on their individual tablet PCs.	Findings indicated that the interactive program was beneficial and had a positive impact on students' learning of force and motion concepts while resulting in a generally favourable shift in attitudes and beliefs about physics.
Tai	2012	NS	Cs	L	ES	35	Students used the devices while working in collaborative groups, with assigned roles to understand the described task by listening to or reading the English instructions.	Evaluation results indicated that students' performance and their language proficiency were enhanced with the mobile-assisted learning practice.
Vaughan & Lawrence	2012	Canada	T-PC	ED	PS	14	Students used their tablets to create a lesson plan, video-record a teaching demo, provide audio assessment feedback to a peer, and develop an online tutorial about an Apple or Android app for educational purposes.	Findings indicated that mobile devices could be useful for supporting future professional responsibilities and facilitating student learning, but less effective for planning, assessment and managing the classroom environment.

STUDY AUTHORS	YEAR	COUNTRY	DEVICES	SUBJECT MATTER	GRADE LEVEL	N	OVERVIEW	OVERALL
Xu	2010	NS	T-PC	ED	PS	40	Tablet PCs were used for in- and out-of-class activities, with the instructor creating digital handwritten feedback directly on students' papers.	Findings indicated that the majority of students preferred digital feedback using the tablet PC and face-to-face conversation compared with other forms of feedback.
Yang & Lin	2010	Taiwan	PDA	S	ES	34	Students used the Shared Display Groupware (SDG) environment while making use of the collaborative environment.	Students' reflected positively on the convenience of the SDG for sharing information and creating a common focus during group discussions. Findings also indicated that students' performance improved on using the SDG environment.

GRADE LEVEL
ES = Elementary school
SS = Secondary school
PS = Post-secondary
M = Mixed

DEVICES
T-PC = Tablet PC
iP = iPad
Cs = Combination

SUBJECT MATTER
L= Language
M = Math, including statistics
S = Science
E = Engineering
ED = Education
IA = Information analysis

OUTCOME MEASURE
T = Test
RC = Report card
O = Observation
E = Experiment

Turkey's Al Fatih Case Study

Beyond the individual qualitative research projects identified were also several studies that investigated the Fatih Project launched by the Turkish government. Because this is one of the 11 large-scale, government-supported educational tablet initiatives that was identified in the Tamim et al. (2015) review, it was impressive to find out that a number of research projects have been conducted to evaluate its overall success.

Due to the pre-set inclusion/exclusion criteria, most of the studies addressing the Fatih Project were not included in the meta-analysis or the quantitative review. However, the availability of more than one research project renders the Fatih initiative an informative case study. As such, the decision was to offer an in-depth overview of the Fatih project and a review of the evidence provided by the available research studies. As noted in Tamim et al. (2015):

> "The Turkish Ministry of Education initiated the Fatih Project in 2012 in collaboration with the Ministry of Transport, Maritime Affairs and Communications (Republic of Turkey, Ministry of National Education, 2012). The objective of the project is to activate the concept 'Smart Class' in 570,000 classes in 42,000 Turkish schools. The project also incorporates in-service teacher training, in addition to the development of educational e-content in accordance with the Turkish curriculum. While the project is not specifically tablet-focused, it is still considered to be a positive support to the move by Turkish schools towards stronger ICT integration in schools. To achieve its objectives, the project includes five different components: a) provision of equipment and software substructure; b) provision and management of educational e-content; c) use of ICT in teaching programmes; d) in-service teacher training; and e) use of ICT in conscious, reliable, manageable and measurable ways."

In the pilot phase of the project, 52 schools in 17 cities were provided with tablet computers, interactive boards, document cameras and multifunctioning printers as new media technologies. Teachers participating in the Fatih project were expected to comply with the National Educational Technology Standards for Teachers (NETS-T) issued by the International Society for Technology in Education (ISTE) — the accrediting criteria since 2008. Using a quality assurance perspective, Çağlar (2012) conducted a massive investigation to assess the level of compliance of the Fatih Project teachers' usage of the technology-enhanced education environment and the ISTE's NETS-T requirements. In all, 1,005 teachers using the new media provided by the Fatih Project in the 52 schools were asked to complete an online survey composed of 162 items. Findings indicated that the majority of the teachers were not adhering to or implementing the ISTE's standards appropriately.

Another perspective is shown from a preliminary investigation gauging teachers' perceptions about the potential success of the Fatih project. In that work, data was collected from 80 in-service teachers (Çiftçi, Taşkaya, & Alemdar, 2013). Findings reflected a high level of skepticism about the success of the initiative, with technical problems being the most feared challenge. Moreover, results indicated that teachers were worried about the tablets' potential negative impact on students' reading, writing and verbal skills. At the same time, however, the findings also indicated that teachers expected some advantages for students, such as not having to carry heavy school bags, accessing information easily and being able to use technology efficiently. As well, teachers said they believed that they themselves would have access to numerous resources and educational material, although were skeptical overall about teachers' skill in teaching with technology. The most important implication of that investigation, according to the researchers, was the need to provide in-depth and extensive in-service teacher training to ensure the success of the initiative.

In another research project, both students' and teachers' perceptions about the use of the Fatih Project's interactive boards and tablet PCs were investigated (Pamuk, Çakır, Ergun, Yılmaz, & Ayas, 2013). Data was collected through teacher and student questionnaires, semi-structured interviews, in-class observations, and focus groups, with participants from 11 schools in four different cities. Results indicated that actual use of tablet PCs in the classroom was rather limited and in some cases non-existent. While perceptions of both teachers and students about interactive whiteboards were favourable, findings reflected a high level of skepticism about the tablets. As expected, the most pressing issues were found to be technical problems, pedagogical concerns, and professional development needs.

Beyond actual evaluation studies, the Fatih initiative has sparked some interest in investigating potential technology use among pre-service teachers. Such is the case where a team investigated pre-service teachers' perceptions about the use of blogs in educational contexts, with the aim of informing ICT integration with the Fatih Project (Ocak, Gökçearslan, & Solmaz, 2014). Given that pre-service teachers may be the strongest change agent when they join the teaching workforce in the near future, the study focused on assessing the experience of those teachers with blogs. After an implementation period for the blogs that lasted five weeks, data was collected with a questionnaire that measured pre-service teachers' opinions about their experience and successful use of blogs in educational contexts. The questionnaire addressed a range of aspects, such as learning, motivation, active participation, writing skills, group work and critical thinking. About 174 pre-service teachers responded. Findings revealed that they believed that blog use in classes tends to have a positive impact on the teaching and learning process. Specifically, participants noted that blogs contributed to the improvement of critical thinking and writing skills while also enhancing social interaction and communication with peers.

Based on the findings, the research team recommended blogs as an alternative option for improving students' writing skills; and suggested their use as a supportive tool for effective group works. The final recommendation was for blogs to be used as enriching tools in association with other methods, platforms and materials on tablet computers.

DISCUSSION

As a follow-up to the *Large-Scale, Government-Supported Educational Tablet Initiatives* (2015) report completed by the team, the current systematic review and meta-analysis aimed at providing research-based evidence on the effectiveness of using tablets and smart mobile devices in educational contexts. The 1,010 research documents located through the original literature search, together with the substantial subset of 68 studies included in the final review after screening, attest to the attention given to the latest technology on the block.

Based on an extensive targeted search and rigorous process that made use of multiple sources of evidence, major findings from the current review are in agreement with previous research outcomes indicating the importance of pedagogy in technology integration. More specifically, the results from the meta-analysis, the qualitative research review, and the particular Fatih Project case study combine to underscore the importance of *how* technological devices are used rather than their mere introduction into the educational context.

Meta-Analysis

Similar to results from previous meta-analyses addressing the impact of technology integration on students' performance, findings from the current meta-analysis indicate a moderate strength average effect size for the impact of tablets and smart mobile devices on student outcome measures. Although not statistically tested, the current findings also indicate that higher effect sizes result when the devices are used in a student-centred context and approach rather than within teacher-led environments.

An interesting outcome was the significance of grade level as a moderator variable. The use of tablets and smart mobile devices with post-secondary students resulted in a substantively higher effect size than did the technologies' use with elementary and secondary students. As noted previously, this may be related to the older students' maturity and independence as well as to their self-regulation capabilities. Another outcome was the significantly stronger effect size found with tablet PCs than with iPads and combination devices. More in-depth research to investigate this difference maybe be helpful to policy-makers and key stakeholders when deciding on the devices to be used and introduced into the classroom.

One finding of particular interest in the current context is the stronger effect size achieved with shorter duration studies. The novelty effect may be an explanation. However, the notable implication is that although the students are considered to be digital natives, living with technology gadgets all around them, this does not mean there is intuitive use of the technology in the educational context. Rather, students still consider the technology to be new when it is introduced into their classroom, and they still feel motivated by its presence. More importantly, they may still need to be trained on how to use it for educational purposes, as indicated by previous meta-analytic findings (Tamim et al., 2014).

Qualitative Literature Review

Results from the qualitative literature review provide findings that may be of a different nature than effect sizes, but the review results offer a similar message. Overall, tablets and smart mobile devices seem to be garnering positive perceptions about their effectiveness within educational context. Nevertheless, the effectiveness of the devices was noted to be higher for particular tasks and when used with a specific approach. Generally speaking, when tablets were used in student-centred contexts, students responded with more positive perceptions about the tablets' successful use.

While these findings agree with the results of the meta-analysis, the qualitative literature review offered a deeper understanding about aspects related to tablet integration. In addition to tablets improving student performance, students commonly cited several other advantages of tablets, including that they:

- improved students' organisational and note-taking skills;
- enhanced students' ability to express themselves and their understanding in creative ways;
- supported students' independence and communication skills;
- increased students' accessibility to resources while supporting complex visualisation of concepts; and
- improved students' literacy and math skills.

Furthermore, the qualitative literature review provided an idea about some of the challenges faced by the students when using tablets and smart mobile devices for teaching and learning. The most prominently reported challenges included:

- the technical issues the devices can have and the expertise needed for their use;
- the distracting nature of the devices and the plethora of apps; and
- the pressing need for professional development to enable teachers to properly integrate the device into the teaching and learning process.

The Fatih Case Study

The Fatih case study provided a holistic perspective about the success of large-scale tablet initiatives based on more than one research study. The located articles clearly reflected the common skepticism that is usually prominent with large-scale initiatives, in addition to reflecting quality assurance and compliance issues and concerns. However, the studies also pointed to themes similar to those emerging from the qualitative and quantitative review, particularly the importance of pedagogy and how the devices are used, and the need for extensive professional development and training.

Interestingly, the final article discussed in relation to the Fatih case study represents a much-needed approach to informing innovative projects that focus on integrating contemporary technology within educational contexts. Ocak, Gökçearslan, and Solmaz (2014) conducted a research study focused on use of technology in a teaching and learning approach by pre-service teachers (i.e., the future teaching work force), with the objective of making use of lessons learned for the benefit of a large-scale, more comprehensive initiative.

CONCLUSION

The review, meta-analysis and case study presented in this report provide a holistic and in-depth summary of the current status of research addressing the effect of tablets and smart mobile devices in increasing students' achievements and their perceptions about the technologies' contribution to teaching and learning success.

Findings from these multiple resources confirm previous findings about the average effect of contemporary technology on students' achievement, the benefits that go beyond mere performance on tests, and the importance of pedagogy in the successful integration of technology in educational contexts.

Moreover, the findings highlight the need for providing teachers with professional development to support their ability to integrate the *technology of the day* effectively into their teaching and to create teaching and learning environments conducive for meaningful learning.

APPENDIX A: QUANTIFICATION IN META-ANALYSIS AND CALCULATION OF EFFECT SIZES

Quantification in Meta-Analysis

The basic metric and unit of analysis in a meta-analysis is *effect size*. There are three basic forms (also often called families) of effect sizes:

1) the *d*-type expresses the standardised difference between the means of two groups;
2) the *r*-type represents the relationship (i.e., correlation) between two measures in question; and
3) the odds-ratio type describes the probability of either level of a dichotomous dependent variable (e.g., passed/failed) due to the group membership (i.e., intervention/no intervention).

Although these three forms of effect size arise from somewhat different research traditions and methodologies, they could be converted to one another through various formulas and expressed as compatible metrics across primary research studies.

In social sciences, especially in education, the *d*-type effect size is the most commonly used because it best reflects comparisons between experimental and control conditions measured on a continuous scales, such as academic achievement (e.g., exams) and student attitude (e.g., satisfaction with the instruction).

For the standardisation term, Glass (1976) suggested using standard deviation of the control condition (not affected by the treatment in question and, as such, supposedly representing variability in the population). This earliest form of *d*-type effect size is called Glass's Δ. In practice, however, Cohen's *d* (Cohen, 1988) has become the more accepted form of the *d*-type effect size. It pools the standard deviations of the experimental and control groups and uses the result as the denominator of the respective groups' mean difference. Hedges and Olkin (1985) introduced a multiplier to Cohen's *d* to correct for potential bias associated with small samples (under c. 30–40 participants in total). That modification is referred to as Hedges' *g*. The effect sizes of small samples are then slightly adjusted toward lower values, whereas larger (and thus, more representative) samples remain unaffected.

This conversion of Cohen's *d* into Hedges' *g* is generally recommended for all studies included in a meta-analysis, as it corrects bias in small sample studies without influencing the outcomes for larger samples.

Calculating Effect Sizes and Related Statistics

Several basic equations are used to calculate *d*-type effect sizes and related statistics.

The very essence of *d*-type effect size, (Cohen's *d*) — the standardised mean difference (of the experimental and control groups –$\bar{X}_E$ and $\bar{X}_C$, respectively) — is depicted in *Equation 1:*

Equation 1

$$d = \frac{\bar{X}_E - \bar{X}_C}{SD_{Pooled}}$$

Its denominator — pooled standard deviation (of both experimental and control groups) — is the standardisation term, calculated as follows *(Equation 2):*

Equation 2

$$SD_{Pooled} = \sqrt{\frac{(n_E - 1)SD_E^2 + (n_C - 1)SD_C^2}{(n_E - 1) + (n_C - 1)}}$$

A *d*-type effect size can also be calculated from inferential statistics, such as *t*-tests, *F*-ratios and/or associated *p*-values, using an array of formulas provided by Glass, McGaw, and Smith (1981) and Hedges, Shymansky, and Woodworth (1989). Regardless of the formula used, a sample size of experimental and control groups (or at least a total number of participants) must be available; and, for non-signed statistics, the direction of the effect must be indicated in the report.

There is a correction for small sample bias to *d*, known as Hedges' *g*. It is calculated using *Equation 3:*

Equation 3

$$g \cong d\left(1 - \frac{3}{4N - 9}\right)$$

To enable weighting of individual effect sizes taking into account the associated sample sizes, the standard error of *g* is calculated using *Equation 4:*

Equation 4

$$SE_g = \sqrt{\frac{1}{n_e} + \frac{1}{n_c} + \frac{g^2}{2(n_e + n_c)}}\left(1 - \frac{3}{4(n_e + n_c) - 9}\right)$$

The 95% confidence intervals are then constructed by applying *Equation 5:*

Equation 5

$$C.I. = g \pm (1.96 \cdot SE_g)$$

To assess significance of the effect size *g*, the value of the *z*-test is calculated using *Equation 6*; and is then tested for statistical significance using the unit normal distribution (∂ = 1.96).

Equation 6

$$z_g = \frac{g_i}{SE_g}$$

For further aggregation of the effect sizes, the within-study variance of *g* (*Vg*) must be calculated by squaring the standard error, as shown in *Equation 7:*

Equation 7

$$V_g = SE_g^2$$

Synthesising Effect Sizes

At the synthesis phase, effect sizes are always weighted to be truly representative of an overall average. There are two approaches to creating weights: the fixed-effects model and the random-effects model.

Conceptual and procedural specifics of the two and their respective underlying assumptions are described in greater detail in the literature on meta-analysis (e.g., Borenstein, Hedges, Higgins, & Rothstein, 2009; Borenstein, Hedges, Higgins & Rothstein, 2010; Hedges & Olkin, 1985; Pigott, 2012).

For the purposes of the review discussed in this report, the fixed-effects model was used to estimate heterogeneity of the distribution of effect size; and the random-effects model was used, by synthesising effect sizes into an overall average weighted effect size, to estimate the influence of the educational use of tablet-type mobile devices on student achievement in general population. The mixed model was then used in moderator variable analyses.

In the fixed-effects model, the weight of each individual effect size is the inverse of the within-study variance (*Equation 8*). In comparison, under the random-effects model, between-study variance is added to within-study variance and then the inverse is calculated as depicted (*Equation 9*).

Equation 8

$$W_{g(Fixed)} = \frac{1}{V_g}$$

Equation 9

$$W_{g(Random)} = \frac{1}{V_g + \tau^{2*}}$$

*Tau-squared (τ^2) is the average between-study variance that is added to within-study variability (*Vg*) to form the inverse variance weighting in the random-effects model (see, for example, Borenstein, Hedges, Higgins, & Rothstein [2010]; and Pigott [2012]).

Fixed-effects model

The fixed-effects model is based on the underlying assumption that single (fixed) average effect size can represent the entire collection of studies in the given meta-analysis, as long as they are of similar research design, treatment definition, outcome measures and sample demographics. The first-level synthesis of a distribution of k effect sizes under the fixed-effects model leads to two primary outcomes:

1) the average weighted effect size of k effect sizes and associated statistics (i.e., standard error, variance, the upper and lower limits of the 95th confidence interval, a z-test and associated probability); and
2) the heterogeneity assessment and its associated test statistics.

A Q-statistic (i.e., Cochran's Q) is created in a heterogeneity analysis from the squared sum of each effect size subtracted from the average effect size. The Q-statistic is a sum of squares that is assessed using the Chi-squared distribution with (p – 1) degrees of freedom. Failure to reject the null hypothesis leads to the conclusion that the distribution is homogeneous (i.e., between-study variability does not exceed chance expectations). A significant Q-value denotes heterogeneity that exceeds the expected level of chance. Higgins, Thompson, Deeks, and Altman (2003) developed I^2 as a more intuitive measure of heterogeneity. It ranges from 0.0 to 1.0, read as a percentage of between-study variability contained in total variability.

Random-effects model

The random-effects model is the more appropriate approach when studies in the meta-analysis are not very similar and differ in terms of methodology, treatment definition, demographics and so on. As such, studies are not assumed to be alike except in the general research question that they address (e.g., What are the effects of the educational use of tablet-type mobile devices on student achievement outcomes?). Each study is considered a random sample from a micro-population of similar studies.

Under the random-effects synthesis model, average between-study variability (τ^2) is added to within-study variability (Vg), and therefore weights tend to be smaller and less variable, thus giving less importance to any individual study within the distribution. Consequently, there is no heterogeneity assessment, as all between-study variability is resolved within each study.

Mixed model

The mixed model is a combination of the characteristics of the fixed- and random-effects models. First, the average effects at each level of the moderator variable are synthesised using the random-effects model, where is calculated separately for each level. Then, synthesis across levels is performed using the fixed-effects model.

APPENDIX B: RESULTS OF ABSTRACT SCREENING AND FULL-TEXT ARTICLE REVIEWS

Abstract Screening

The initial literature searches produced 1,010 hits. At the first stage of the review, the abstracts for these articles were collected and reviewed: 460 of them (approximately 45.5%), by two reviewers working independently to establish acceptable level of inter-coder reliability. A 5-point scale was used, from 1 — "definitely exclude" to 5 — "definitely retain full-text for further review," with the middle point warranting skeptical retention. The inter-coder agreement rates were Pearson's $r = 0.79$ ($p < .001$) and Cohen's $\kappa = 0.85$ (92.4% of agreement rate). Disagreements were discussed and a third opinion invited when necessary to help with resolution.

The rest of the collection was reviewed by individual coders who participated in the double coding of 460 abstracts described above.

Screening of abstracts resulted in the decision to retrieve 233 full-text documents for further review. Excluded from further consideration at this stage of the review were 777 documents. The reasons for exclusion are summarised in Table A2.1 Some documents were discarded for several reasons, but only the major one is indicated in the table.

Table A2.1: Coding results for screening abstracts: primary exclusions reasons

	NO. OF DOCUMENTS	% OF TOTAL
Does not represent tablet-based intervention	134	17.25
Not empirical research (description/opinion article)	137	17.63
Irrelevant outcomes (no achievement measures)	247	31.79
Medical and healthcare context	43	.53
Studies conducted in non-formal settings	126	16.22
Review of research articles	28	3.60
Irrelevant populations	62	7.98
	777	100.00

Full-Text Article Review

Due to time restrictions, the same approach was used to review retained documents: establish reliability of coding on the representative sample of studies and then proceed with the individual reviews of the remaining documents. Two researchers worked independently to examine 70 documents (approximately 30%) of 233 retained for the full-text review. The researchers applied the same set of inclusion criteria (with the addition of statistical data sufficient to enable subsequent effect-size extraction). At this stage of the review, the inter-coder agreement rates were Pearson's $r = 0.82$ ($p < .001$), Cohen's $\kappa = 0.87$ (93.3% of agreement rate). Disagreements were discussed and resolved.

The full-text review of the 233 documents resulted in exclusion of 159 studies. Reasons for exclusion are summarised in Table A2.2.

Table A2.2: Coding results for full texts: primary exclusions reasons

	NO. OF DOCUMENTS	% OF TOTAL
Does not represent tablet-based intervention	48	30.19
Not empirical research (description/opinion article)	10	6.30
Irrelevant outcomes (no achievement measures)	91	57.23
Medical and healthcare context	2	1.26
Studies conducted in non-formal (school) settings	3	1.88
Review of research articles	2	1.26
Insufficient statistical data (for QNT studies)	3	1.88
	159	100.00

In total, 74 studies were marked for inclusion in our review. Of this number, 27 were quantitative empirical studies and were used in a meta-analysis. The remaining 47 studies were of two types of empirical research: 1) qualitative (40 studies), containing case studies, observations, broad-scope surveys, interviews, etc.; and 2) quantitative (7 studies) that used one group pre-post-test design (these were deemed by the research team to be potentially informative of tablet-based instructional interventions and thus added to the category of qualitative empirical studies).

Further screening resulted in the exclusion of 6 qualitative studies, resulting in a final set of 41 studies. Subsequently, 27 quantitative studies were subjected to a full-scale meta-analytic procedure, whereas the remaining 41 studies were coded for the main set of substantive study characteristics.

A full list of the studies synthesised in this review is provided in the References section. *Note*: The quantitative studies are shown with a single asterisk; the qualitative studies are shown with double asterisks.

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