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# What Forty Years of Research Says About the Impact of Technology on Learning: A Second-Order Meta-Analysis and Validation Study

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*This research study employs a second-order meta-analysis procedure to summarize 40 years of research activity addressing the question, does computer technology use affect student achievement in formal face-to-face classrooms as compared to classrooms that do not use technology? A study-level meta-analytic validation was also conducted for purposes of comparison. An extensive literature search and a systematic review process resulted in the inclusion of 25 meta-analyses with minimal overlap in primary literature, encompassing 1,055 primary studies. The random effects mean effect size of 0.35 was significantly different from zero. The distribution was heterogeneous under the fixed effects model. To validate the second-order meta-analysis, 574 individual independent effect sizes were extracted from 13 out of the 25 meta-analyses. The mean effect size was 0.33 under the random effects model, and the distribution was heterogeneous. Insights about the state of the field, implications for technology use, and prospects for future research are discussed.*

**KEYWORDS:** computers and learning, instructional technologies, achievement, meta-analysis.

In 1913 Thomas Edison predicted in the *New York Dramatic Mirror* that “books will soon be obsolete in the schools. . . . It is possible to teach every branch of human knowledge with the motion picture. Our school system will be completely changed in ten years” (quoted in Saettler, 1990, p. 98). We know now that this did not exactly happen and that, in general, the effect of analog visual media on schooling, including video, has been modest. In a not so different way, computers and

associated technologies have been touted for their potentially transformative properties. No one doubts their growing impact in most aspects of human endeavor, and yet strong evidence of their direct impact on the goals of schooling has been illusory and subject to considerable debate. In 1983, Richard E. Clark famously argued that media have no more effect on learning than a grocery truck has on the nutritional value of the produce it brings to market. He also warned against the temptation to compare media conditions to nonmedia conditions in an attempt to validate or justify their use. Features of instructional design and pedagogy, he argued, provide the real active ingredient that determines the value of educational experiences. Others, like Robert Kozma (e.g., 1991, 1994) and Chris Dede (e.g., 1996), have argued that computers may possess properties or affordances that can directly change the nature of teaching and learning. Their views, by implication, encourage the study of computers and other educational media use in the classroom for their potential to foster better achievement and bolster student attitudes toward schooling and learning in general.

Although the debate about technology's role in education has not been fully resolved, literally thousands of comparisons between computing and noncomputing classrooms, ranging from kindergarten to graduate school, have been made since the late 1960s. And not surprisingly, these studies have been meta-analyzed at intervals since then in an attempt to characterize the effects of new computer technologies as they emerged. More than 60 meta-analyses have appeared in the literature since 1980, each focusing on a specific question addressing different aspects such as subject matter, grade level, and type of technology. Although each of the published meta-analyses provides a valuable piece of information, no single one is capable of answering the overarching question of the overall impact of technology use on student achievement. This could be achieved by conducting a large-scale comprehensive meta-analysis covering various technologies, subject areas, and grade levels. However, such a task would represent a challenging and costly undertaking. Given the extensive number of meta-analyses in the field, it is more reasonable and more feasible to synthesize their findings. Therefore, the purpose of this study is to synthesize findings from meta-analyses addressing the effectiveness of computer technology use in educational contexts to answer the big question of technology's impact on student achievement, when the comparison condition contains no technology use.

We employ an approach to meta-analysis known as second-order meta-analysis (Hunter & Schmidt, 2004) as a way of summarizing the effects of many meta-analyses. Second-order meta-analysis has its own merits and has been tried by reviewers across several disciplines (e.g., Butler, Chapman, Forman, & Beck, 2006; Lipsey & Wilson, 1993; Møller & Jennions, 2002; Wilson & Lipsey, 2001). According to those who have experimented with it, the approach is intended to offer the potential to summarize a growing body of meta-analyses, over a number of years, in the same way that a meta-analysis attempts to reach more reliable and generalizable inferences than individual primary studies (e.g., Peterson, 2001). However, no common or standard set of procedures has emerged, and specifically there has been no attempt to address the methodological quality of the included meta-analyses or explain the variance in effect sizes.

This second-order meta-analysis attempts to synthesize the findings of the corpus of meta-analyses addressing the impact of computer technology integration on

student achievement. To validate its results, we conduct a study-level synthesis of research reports contained in the second-order meta-analysis. Results will help answer the overarching question of the impact of technology use on students' performance as compared to the absence of technology and may lay the foundation for new forms of quantitative primary research that investigates the comparative advantages or disadvantages of more or less technology use or functions of technology (e.g., cognitive tools, interaction tools, information retrieval tools).

### *Syntheses of Meta-Analyses*

A second-order meta-analysis (Hunter & Schmidt, 2004) is defined as an approach for quantitatively synthesizing findings from a number of meta-analyses addressing a similar research question. In some ways, the methodological issues are the same as those addressed by "first-order" meta-analysts; as we note, in some ways they are quite different. As previously indicated, a number of syntheses of meta-analyses have appeared in the literatures in various disciplines.

Among researchers who have used quantitative approaches to summarize meta-analytic results are Mark Lipsey and David Wilson (Lipsey & Wilson, 1993; Wilson & Lipsey, 2001), both addressing psychological, behavioral, and educational treatments; Sipe and Curlette (1997), targeting factors related to educational achievement; Møller and Jennions (2002), focusing on issues in evolutionary biology; Barrick, Mount, and Judge (2001), addressing personality and performance; Peterson (2001), studying college students and social science research; and Luborsky et al. (2002), addressing psychotherapy research.

All of these previous syntheses attempted to reach a summary conclusion by answering a "big question" that was posed in the literature by previous meta-analysts. However, none addressed the methodological quality of the included meta-analyses in the same way that the methodological quality of primary research is addressed in a typical first-order meta-analysis (e.g., Valentine & Cooper, 2008), and none attempted to explain the variance in effect sizes. However, the issue of overlap in primary literature included in the synthesized meta-analyses was tackled in some. For example, Wilson and Lipsey (2001) excluded one review from each pair that had more than 25% overlap in primary research addressed while making judgment calls when the list of included studies was unavailable. Barrick et al. (2001) conducted two separate analyses, one with the set of meta-analyses that had no overlap in the studies integrated and one with the full set of meta-analyses, including those with substantial overlap in the studies they include. In a combination of both approaches, Sipe and Curlette (1997) considered meta-analyses as unique if they had no overlap or fewer than 3 studies in common. The meta-analysis with the larger number of studies was included, and if both were not more than 10 studies apart, the more recently published one was included. In addition, analyses were conducted for the complete set and for the set that they considered to be unique.

### *Technology Integration Meta-Analyses*

As noted previously, numerous meta-analyses addressing technology integration and its impact on students' performance have been published since Clark's (1983) initial proclamation on the effects of media. Schacter and Fagnano (1999) conducted a qualitative review of meta-analyses, and Hattie (2009) conducted a

comprehensive synthesis of meta-analyses in the field of education, but no second-order meta-analysis has been reported or published targeting the specific area of computer technology and learning.

In examining the entire collection of published meta-analyses, it becomes clear that each focuses on a specific question addressing particular issues and aspects of technology integration. For example, Bangert-Drowns (1993) studied the influence of word processors on student achievement at various grade levels (reported mean  $ES = 0.27$ ), whereas P. A. Cohen and Dacanay (1992) focused on the impact of computer-based instruction (CBI) on students' achievement at the postsecondary levels (reported mean  $ES = 0.41$ ). Christmann and Badgett (2000) investigated the impact of computer-assisted instruction (CAI) on high school students' achievement (reported mean  $ES = 0.13$ ), and Bayraktar (2000) focused on the impact of CAI on K–12 students' achievement in science (reported mean  $ES = 0.27$ ). The meta-analysis conducted by Timmerman and Kruepke (2006) addressed CAI and its influence on students' achievement at the college level (reported mean  $ES = 0.24$ ). Although the effect sizes vary in magnitude, and although there is some redundancy in the issues addressed by the different meta-analyses and some overlap in the empirical research included in them, the existence of this corpus allows us an opportunity to derive an estimate of the overall impact of technology integration as it has developed and been studied in technology-rich versus technology-impooverished educational environments.

By applying the procedures and standards of systematic reviews to the synthesis of meta-analyses in the field, this study is intended to capture the essence of what the existing body of literature says about the impact of computer technology use on students' learning performance and inform researchers, practitioners, and policymakers about the state of the field. In addition, this approach may prove to be extremely helpful in certain situations when reliable answers to global questions are required within limited time frames and with limited resources. The approach may be considered a brief review (Abrami et al., 2010) that offers a comprehensive understanding of the empirical research up to a point in time while utilizing relatively fewer resources than an extensive brand-new meta-analysis.

## **Method**

The general systematic approach used in conducting a regular meta-analysis (e.g., Lipsey & Wilson, 2001) was followed in this second-order meta-analysis with some modifications to meet its objectives as presented in the following section.

### *Inclusion and Exclusion Criteria*

Similar to all forms of systematic reviews, a set of inclusion or exclusion criteria was specified to help (a) set the scope of the review and determine the population to which generalizations will be possible, (b) design and implement the most adequate search strategy, and (c) minimize bias in the review process for inclusion of meta-analyses. For this second-order meta-analysis, a meta-analysis was included if it:

- addressed the impact of any form of computer technology as a supplement for in-class instruction as compared to traditional, nontechnology instruction in regular classrooms within formal educational settings (this

criterion excluded distance education and fully online learning comparative studies, previously reviewed by Bernard et al., 2004; U.S. Department of Education, 2009; and others);

- focused on students' achievement or performance as an outcome measure;
- reported an average effect size;
- was published during or after 1985 and was publicly available.

If any of the above-mentioned criteria were not met, the study was disqualified and the reason for exclusion noted.

The year 1985 was considered as a cut point since it was around that year that computer technologies became widely accessible to a large percentage of schools and other educational institutions (Alessi & Trollip, 2000). Moreover, by 1985 meta-analysis had been established as an acceptable form of quantitative synthesis with clearly specified and systematic procedures. As highlighted by Lipsey and Wilson (2001), this is supported by the fact that by the early 1980s there was a substantial corpus of books and articles addressing meta-analytic procedures by prominent researchers in the field, such as Glass, McGaw, and Smith (1981); Hunter, Schmidt, and Jackson (1982); Light and Pillemer (1984); Rosenthal (1984); and Hedges and Olkin (1985).

#### *Developing and Implementing Search Strategies*

To capture the most comprehensive and relevant set of meta-analyses, a search strategy was designed with the help of an information retrieval specialist. To avoid publication bias and the file drawer effect, the search targeted published and unpublished literature. The following retrieval tools were used:

1. Electronic searches using major databases, including ERIC, PsycINFO, Education Index, PubMed (Medline), AACE Digital Library, British Education Index, Australian Education Index, ProQuest Dissertations and Theses Full-text, EdITLib, Education Abstracts, and EBSCO Academic Search Premier
2. Web searches using the Google and Google Scholar search engines
3. Manual searches of major journals, including *Review of Educational Research*
4. Reference lists of prominent articles and major literature reviews
5. The Centre for the Study of Learning and Performance's in-house eLEARNING database, compiled under contract from the Canadian Council on Learning

The search strategy included the term *meta-analysis* and its synonyms, such as *quantitative review* and *systematic review*. In addition, an array of search terms relating to computer technology use in educational contexts was used. They varied according to the specific descriptors within different databases but generally included terms such as computer-based instruction, computer-assisted instruction, computer-based teaching, electronic mail, information communication technology, technology uses in education, electronic learning, hybrid courses, blended

learning, teleconferencing, Web-based instruction, technology integration, and integrated learning systems.

Searches were updated at the end of 2008, and results were compiled into a common bibliography. This year seems an appropriate place to draw a line between meta-analyses summarizing technology versus no technology contrasts as more and more research addresses the comparative effectiveness of different technologies.

### *Reviewing and Selecting Meta-Analyses*

The searches resulted in the location of 429 document abstracts that were reviewed independently by two researchers. From the identified set of documents, 158 were retrieved for full-text review. The interrater agreement for this step was 85.5% (Cohen's  $\kappa = .71$ ).

To establish coding reliability for full-text review, two researchers reviewed 15 documents independently, resulting in an interrater agreement of 93.3% (Cohen's  $\kappa = .87$ ). The primary investigator reviewed the rest of the retrieved full-text documents, and in cases where the decision was not straightforward, a second reviewer was consulted. From the 158 selected documents, 12 were not available, leaving 146 for full-text review. From these, 37 met all of the inclusion criteria.

An important issue in meta-analysis is that of independence of samples. It is not uncommon, for instance, to find a single control condition compared to multiple treatments. When the same sample is used repeatedly, the chance of making a Type I error increases. An analogous problem exists in a second-order meta-analysis, when the same studies are included in more than one meta-analysis (Sipe & Curlette, 1997). To minimize this problem, the first step taken in this second-order meta-analysis was to compile the overall set of primary studies included in the 37 different meta-analyses and to specify the single or multiple meta-analyses in which each study appeared. The overall number of different primary studies that appeared in one or more meta-analyses was 1,253. For each meta-analysis, the number and frequency of studies that were included in another meta-analysis were calculated.

We identified the set of meta-analyses that contained the largest number of primary studies with the least level of overlap among them. Because of the fact that primary studies included in more than one meta-analysis did not only appear in two particular meta-analyses, the removal of one meta-analysis from the overall set resulted in a change in the frequencies of overlap in other meta-analyses. Therefore, the highest overlapping meta-analyses were removed one at a time until 25% or less of overlap (Wilson & Lipsey, 2001) in included primary studies was attained for each of the remaining meta-analyses. After the exclusion of any meta-analysis, the percentage of overlap for the remaining set of meta-analyses was recalculated, and based on the new frequencies another highly overlapping meta-analysis was excluded. This process was repeated 12 times.

The process was completed by the principal investigator, with spot checks conducted to ensure that no mistakes were made. The final number of meta-analyses that were considered to be unique or having acceptable levels of overlap was 25, with none having a count of overlapping studies beyond 25%. The overall number of primary studies included in this set was 1,055 studies, which represents 84.2% of the total number of primary studies included in the overall set of meta-analyses.

**TABLE 1***List of technologies, grade levels, and subject matter in each meta-analysis*

Meta-analysis	Technology	Grade level	Subject matter
Bangert-Drowns (1993)	Word processor	All	Combination
Bayraktar (2000)	CAI	S and P	Science and health
Blok, Oostdam, Otter, and Overmaat (2002)	CAI	E	Language
Christmann and Badgett (2000)	CAI	S	Combination
Fletcher-Flinn and Gravatt (1995)	CAI	P	Combination
Goldberg, Russell, and Cook (2003)	Word processor	E and S	Language
Hsu (2003)	CAI	P	Mathematics
Koufogiannakis and Wiebe (2006)	CAI	P	Information Literacy
Kuchler (1998)	CAI	S	Mathematics
Kulik and Kulik (1991)	CBI	All	Combination
Y. C. Liao (1998)	Hypermedia	All	Combination
Y.-I. Liao and Chen (2005)	CSI	E and S	Combination
Y. K. C. Liao (2007)	CAI	All	Combination
Michko (2007)	Technology	P	Engineering
Onuoha (2007)	Simulations	S and P	Science and health
Pearson, Ferdig, Blomeyer, and Moran (2005)	Digital media	S	Language
Roblyer, Castine, and King (1988)	CBI	All	Combination
Rosen and Salomon (2007)	Technology	E and S	Mathematics
Schenker (2007)	CAI	P	Mathematics
Soe, Koki, and Chang (2000)	CAI	E and S	Language
Timmerman and Kruepke (2006)	CAI	P	Combination
Torgerson and Elbourne (2002)	ICT	E	Language
Waxman, Lin, and Michko (2003)	Technology	E and S	Combination
Yaakub (1998)	CAI	S and P	Combination
Zhao (2003)	ICT	P	Language

*Note.* E = elementary; S = secondary; P = postsecondary; CAI = computer-assisted instruction; CBI = computer-based instruction; ICT = information and communication technology.

The final set of 25 included meta-analyses with a list of technologies, subject matter, and grade level addressed is presented in Table 1. The list offers an idea of the variety and richness of the topics addressed in the various meta-analyses and thus the inability to select a single representative meta-analysis to answer the overarching question. The list of included meta-analyses along with the number of

studies and the percentage of overlap along with the list of excluded meta-analyses is available on request.

### *Extracting Effect Sizes and Standard Errors*

*Effect sizes.* An effect size is the metric introduced by Glass (1977) representing the difference between the means of an experimental group and a control group expressed in standardized units (i.e., divided by a standard deviation). As such, an effect size is easily interpretable and can be converted to a percentile difference between the treatment and control groups. Another benefit is the fact that an effect size is not greatly affected by sample size, as are test statistics, thus reducing problems of power associated with large and small samples. Furthermore, an aspect that is significant for meta-analysis is that effect sizes can be aggregated and then subjected to further statistical analyses (Lipsey & Wilson, 2001). The three most common methods for calculating effect sizes are (a) Glass's  $\Delta$ , which uses the standard deviation of the control group, (b) Cohen's  $d$ , which makes use of the pooled standard deviation of the control and experimental groups, and (c) Hedges's  $g$ , which applies a correction to overcome the problem of the overestimation of the effect size based on small samples.

For the purpose of this second-order meta-analysis, the effect sizes from different meta-analyses were extracted while noting the type of metric used. In a perfect situation, where authors provide adequate information, it would be possible to transform all of the three types of group comparison effect sizes to one type, preferably Hedges's  $g$ . However, because of reporting limitations, this was not possible, particularly when Glass's  $\Delta$  was used in a given meta-analysis. Knowing that all three ( $\Delta$ ,  $d$ ,  $g$ ) are variations for calculating the standardized mean difference between two groups, and assuming that the sample sizes were large enough to consider the differences between the three forms to be minimal, we decided to use the effect sizes in the forms in which they were reported.

In cases where the included meta-analysis expressed the effect size as a standard correlation coefficient, the reported effect size was converted to Cohen's  $d$  by applying Equation 1 (Borenstein, Hedges, Higgins, & Rothstein, 2009).

$$d = \frac{2r_{XY}}{\sqrt{1-r_{XY}^2}} \quad (1)$$

*Standard error.* Standard error is a common metric used to estimate variability in the sampling distribution and thus in the population. Effect sizes calculated from larger samples are better population estimates than those calculated from studies with smaller samples. Thus, larger samples have smaller standard errors and smaller studies have larger standard errors. The standard error of  $g$  is calculated by applying Equation 2. Notice that the standard error is largely based on sample size, with the exception of the inclusion of  $g^2$  under the radical. As a result of this, two samples of equal size but with different effect sizes will have slightly different standard errors. Standard error squared is the variance of the sampling distribution, and the inverse of the variance is used to weight studies under the fixed effects model.

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

In this second-order meta-analysis four different procedures for extracting standard errors from the included meta-analyses were used, depending on the availability of information in a given meta-analysis:

- Extraction of the standard error as reported by the author
- Calculation of the standard error from individual effect sizes and corresponding sample sizes for the included primary studies
- Calculation of the standard error from a reported confidence interval
- Imputation of the standard error from the calculated weighted average standard error of the included meta-analyses

### *Coding Study Features*

In a regular meta-analysis, study features are typically extracted from primary studies as a means of describing the studies and performing moderator analysis. A similar approach was followed in this second-order meta-analysis targeting common qualities available in the included meta-analyses. A variety of resources was reviewed for possible assistance in the design of the codebook for the current project, including (a) literature pertaining to meta-analytic procedural aspects (e.g., Bernard & Naidu, 1990; Lipsey & Wilson, 2001; Rosenthal, 1984), (b) published second-order meta-analyses and reviews of meta-analyses (e.g., Møller & Jennions, 2002; Sipe & Curlette, 1997; Steiner, Lane, Dobbins, Schnur, & McConnell, 1991), and (c) available standards and tools for assessing the methodological quality of meta-analyses such as Quality of Reporting of Meta-Analyses (Moher et al., 2000) and the Quality Assessment Tool (Health-Evidence, n.d.).

The overall structure of the codebook was influenced by the synthesis of meta-analyses conducted by Sipe and Curlette (1997). The four main sections of the codebook are (a) study identification (e.g., author, title, and year of publication), (b) contextual features (e.g., research question, technology addressed, subject matter, and grade level), (c) methodological features (e.g., search phase, review phase, and study feature extraction), and (d) analysis procedures and effect size information (e.g., type of effect size, independence of data, and effect size synthesis procedures). The full codebook is presented in Appendix A.

The process of study feature coding was conducted by two researchers working independently. Interrater agreement was 98.7% (Cohen's  $\kappa = .97$ ). After completing the coding independently, the two researchers met to resolve any discrepancies.

### *Methodological Quality Index*

Unlike the report of a single primary study, a meta-analysis carries the weight of a whole literature of primary studies. Done well, its positive contribution to the growth of a field can be substantial; done poorly and inexpertly, it can actually do damage to the course of research. Consequently, while developing the codebook, specific study features were designed to help in assessing the methodological quality of the included meta-analyses. The study features addressed aspects pertaining to conceptual clarity (two items), comprehensiveness (seven items), and rigor of a meta-analysis (seven items). Items addressing conceptual clarity targeted (a) clarity of the experimental group definition and (b) clarity of the control group definition. Items that addressed comprehensiveness targeted the (a) literature covered,

(b) search strategy, (c) resources used, (d) number of databases searched, (e) inclusion or exclusion criteria, (f) representativeness of included research, and (g) time between the last included study and the publication date. Finally, items that addressed aspects of rigor targeted the thoroughness, accuracy, or availability of the (a) article review, (b) effect size extraction, (c) codebook description or overview, (d) study feature extraction, (e) independence of data, (f) standard error calculation, and (g) weighting procedure. For each of the included items, a meta-analysis could have received a score of either 1 (*low quality*) or 2 (*high quality*). The total score out of 16 indicated its methodological quality; the higher the score, the better the methodological quality.

The methodological quality scores for the 25 meta-analyses ranged between 5 and 13. The studies were grouped into weak, moderate, and strong meta-analyses. Meta-analyses scoring 10 or more were considered strong ( $k = 10$ ). Meta-analyses scoring 8 or 9 were considered moderate ( $k = 7$ ), whereas meta-analyses scoring 7 or less were considered weak ( $k = 8$ ).

#### *Data for Validation Process*

To allow for the validation of the findings of the second-order meta-analysis, individual study-level effect sizes and sample sizes from the primary studies included in the various meta-analyses were extracted. In the cases where the overall sample size was provided, it was assumed that the experimental and control groups were equal in size, and in the case of an odd overall number of participants, the sample size was reduced by one. However, because these data were to be used for validation purposes, if sample sizes were not given by the authors for the individual effect sizes, no imputations were done. From the 25 studies, 13 offered information allowing for the extraction of 574 individual effect sizes and their corresponding sample sizes, with the overall sample size being 60,853 participants. The principal investigator conducted the extraction, and random spot checks were done as a mistake-prevention measure.

#### *Data Analysis*

For the purpose of outlier, publication bias, effect size synthesis, and moderator analyses, the Comprehensive Meta Analysis 2.0 software package (Borenstein, Hedges, Higgins, & Rothstein, 2005) was used. The effect size, standard error, methodological quality indexes, and scores for the extracted study features for each of the 25 different meta-analyses were input into the software. A list containing information about the included studies, their mean effect size type, effect size magnitude, standard errors, number of overlapping studies, and percentage overlap in primary literature with other meta-analyses for each of the included meta-analyses is presented in the table in Appendix B.

### **Results**

In total, 25 effect sizes were extracted from 25 different meta-analyses involving 1,055 primary studies (approximately 109,700 participants). They represented comparisons of student achievement between technology-enhanced classrooms and more traditional types of classrooms without technology. The meta-analyses addressed a variety of technological approaches that were used in the experimental conditions to

**TABLE 2***Mixed effects comparison of levels of methodological quality*

Level	<i>k</i>	<i>ES</i>	<i>SE</i>	<i>Q</i> statistic
Low	8	0.42*	0.07	
Medium	7	0.35*	0.04	
High	10	0.31*	0.03	
Total between				2.50 <sup>†</sup>

<sup>†</sup>*p* = .29. \**p* < .05.

enhance and support face-to-face instruction. The control group was what many education researchers refer to as the “traditional” or “computer-free” settings.

#### *Outlier Analysis and Publication Bias*

Outlier analysis through the “one study removed” approach (Borenstein et al., 2009) revealed that all effect sizes fell within the 95th confidence interval of the average effect size, and thus, there was no need to exclude any studies. Examination of the funnel plot revealed an almost symmetrical distribution around the mean effect size with no need for imputations, indicating the absence of any obvious publication bias.

#### *Methodological Quality*

In approaching the analysis, we wanted to determine if the three levels of methodological quality were different from one another. This step is analogous to a comparison among different research designs or measures of methodological quality that is commonly included in a regular meta-analysis. The mixed effects comparison of the three levels of methodological quality of the 25 meta-analyses is shown in Table 2. Although there seems to be a particular tendency for smaller effect sizes to be associated with higher methodological quality, the results of this comparison were not significant. On the basis of this analysis, we felt justified in combining the studies and not differentiating among levels of quality.

#### *Effect Size Synthesis and Validation*

The weighted mean effect size of the 25 different effect sizes was significantly different from zero for both the fixed effects and the random effects models. For the fixed effects model, the point estimate was 0.32,  $z(25) = 34.51$ ,  $p < .01$ , and was significantly heterogeneous,  $Q_T(25) = 142.88$ ,  $p < .01$ ,  $I^2 = 83.20$ . The relatively high *Q* value and *I*<sup>2</sup> reflect the high variability in effect sizes at the meta-analysis level. Applying the random effects model, the point estimate was also significant, 0.35,  $z(25) = 14.03$ ,  $p < .01$ . The random effects model was considered most appropriate for interpretation because of the wide diversity of technologies, settings, subject matter, and so on among the meta-analyses (Borenstein et al., 2009). However, the presence of heterogeneity, detected in the fixed effects model result, suggested that a probe of moderator variables might reveal additional insight into the nature of differences among the meta-analyses. For this, we applied the mixed effects model.

For the purpose of validating the findings of the second-order meta-analysis, the extracted raw data were used in the calculation of the point estimate in a

**TABLE 3***Results of the analysis of two moderator variables*

Level	<i>k</i>	<i>ES</i>	<i>SE</i>	<i>Q</i> statistic
Primary purpose of technology use				
Direct instruction	15	0.31*	0.01	
Support instruction	10	0.42*	0.02	
Total between				3.86*
Grade level of student				
K–12	9	0.40*	0.04	
Postsecondary	11	0.29*	0.03	
Total between				4.83*

\* $p < .05$ .

process similar to a regular meta-analysis. As described earlier, 574 individual effect sizes and their corresponding sample sizes were extracted, with the total number of participants being 60,853. The weighted mean effect size for the 574 individual effect sizes was significantly different from zero with both the fixed effects model and the random effects models. From the fixed effects model, the point estimate was 0.30,  $z(574) = 37.13$ ,  $p < .01$ , and heterogeneous,  $Q_T(574) = 2,927.87$ ,  $p < .01$ ,  $I^2 = 80.43$ . With the random effects model, the point estimate was 0.33.

In comparing the second-order analysis with the validation sample, it is clear that the average effect sizes are similar for both the fixed effects and the random effects models. The  $I^2$  for the second-order meta-analysis and the validation sample indicates similar variability, although the  $Q$  totals are very different (i.e., the  $Q$  total tends to increase as the sample size increases).

#### *Moderator Variable Analysis*

To explore variability, a mixed effects model was used in moderator variable analysis with the coded study features. A mixed effects model summarizes effect sizes within subgroups using a random model but calculates the between-group  $Q$  value using a fixed model (Borenstein et al., 2009). Moderator analyses for subject matter, type of publication, and type of research designs included did not reveal any significant findings. For two substantive moderator variables (i.e., subject matter and type of technology) the number of levels (five and eight, respectively) mitigated against finding differences. However, the analysis revealed that “primary purpose of instruction” (i.e., “direct instruction” vs. “support for instruction”) was significant in favor of the “support instruction” condition (see Table 3). These two levels of purpose of instruction were formed by considering technology use in the bulk of studies contained in each meta-analysis, as to whether they involved direct instruction (e.g., CAI and CBI) or provided support for instruction (e.g., the use of word processors and simulations).

Likewise, when studies involving K–12 applications of technology were compared to postsecondary applications, a significant difference was found. This result favored K–12 applications (Table 3). This comparison involved a subset of 20 studies out of the total of 25. The other 5 studies were mixtures of studies involving K–12 and postsecondary.

### *Summary of the Findings*

The current second-order meta-analysis summarized evidence regarding the impact of technology on student achievement in formal academic contexts based on an extensive body of literature. The synthesis of the extracted effect sizes, with the support of the validation process, revealed a significant positive small to moderate effect size favoring the utilization of technology in the experimental condition over more traditional instruction (i.e., technology free) in the control group. The analysis of two substantive moderator variables revealed that computer technology that supports instruction has a marginally but significantly higher average effect size compared to technology applications that provide direct instruction. Also, it was found that the average effect size for K–12 applications of computer technology was higher than computer applications introduced in postsecondary classrooms.

### **Discussion**

The main purpose of this second-order meta-analysis is to bring together more than 40 years of investigations, beginning with Schurdak (1967), that have asked the general question, “What is the effect of using computer technology in classrooms, as compared to no technology, to support teaching and learning?” It is a relevant question as we enter an age of practice and research in which nearly every classroom has some form of computer support. Although research studies comparing various forms of technology use in both control and treatment groups are becoming popular, it does not seem that technology versus no technology comparisons will become obsolete. Studies of this sort may still be useful for answering specific targeted questions, as in the case of software development (e.g., software that replaces or enhances traditional teaching methods). A case in point is a recent meta-analysis (Sosa, Berger, Saw, & Mary, 2010) of statistics instruction in which CAI classroom conditions were compared to standard lecture-based instruction conditions. The overall results favored CAI ( $d = 0.33$ ,  $p = .00$ ,  $k = 45$ ), similar to the findings from the current study. The results of this very targeted meta-analysis provide evidence of the important contributions that CBI can provide to teachers of statistics. Relating these findings to the current work, we averaged 4 meta-analyses of mathematics instruction from the 25 previously described (two were referenced by Sosa et al., 2010) and found that the average effect size was 0.32 under the fixed effects model (0.39 under the random effects model).

However, and similar to classroom comparative studies of distance education and online learning (e.g., Bernard et al., 2004, 2009), we feel that we are at a place where a shift from technology versus no technology studies to more nuanced studies comparing different conditions, both involving CBI treatments, would help the field progress. And because such a rich corpus of meta-analyses exists, spanning virtually the entire history of technology integration in education, we feel that it may be unnecessary to mount yet another massive systematic review, limited to technology versus no-technology studies. Moreover, it appears that the second-order meta-analysis approach represents an economical means of providing an answer to big questions. The validation study, although not a true systematic review, offered support for the accuracy of the effect size synthesis and indicated that the results of the second-order meta-analysis were not anomalous, where we found approximately the same average effect using both approaches.

The average effect size in both the second-order meta-analysis and the validation study ranged between 0.30 and 0.35 for both the fixed effects and the random effects models, which is low to moderate in magnitude according to the qualitative standards suggested by J. Cohen (1988). Such an effect size magnitude indicates that the mean in the experimental condition will be at the 62nd percentile relative to the control group. In other words, the average student in a classroom where technology is used will perform 12 percentile points higher than the average student in the traditional setting that does not use technology to enhance the learning process. It is important to note that these average effects must be interpreted cautiously because of the wide variability that surrounds them. We interpret this to mean that other factors, not identified in previous meta-analyses or in this summary, may account for this variability. We support Clark's (1983, 1994) view that technology serves at the pleasure of instructional design, pedagogical approaches, and teacher practices and generally agree with the view of Ross, Morrison, and Lowther (2010) that "educational technology is not a homogeneous 'intervention' but a broad variety of modalities, tools, and strategies for learning. Its effectiveness, therefore, depends on how well it helps teachers and students achieve the desired instructional goals" (p. 19). Thus, it is arguable that it is aspects of the goals of instruction, pedagogy, teacher effectiveness, subject matter, age level, fidelity of technology implementation, and possibly other factors that may represent more powerful influences on effect sizes than the nature of the technology intervention. It is incumbent on future researchers and primary meta-analyses to help sort out these nuances, so that computers will be used as effectively as possible to support the aims of instruction.

Results from the moderator analyses indicated that computer technology supporting instruction has a slightly but significantly higher average effect size than technology applications used for direct instruction. The average effect size associated with direct instruction utilization of technology (0.31) is highly consistent with the average effect size reported by Hattie (2009) for CAI in his synthesis of meta-analyses, which was also 0.31. Moreover, the overall current findings are in agreement with the results provided by a Stage 1 meta-analysis of technology integration recently published by Schmid et al. (2009), where effect sizes pertaining to computer technology used as "support for cognition" were significantly greater than those related to computer use for "presentation of content." Taken together with the current study, there is the suggestion that one of technology's main strengths may lie in supporting students' efforts to achieve rather than acting as a tool for delivering content. Low power prevented us from examining this comparison between purposes, split by other instructional variables and demographic characteristics.

### **Second-Order Meta-Analysis and Future Perspectives**

With the increasing number of published meta-analyses in a variety of areas, there is a growing need for a systematic and reliable methodology for synthesizing related findings. We have noted in this review a degree of fragmentation in the coverage of the literature, with the next meta-analysis overlapping the previous one but not including much of the earlier literature. We suspect that this is not a unique case. At some point in the development of a field there comes the need to summarize the literature over the entire history of the issue in question. We see only

two choices: (a) conduct a truly comprehensive meta-analysis of the entire literature or (b) conduct a second-order meta-analysis that synthesizes the findings and judges the general trends that can be derived from the entire collection. A large review can be time-consuming and expensive, but it has a better chance of identifying underlying patterns of variability that may be of use to the field. A second-order meta-analysis is less costly and less time-consuming while providing sufficient power with regard to the findings. In the case of technology integration, we see the second-order approach to be a viable option. First, time is of the essence in a rapidly expanding and changing field such as this. Second, since we are unlikely to see the particular technologies summarized here reappearing in the future, it is probably enough to know that in their time and in their place these technologies produced some measure of success in achieving the goals they were designed to enable.

The strongest point in a second-order meta-analysis is its ability to provide evidence to answer a general question by taking a substantive body of research into consideration. The current synthesis with the validation process indicated that the approach is an adequate technique for synthesizing effect sizes and estimating the average effect size in relation to a specific phenomenon. Future advancement in the reporting of meta-analyses may allow for using moderator analysis in second-order meta-analysis to answer more specific questions pertaining to various study features of interest.

## APPENDIX A

### *Codebook of variables in the second-order meta-analysis*

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#### *Study identification*

- Identification number
- Author
- Title
- Year of publication
- Type of publication
  1. Journal
  2. Dissertation
  3. Conference proceedings
  4. Report or gray literature

#### *Contextual features*

- Research question
- Technology addressed
- Control group definition or description
- Clarity of the control group definition
  1. Control group not defined, no reference to specifics of the treatment
  2. Providing general name for control group with brief description of the treatment condition
  3. Control group defined specifically with some missing aspects from the full definition as described in level

4. Clearly defined intervention, with a working or operational definition linked to conceptual or theoretical model with examples
- Experimental group treatment definition or description
  - Clarity of the experimental group definition
    1. Experimental group not defined, no reference to specifics of the treatment
    2. Providing general name for experimental group with brief description of the treatment condition
    3. Experimental group defined specifically with some missing aspects from the full definition as described in number
    4. Clearly defined intervention, with a working or operational definition linked to conceptual or theoretical model with examples
  - Grade level
  - Subject matter
    1. Science or health
    2. Language
    3. Math
    4. Technology
    5. Social Science
    6. Combination
    7. Information literacy
    8. Engineering
    9. Not specified

*Methodological features*

- Search phase
- Search time frame
- Justification for search time frame
  1. No
  2. Yes
- Literature covered
  1. Published studies only
  2. Published and unpublished studies
- Search strategy
  1. Search strategy not disclosed, no reference to search strategy offered
  2. Minimal description of search strategy with brief reference to resources searched
  3. Listing of resources and databases searched
  4. Listing of resources and databases searched with sample search terms
- Resources used
  1. Database searches
  2. Computerized search of Web resources
  3. Hand search of specific journals
  4. Branching
- Databases searched
- Number of databases searched

*Review phase*

- Inclusion or exclusion criteria
  1. Criteria not disclosed with no description offered
  2. Overview of criteria presented briefly
  3. Criteria specified with enough detail to allow for easy replication
- Included research type
  1. Randomized controlled trial (RCT) only
  2. RCT, quasi
  3. RCT, quasi, pre
  4. Not specified
- Article review
  1. Review process not disclosed
  2. Review process by one researcher
  3. Rating by more than one researcher
  4. Rating by more than one researcher with interrater agreement reported

*Effect size (ES) and study feature extraction phase*

- ES extraction
  1. Extraction process not disclosed, no reference to how it was conducted
  2. Extraction process by one researcher
  3. Extraction process by more than one researcher
  4. Extraction process by more than one researcher with interrater agreement reported
- Code book
  1. Code book not described, no reference to features extracted from primary literature
  2. Brief description of main categories in code book
  3. Listing of specific categories addressed in code book
  4. Elaborate description of code book allowing for easy replication
- Study feature extraction
  1. Extraction process not disclosed, no reference to how it was conducted
  2. Extraction process by one researcher
  3. Extraction process by more than one researcher
  4. Extraction process by more than one researcher with interrater agreement reported

*Analysis*

- Independence of data
  1. No
  2. Yes
- Weighting by number of comparisons
  1. Yes
  2. No
- ES weighted by sample size
  1. No
  2. Yes

- Homogeneity analysis
  1. No
  2. Yes
- Moderator analysis
  1. No
  2. Yes
- Metaregression conducted
  1. No
  2. Yes

*Further reporting aspects*

- Inclusion of list of studies
  1. No
  2. Yes
- Inclusion of ES table
  1. No
  2. Yes
- Time between last study and publication date

*ES information*

- ES type
  1. Glass
  2. Cohen
  3. Hedges
  4. Others: specify
- Total *ES*
- Mean *ES*
- *SE*
- *SE* extraction
  1. Reported
  2. Calculated from *ES* and sample size
  3. Calculated from confidence interval
  4. Replaced with weighted average *SE*
- Time frame included
- Number of studies included
- Number of *ES* included
- Number of participants
- Number of participants extraction
  1. Calculated
  2. Given

*Specific ES*

- Specific variable
- Mean *ES*
- *SE*
- *SE* extraction
  1. Reported

- 2. Calculated from *ES* and sample size
- 3. Calculated from confidence interval
- 4. Replaced with weighted average *SE*
- Time frame included
- Number of studies included
- Number of *ES* included
- Number of participants
- Number of participants extraction
  - 1. Calculated
  - 2. Given

**APPENDIX B**

*Included meta-analyses with number of studies, effect size (ES) types, mean ESs, standard errors, number of overlapping studies, and percentage of overlaps*

Meta-analysis	Number of studies	ES type	Mean ES	SE	Number of overlapping studies	Percentage of overlap
Bangert-Drowns (1993)	19	Missing	0.27	0.11	1	5.3
Bayraktar (2000)	42	Cohen's <i>d</i>	0.27	0.05	7	16.7
Blok, Oostdam, Otter, and Overmaat (2002)	25	Hedges's <i>g</i>	0.25	0.06	2	8.0
Christmann and Badgett (2000)	16	Missing	0.13	0.05	4	25.0
Fletcher-Flinn and Gravatt (1995)	120	Glass's $\Delta$	0.24	0.05	26	21.7
Goldberg, Russell, and Cook (2003)	15	Hedges's <i>g</i>	0.41	0.07	1	6.7
Hsu (2003)	25	Hedges's <i>g</i>	0.43	0.03	4	16.0
Koufogiannakis and Wiebe (2006)	8	Hedges's <i>g</i>	-0.09	0.19	1	12.5
Kuchler (1998)	65	Hedges's <i>g</i>	0.44	0.05	7	10.8
Kulik and Kulik (1991)	239	Glass's $\Delta$	0.30	0.03	8	3.3
Y. C. Liao (1998)	31	Glass's $\Delta$	0.48	0.05	2	6.4
Y.-I. Liao and Chen (2005)	21	Glass's $\Delta$	0.52	0.05	2	9.5
Y. K. C. Liao (2007)	52	Glass's $\Delta$	0.55	0.05	2	3.8

(continued)

## APPENDIX B (continued)

Meta-analysis	Number of studies	ES type	Mean ES	SE	Number of overlapping studies	Percentage of overlap
Michko (2007)	45	Hedges's <i>g</i>	0.43	0.07	0	0.0
Onuoha (2007)	35	Cohen's <i>d</i>	0.26	0.04	3	8.6
Pearson, Ferdig, Blomeyer, and Moran (2005)	20	Hedges's <i>g</i>	0.49 <sup>a</sup>	0.11	2	10.0
Roblyer, Castine, and King (1988)	35	Hedges's <i>g</i>	0.31	0.05	4	11.4
Rosen and Salomon (2007)	31	Hedges's <i>g</i>	0.46	0.05	0	0.0
Schenker (2007)	46	Cohen's <i>d</i>	0.24	0.02	9	19.6
Soe, Koki, and Chang (2000)	17	Hedges's <i>g</i> and Pearson's <i>r</i> <sup>a</sup>	0.26 <sup>a</sup>	0.05	2	11.8
Timmerman and Kruepke (2006)	114	Pearson's <i>r</i> <sup>a</sup>	0.24	0.03	27	23.7
Torgerson and Elbourne (2002)	5	Cohen's <i>d</i>	0.37	0.16	0	0.0
Waxman, Lin, and Michko (2003)	42	Glass's $\Delta$	0.45	0.14	5	11.9
Yaakub (1998)	20	Glass's $\Delta$ and <i>g</i>	0.35	0.05	4	20.0
Zhao (2003)	9	Hedges's <i>g</i>	1.12	0.26	1	11.1

a. Converted to Cohen's *d*.

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