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Learning in One-to-One Laptop Environments: A Meta-Analysis and Research Synthesis

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Over the past decade, the number of one-to-one laptop programs in schools has steadily increased. Despite the growth of such programs, there is little consensus about whether they contribute to improved educational outcomes. This article reviews 65 journal articles and 31 doctoral dissertations published from January 2001 to May 2015 to examine the effect of one-to-one laptop programs on teaching and learning in K–12 schools. A meta-analysis of 10 studies examines the impact of laptop programs on students' academic achievement, finding significantly positive average effect sizes in English, writing, mathematics, and science. In addition, the article summarizes the impact of laptop programs on more general teaching and learning processes and perceptions as reported in these studies, again noting generally positive findings.

Keywords: 21st century skills, academic achievement, meta-analysis, one-to-one laptop program, processes and perceptions

The effects of new technology on teaching and learning are one of the most hotly debated topics in U.S. education. The argument against an emphasis on technology is most eloquently made by Cuban (1986), a historian who has investigated 100 years of educational technology. Cuban (1993b) argued that schools are deeply conservative institutions, shaped by difficult-to-change social mores. Because of that, he believes that computers are bound to play the same marginal role in schools that earlier technologies, such as radio, film, and television, did

(Cuban, 2003). A more nuanced critique of the transformative power of technology is made by Mayer (as interviewed in Veronikas & Shaughnessy, 2005), who puts forth what might be called an instrumental perspective (Feenberg, 1991). From this view, computers or other educational technologies are neutral tools that can be put to any purpose, good or bad, and therefore, trying to make an evaluation of their general impact is useless.

In contrast to these is a Vygotskian approach, which views all human activity as mediated by tools (Vygotsky, 1962, 1978). From this perspective, the integration of new tools into an environment is bound to transform that activity, and understanding the nature of that transformation is of great value (e.g., Wertsch, 1991). In other words, just as activity shapes the value of tools (as argued by Mayer), tools simultaneously shape the nature of activity. This contention leads to Kranzberg's (1986) famous dictum—that technology is neither good nor bad, nor is it neutral. Instead, technology has affordances that make certain types of outcomes more likely (see also Levinson, 1997). We believe that the affordances of computers for learning and knowledge production are radically different from those of radio, television, and film, which explains why computers, unlike those previous technologies, are bound to have a very different educational fate from the one suggested by Cuban (1993a, p. 185), who wrote that "computer meets classroom: classroom wins."

It is with this perspective in mind that we have conducted this meta-analysis and review of what are called *one-to-one* laptop programs, in which all the students in a class, grade level, school, or district are provided computers for use throughout the school day and, in some cases, at home. We agree with Cuban (1993a, 1993b) that the role of computers is likely to be marginal when they are scattered in small numbers throughout schools, and other research bears this out (e.g., Becker, 2000). It is when each student has access to an individual computer that the effects of technology on instruction are most likely to be felt (see Warschauer, 2006), and these one-to-one programs thus deserve special attention. An evaluation of such programs also has important policy implications at this point in time. With individual laptop computers, such as Chromebooks, now falling below $200, and schools in the United States and other countries transitioning to more computerized assessment, a growing number of schools are considering implementing individualized laptop programs. Knowing the general impact of these programs can help school districts shape their technology policies.

One-to-one laptop programs have spread widely since they were first introduced in Australia and the United States in the 1990s (Johnstone, 2003). Maine's statewide program was launched in 2002, with smaller programs starting in many other states and countries in the years that followed (Howard, Chan, & Caputi, 2015; Klieger, Ben-Hur, & Bar-Yossef, 2010; Newhouse & Rennie, 2001; Towndrow & Vaish, 2009; Warschauer, 2006). Laptops are typically purchased by schools and sometimes by parents, and they are largely used to write and revise papers, conduct Internet searches, and engage in personalized instruction and assessment using educational software or online tools (see Warschauer, 2006, for an overview).

Only a few research syntheses, and no prior meta-analyses, have been published on the results of these one-to-one laptop programs. An early review by Penuel et al. (2001) reported that the few studies available at that time suffered serious methodological problems. A few years later, Penuel (2006) reviewed 30 studies of one-to-one laptop initiatives, categorizing them into implementation studies and outcome studies, and suggested that more rigorously designed studies were still needed. The New South Wales Department of Education and Training (2009) conducted a one-to-one computing literature review, examining factors that affect the implementation of laptop programs, classroom use of laptops, and type of supports required for them to succeed. The review concluded that pedagogy was more important than technology in determining the effectives of the laptop programs. Specific factors, such as teachers' attitudes and beliefs, school leadership, classroom management strategies, technical support, and ongoing professional development, played a vital role in ensuring the success of the laptop implementation program. Bebell and O'Dwyer (2010) synthesized four empirical studies of K–12 one-to-one laptop programs, concluding that more studies should focus on how technology can be used to support educational processes rather than just describing the technology access.

We aim to bring our understanding of one-to-one computing up to date by synthesizing research studies that examine the effect of one-to-one laptop programs on teaching and learning processes and outcomes in K–12 schools. We attempt to answer two questions: (a) What is the impact of laptop programs on academic achievement? (b) What is the broader program impact on teaching and learning processes, teacher and student perceptions, and other learning outcomes?

Method

We conducted the study in the following steps: (a) literature search, (b) selection of eligible studies for research synthesis and meta-analysis, (c) developing and applying coding scheme for research synthesis, (d) developing and applying coding scheme for meta-analysis, and (e) data analysis. The R software (package: *metafor*; Viechtbauer, 2010) was adopted to conduct the meta-analysis.

The Literature Search

To locate studies for inclusion in the synthesis, keyword searches were first conducted using the Educational Resources Information Center (ERIC) database. This database provides broad coverage of journals in the field of educational technology and is frequently used in meta-analyses (e.g., Lin, Huang, & Liou, 2013; Zhao, 2003). Our searches used the following words and word combinations: (a) one-to-one laptop, (b) one-to-one computing, (c) 1:1 laptop, (d) laptop program, (e) laptop initiative, and (f) laptop computing.

In addition to searching the ERIC database, we checked nine major journals in the fields of education and educational technology that have published studies on one-to-one computing: including the *American Educational Research Journal*, the *British Journal of Educational Technology*, the *Canadian Journal of Learning and Technology*, *Computers & Education*, the *Journal of Computer Assisted Learning*, the *Journal of Educational Computing Research*, the *Journal of*

Educational Research, the *Journal of Research on Technology in Education*, and the *Journal of Technology, Learning and Assessment*. All the references sections from each article in our study were also examined for additional studies.

Due to the changes in computer technology, we excluded studies published in the year 2000 and earlier and only included studies published from January 2001 to May 2015. We limited our analysis to journal articles and doctoral dissertations, as these have both gone through a formal review process. We excluded conference papers as we had limited access to full texts of these papers and excluded reports that had not gone through a formal peer-review process. We also excluded studies based on other kinds of technology, such as tablets, smartphones, or desktop computers, as the affordances they have for learning may be different from those of laptops. On this last point, we also note that, although iPads and other tablets gained market share in schools 2 to 3 years ago, the popularity of Chromebooks—a type of web-centric low-cost laptop—have soared, once again shifting the momentum toward laptops (Molnar, 2014). Our searches generated 945 results. After reading each article's title and abstract to determine whether they fit the research topic, 343 articles were selected in the initial round.

Inclusion Criteria

Broad Research Synthesis

Once the articles were retrieved from the initial selection, we reviewed the content of each article and determined whether it could be included in this study. First, to be included in the broad research synthesis, an article had to meet the following criteria:

1. The study was conducted in a K–12 school setting.
2. The study's focus was on one-to-one laptop programs rather than on shared laptop programs or other interventions that occurred within a laptop environment.
3. The study was an empirical examination of the effect of one-to-one laptop programs on teaching or learning rather than simply a general description or discussion of one-to-one laptop programs.
4. The study had well-defined research questions, involved systematic collection and analysis of empirical quantitative and/or qualitative data, and provided a clear presentation of findings.

After this filtering, a total of 96 articles were selected for the research synthesis, including 65 journal articles and 31 doctoral dissertations, with no duplications between journal articles and dissertations.

Meta-Analysis

Then, to select eligible studies for meta-analysis, we deployed the following more restrictive criteria:

1. Studies had an experimental group and a control group or an identified reference norm.

2. Studies reported quantitative findings of the impact on students' academic achievement.
3. Measurements of academic achievement were standardized assessments or norm-referenced district- or school-wide tests.
4. The duration of the study was recorded.
5. Studies provided sufficient statistical data for computing the effect size.

Two authors conducted the selection process of the meta-analysis. When disagreement occurred, they resolved the matter through discussion. The intercoder agreement was 91%. A total of 10 studies met the criteria and were thus included in the meta-analysis.

Developing and Applying Coding Scheme for Research Synthesis

To synthesize the broader impact of one-to-one laptop programs on teaching and learning processes, teacher and student perceptions, and learning outcomes as reported in these studies, Zucker's (2004) one-to-one initiative evaluation framework was used. That framework includes three aspects: critical features of one-to-one initiatives, interactions and intermediate outcomes, and ultimate outcomes. Critical features of one-to-one initiatives include (a) setting, (b) technology used, (c) implementation plans, and (d) goals and objectives. Interactions and intermediate outcomes include (a) teaching and instruction, (b) school leaders, (c) infrastructure and support, (d) schools and systems, (e) school–community relations, and (f) costs and funding. Finally, ultimate outcomes refer to the impact of one-to-one initiatives on (a) students and their learning, (b) economic competitiveness, and (c) the digital divide. The research synthesis in this article focuses on critical features of one-to-one initiatives, interactions and intermediate outcomes, and two of the issues in ultimate outcomes, specifically students and their learning, and the digital divide; the third issue in ultimate outcomes, economic competitiveness, was beyond the scope of what could be evaluated from the included studies.

Developing and Applying Coding Scheme for Meta-Analysis

The 10 studies that met the criteria were coded to identify their important features. Variables of interest in the studies include duration, subject area, and academic achievement. Effect sizes and variances were calculated from study results.

Effect Size Computation

Most of the studies in the sample presented multiple effect sizes from multiple study subjects, different substudies, and different groups of participants. We first categorized all the effect sizes by different subjects (e.g., math, writing) and treated them independently. For longitudinal studies, only the effect size reported in the last year was used rather than the interim effects. The effect size for each estimate was computed and converted to Cohen's *d* (J. Cohen, 1988). To compute Cohen's *d*, the components for calculating standardized mean differences and odds ratio were extracted (see Cooper, Hedges, & Valentine, 2009). Cohen's *d* was calculated as the difference in posttest scores between the experimental and control groups divided by the pooled standard deviation at posttest (Lipsey & Wilson, 2000).

$$d = \frac{m_{\text{trt}} - m_{\text{cntl}}}{s_{\text{pooled}}}, \tag{1}$$

where m_{trt} and m_{cntl} denote the mean of the treatment group and the mean of the control group and s_{pooled} denotes the pooled standard deviation in the study. For studies in which the mean and standard deviations were not available, an odds ratio r was calculated and converted to Cohen's d via the following formula (Borenstein, Hedges, Higgins, & Rothstein, 2009):

$$d = \text{Log odds} \times \frac{\sqrt{3}}{\pi}, \tag{2}$$

$$V_d = V_{\text{logodds}} \times \frac{3}{\pi^2}. \tag{3}$$

For studies with insufficient reports of means, standard deviations, or frequencies, inferential statistics (e.g., t tests) and sample sizes were extracted to calculate effect sizes, which were then converted to Cohen's d. For example, Cohen's d can also be obtained from

$$d = t\sqrt{\frac{n_{\text{total}}}{n_{\text{trt}} \times n_{\text{cntl}}}}. \tag{4}$$

Studies using regression models were excluded from our pool because of the following reasons. First, these studies failed to provide semipartial correlations, which were used to calculate the effect size of regression models for model-driven meta-analyses (Aloe & Becker, 2012). In addition, due to the fact that combining and comparing unadjusted and adjusted estimates (e.g., model-based regression analyses) was not convincing in meta-analyses, only studies with unadjusted estimates were retained in this study, in order to maintain the validity of the results of the study.

After each individual effect size was calculated and converted, the effect size variances were calculated according to formulas presented in Cooper et al. (2009). The inverse of the variance of effect sizes was regarded as the weight of each effect size in the sample. Hence, the larger the variance, the smaller the weight of the corresponding effect size. The inverse of the variance of effect sizes can also be called precision. Taking an independent sample t test as an example, the variance of the effect size is inversely proportional to the sample size of the two independent groups, as shown in Equation 5:

$$\text{Variance} = \left(\frac{n_{\text{treatment}} + n_{\text{control}}}{n_{\text{treatment}} \times n_{\text{control}}}\right) + \frac{(\text{effect size})^2}{2(n_{\text{treatment}} + n_{\text{control}})}. \tag{5}$$

Subject Area

Effect sizes were categorized in five different subject areas: English, Reading, Writing, Math, and Science. The content keywords that fit different subjects are indicated in Table 1.

TABLE 1

The inclusion description of five subjects in the meta-analyses

Subject	Number of studies	Number of effect size estimates	Content keywords
English	6	19	ELA (English language arts), ELA total score, English, English (listening comprehension), English (grammar)
Reading	4	13	Hebrew (reading comprehension), literacy response and analysis, reading comprehension, reading fluency, word analysis and vocabulary development, reading
Writing	3	11	Writing, writing strategies, written and oral language conventions, English (writing)
Math	7	21	Math (calculation), Math (comparison), Math (word problem), Math
Science	2	3	Science

Duration of the Program

In addition to the average effect size and subjects, we also included the duration of each implementation as differences in duration of educational technology implementations may affect learning outcomes (e.g., Grimes & Warschauer, 2008).

Data Analysis in Meta-Analysis

Univariate meta-analysis was conducted individually for the following five subjects: English, Reading, Writing, Math, and Science. For all subjects, the I^2 index was computed to quantify the extent of heterogeneity in each univariate analysis (Huedo-Medina, Sánchez-Meca, Marín-Martínez, & Botella, 2006). Random effect models were applied to all meta-analyses in this study since, unlike fixed effect models, random effect models take into account between-study variation. Forest plots were developed to visually display the contribution of each study to the meta-analysis by plotting study effect sizes, corresponding confidence interval bars, and a summary effect line in a single graph. In addition, to test for the validity of the meta-analysis, five funnel plots for each individual subject were included as the visual presentation. Test results for funnel plot asymmetries were obtained as the indication of publication bias using standard error as the moderator.

Results and Discussion

We first report the results of the meta-analysis of laptop programs on students' academic achievement, and then synthesize the broader impact that laptop programs have on teaching and learning processes, perceptions, and outcomes.

The I^2 index was calculated to examine the homogeneity of the effect size in all five subjects. The results of the index for English (59.99%), Reading (55.50%), Writing (64.89%), Mathematics (82.15%), and Science (0.00%) identified the proportion of the heterogeneity between studies among the total variation of the effect sizes in each subject field. The Q statistics for English, Reading, Writing, Mathematics, and Science were 43.08 ($p < .001$), 22.10 ($p < .05$), 29.03 ($p < .01$), 93.28 ($p < .001$), and 0.02 ($p > .05$), respectively. Although the heterogeneity measures imply that between-studies variance in science is small, restricting all studies in this subject on common true effect sizes is not practical. Since it is very likely that the true mean differs in different study settings, using the variance in the distribution of the true effect sizes would yield more robust results than using the common mean of the studies. Thus, random-effects models were applied to the meta-analysis models for each of the five subjects.

English Language Arts

Nineteen effect sizes within six studies (Grimes & Warschauer, 2008; Gulek & Demirtas, 2005; Hansen et al., 2012; Hur & Oh, 2012; Lowther, Inan, Ross, & Strahl, 2012; Rosen & Manny-Ikan, 2011) that examined the effect of laptop programs on students' English language arts (ELA) achievement were included in the meta-analysis. The estimated average effect size was $d = .15$ (95% CI = [.029, .273]; see Forest Plot A in Figure 1). This suggested that one-to-one laptop programs helped improve students' general ELA achievement by .15 of a standard deviation on average. One study found that the positive effect on ELA scores only occurred after the second year of implementation (see Grimes & Warschauer, 2008). The study found a negative effect size (−.28) after the first year of implementation and a positive effect size (.30) after the second year of implementation. This second-year effect might be attributed to the fact that, in the first year of implementation, both teachers and students needed to adapt to a new style of teaching and learning, and classes by necessity had to divert time from academic content to teaching requisite computer skills. This would suggest that, in the second year, teachers and students had become more familiar with the technology and thus could focus more on laptop use for subject area learning—an implication supported by teacher interview data in Suhr, Hernandez, Warschauer, and Grimes (2010).

Positive results in ELA were also reported in additional studies not included in the meta-analysis because insufficient statistical information was provided for computing effect size (e.g., Bebell & Kay, 2010; Kposowa & Valdez, 2013; Zheng, Warschauer, & Farkas, 2013). For example, Bebell and Kay (2010) found that eighth-grade students in laptop classroom environments had higher ELA score growth than their comparison peers within 2 years of implementation of the laptop program, based on the Massachusetts Comprehensive Assessment System test. Similarly, in Zheng et al.'s (2013) study, improved ELA scores were detected among students in both a partial laptop program and a full laptop program, compared to their non-laptop peers. Bebell and Kay (2010) also found that eighth-grade laptop students who reported more frequent use of computers for recreation

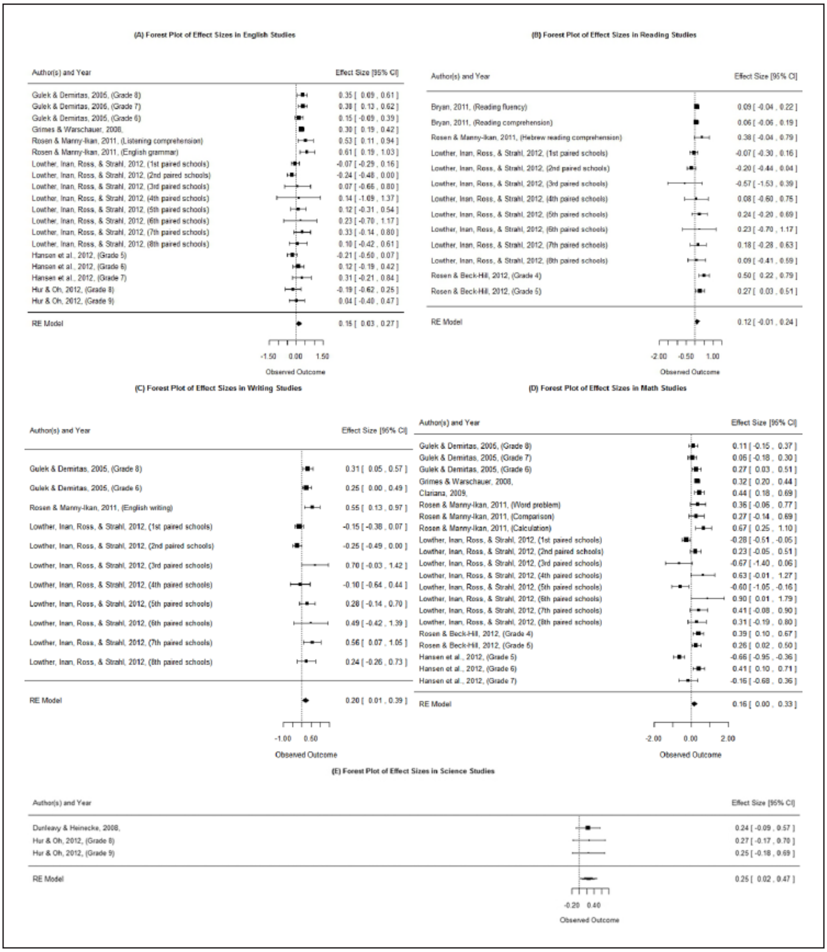

FIGURE 1. *(A) Forest plot of effect sizes of one-to-one laptop program effect in English Studies. (B) Forest plot of effect sizes of one-to-one laptop program effect in Reading Studies. (C) Forest plot of effect sizes of one-to-one laptop program effect in Writing Studies. (D) Forest plot of effect sizes of one-to-one laptop program effect in Math Studies. (E) Forest plot of effect sizes of one-to-one laptop program effect in Science Studies.*

at home tended to have higher ELA achievement; however, this positive effect diminished greatly after controlling for students' socioeconomic status. In another study (Basham, 2012), high school students experienced significant growth in ELA after 2 years' implementation of a laptop program. However, since no control group was provided in this study, it is difficult to determine whether the growth was due to the program or confounding factors.

Reading

Thirteen effect sizes within four studies (Bryan, 2011; Lowther et al., 2012; Rosen & Beck-Hill, 2012; Rosen & Manny-Ikan, 2011) were included in the meta-analysis of laptop program effect on students' reading achievement. The estimated average effect size was $d = .12$ (95% CI = [−.008, .243]; see Forest Plot B in Figure 1), which was not statistically different from zero, indicating that students in the laptop program scored no differently than their comparison group in reading achievement. Besides these included in the meta-analysis, two studies showed no significant growth in reading among laptop students when compared to non-laptop students (Bernard, Bethel, Abrami, & Wade, 2007; Shapley, Sheehan, Maloney, & Caranikas-Walker, 2011).

Another two studies considered how specific factors in laptop programs may have affected students' reading achievement. Shapley, Sheehan, Maloney, and Caranikas-Walker (2010b) examined the relationship between middle school students' reading achievement and laptop immersion support (including leadership, teacher support, parent/community support, technical support, and professional development). Findings suggested that the immersion support positively predicted eighth-grade students' reading achievement, but that the positive effect was not consistent in other cohorts. However, students' use of technology—especially technology use for home learning—strongly predicted students' reading achievement across all three cohorts. Kay (2010) similarly found that one-to-one laptop students who used their computers more frequently at home tended to have a higher ELA total score as well as higher reading and literature subscores. The finding that technology use for home learning can positively affect students' reading achievement underscores the potential importance of one-to-one laptop programs in providing equal opportunities for economically disadvantaged students.

Writing

Meta-analysis of 11 effect sizes across three studies (Gulek & Demirtas, 2005; Lowther et al., 2012; Rosen & Manny-Ikan, 2011) suggested that laptop programs have a positive effect on student writing, with an average effect size, $d = .20$ (95% CI = [.008, .390]; see Forest Plot C in Figure 1).

A number of other quantitative studies that met some but not all of the criteria for the meta-analysis also reported a positive impact on students' writing achievement (see Lowther, Ross, & Morrison, 2003). In one such study, Lowther et al. (2003) found a significant positive effect on students' writing performance in the laptop group, specifically in the area of ideas and content, organization, and style, but not in the area of conventions. In another study, Zheng et al. (2013) found no overall gains in writing scores after 1-year implementation of a laptop program, but reported that fifth-grade at-risk students (i.e., Hispanics and low-income learners) experienced significantly higher writing score gains than their non-at-risk counterparts in the program.

Mathematics

Seven studies of mathematics achievement (Clariana, 2009; Grimes & Warschauer, 2008; Gulek & Demirtas, 2005; Hansen et al., 2012; Lowther et al., 2012; Rosen & Beck-Hill, 2012; Rosen & Manny-Ikan, 2011) with 21 effect sizes were included in the meta-analysis. The average effect size was d = .16 (95% CI = [.003, .326]; see Forest Plot D in Figure 1). Positive effects in mathematics were found in several studies (i.e., Grimes & Warschauer, 2008; Gulek & Demirtas, 2005; Lowther, Strahl, Inan, & Bates, 2007; Rosen & Manny-Ikan, 2011), with two other studies reporting no impact (i.e., Bernard et al., 2007; Dunleavy & Heinecke, 2008) and one study showing negative impact in two of the three grades examined (Hansen et al., 2012). Although not included in the meta-analysis, Shapley et al. (2011) found no effect of laptop immersion on students' mathematics achievement. Clariana (2009) found that laptop students outperformed non-laptop students on a computer-based assessment after the first year of program implementation, but not on a paper-based standardized assessment.

Several other studies (e.g., Basham, 2012; Cottone, 2013; Kposowa & Valdez, 2013) also reported a significant growth in mathematics after laptop program implementation, but no control group was provided in these studies or no baseline data were provided for comparison. Some studies more specifically examined the relationship between the amount of students' technology use and their mathematics achievement. Bebell and Kay (2010) found that more frequent computer use in the laptop classrooms tended to result in higher mathematics scores for students. Interestingly, in the control classrooms, more frequent use of technology was negatively correlated with mathematics scores. This supports a finding by Warschauer (2011) that efficient and effective use of technology is much easier when students have regular daily individual access to laptops, which could further lead to academic achievement improvement.

Science

Only three effect sizes from two studies examining the effect of laptop program on science achievement (Dunleavy & Heinecke, 2008; Hur & Oh, 2012) were included in the meta-analysis. The overall effect size was d = .25 (95% CI = [.024, .474]; see Forest Plot E in Figure 1). Through the use of an experimental design carried out after 2 years of implementation of the laptop program, Dunleavy and Heinecke (2008) found that using laptops had a positive effect on middle school students' science achievement. There was also a significantly positive interaction effect between the laptop program and gender; both girls and boys benefitted from the laptop program, but the effect size for girls was very small (.04), and the effect size for boys was much larger (.55).

Though not included in the meta-analysis, as the multiple regression analysis did not allow for a comparable effect size calculation, Crook, Sharma, and Wilson (2015) also detected a positive impact of laptop program on high school students' biology, chemistry, and physics achievements. Another study by Zheng, Warschauer, Hwang, and Collins (2014) suggested that a laptop program improved at-risk learners' (i.e., English language learners, Hispanics, and low-income learners) science achievement but did not have an overall significant effect. When examining the specific relationship between amount of technology use and science outcomes, Bebell and Kay (2010) found that those eighth-grade students in laptop classrooms who reported more frequent use of technology demonstrated

TABLE 2
Results of meta-analyses in five different subjects

Subjects	Average effect size	*SE*	*z*	*p* value	95% Confidence interval	
					Lower	Upper
English	.151	.062	2.420	.016*	.029	.273
Reading	.117	.064	1.833	.067	−.008	.243
Writing	.199	.098	2.040	.041*	.008	.390
Math	.165	.082	2.001	.045*	.003	.326
Science	.249	.115	2.167	.030*	.024	.474
Total	.160	.036	4.440	.000***	.090	.231

$^*p < .05$. $^{***}p < .001$.

higher standardized science test scores than the laptop students who reported less frequent use of technology.

In summary, the impact of one-to-one laptop programs on academic achievement is generally positive across subject areas, with an overall effect size of .16 (95% CI = [.090, .231]; see Table 2). Among all five subjects, the largest effect size appears in science ($\bar{d}_{\text{science}} = .25$), writing ($\bar{d}_{\text{writing}} = .20$), and math ($\bar{d}_{\text{math}} = .17$), followed by English ($\bar{d}_{\text{English}} = .15$) and reading ($\bar{d}_{\text{reading}} = .12$), and these average effect sizes are all statistically significant except for reading. Since the number of studies included in science subjects is limited, extra caution should be exercised when interpreting or generalizing the average effect size found in that domain. Analysis of publication bias was conducted to verify the results of these meta-analyses (Borenstein et al., 2009). None of the five subject area meta-analyses showed publication bias (see Figure 2 for funnel plots).

By many standards, the effect sizes of these meta-analyses, which range from .12 to .25, are small (J. Cohen, 1998), for example, considers an effect size of .20 as small and an effect size of .50 as medium. Hattie (2009), who reviewed 800 meta-analyses on student learning published over several decades, claims that the average meaningful effect size across these studies is .40. The effect size of other widely discussed educational interventions ranges from .22 for small classes (see Krueger, 1999) to .40 for individual tutoring (see P. A. Cohen, Kulik, & Kulik, 1982).

Broader Research Synthesis

The meta-analysis reported above only covers a small portion of the literature (10 out of 96 studies; see Figure 3 for a description of the characteristics of all 96 studies included). The remaining 86 studies also reported findings that contribute to our understanding of one-to-one laptop environments, often focusing on broader processes and outcomes that are among the goals of one-to-one laptop initiatives but are not easily captured by the kinds of research designs and

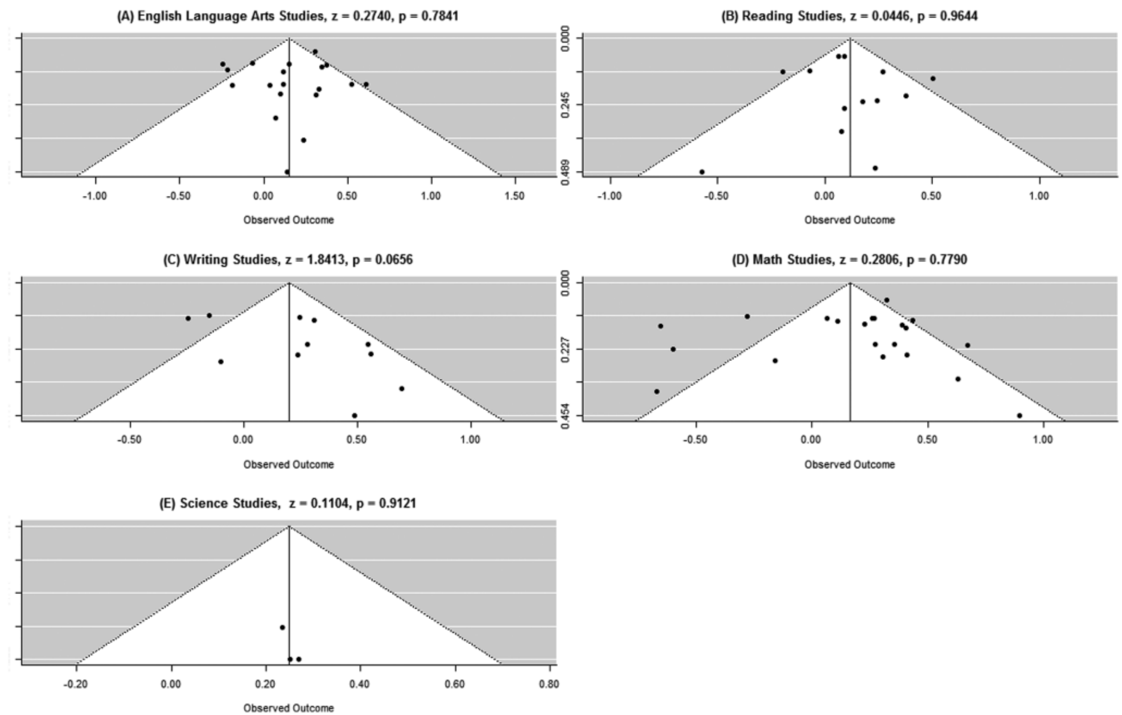

FIGURE 2. *(A) Funnel plots and corresponding tests for plot asymmetries for English Studies. (B) Funnel plots and corresponding tests for plot asymmetries for Reading Studies. (C) Funnel plots and corresponding tests for plot asymmetries for Writing Studies. (D) Funnel plots and corresponding tests for plot asymmetries for Math Studies. (E) Funnel plots and corresponding tests for plot asymmetries for Science Studies.*

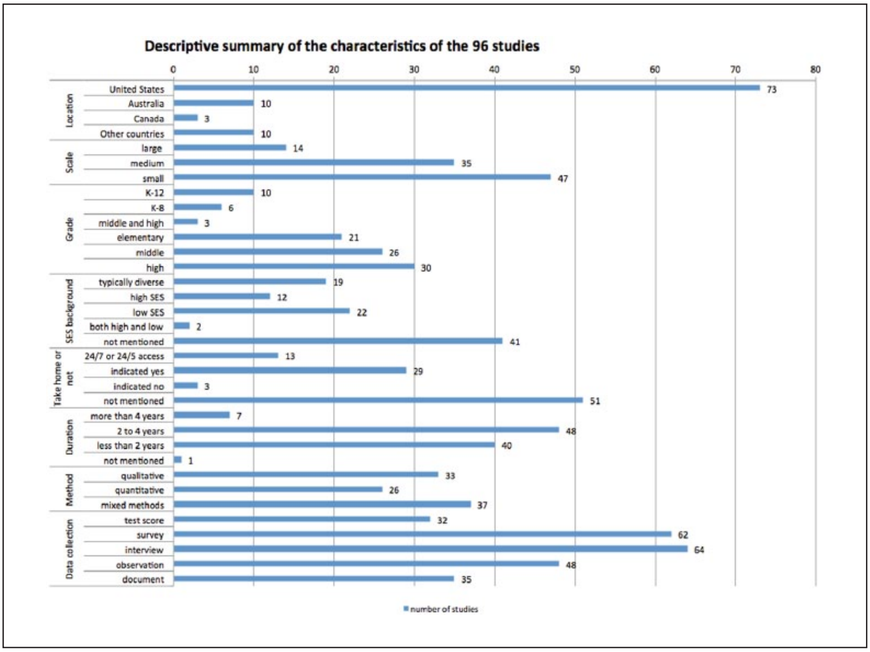

FIGURE 3. *Descriptive summary of the characteristics of the included studies.*

measures that met the requirements of our meta-analysis. Based on the focus of these studies, we synthesized the findings of all 96 studies in the following four areas: teaching and learning processes, teacher and student perceptions, 21st-century skills, and the digital divide.

Teaching and Learning Processes

Seventy out of the 96 studies in this research synthesis covered topics related to teaching and learning processes with the following four main findings noted.

Increased frequency and breadth of student technology use. Not surprisingly, students in one-to-one laptop environments were found to use technology more frequently than in non-laptop classrooms (e.g., Bebell & Kay, 2010; Bernard et al., 2007; Russell, Bebell, & Higgins, 2004). Studies suggested that writing and editing (discussed below) and gathering information from the Internet were the two most common uses of laptops (see, e.g., Bebell & Kay, 2010; Dunleavy, Dexter, & Heinecke, 2007; Lei, 2010; Lei & Zhao, 2008; Lowther et al., 2012; Shapley, Sheehan, Maloney, & Caranikas-Walker, 2010a, 2010b; Trimmel & Bachmann, 2004; Warschauer, 2007). Other frequent use of laptops for learning include taking notes, searching and organizing information, completing assignments and homework, reading on electronic textbooks, and conducting research (e.g., Crook, Sharma, Wilson, & Muller, 2013; McKeeman, 2008; Newhouse & Rennie, 2001; Schleicher, 2011; Tallvid, Lundin, Svensson, & Lindström, 2015; Warschauer, Grant, Real, & Rousseau, 2004; Zuber & Anderson, 2013).

Individual student laptops enabled teachers and students to explore a wide range of technology-enhanced learning activities at all grade levels from kindergarten to high school, and for multiple subjects (e.g., Lei & Zhao, 2008; Swan, van't Hooft, Kratcoski, & Schenker, 2007; Zucker & Hug, 2008). One study (Hansen et al., 2012) compared laptop use between students in higher grades and students in lower grades in elementary school, and suggested that older students were engaged in a more diverse range of technology-facilitated activities, whereas younger children tended to use laptops less and usually in activities that could also have been conducted without them.

A few studies ran counter to this trend of reporting positive effects on teaching and learning processes (see Morris, 2011; Padmanabhan & Wise, 2012). In a counterexample to widespread technology use, Warschauer, Cotten, and Ames (2011) reported on the One Laptop per Child (OLPC) program in Birmingham, Alabama. A total of 80.3% of fourth- and fifth-grade students surveyed indicated that they never or seldom used the laptops in school. This program appears to be an outlier among North American K–12 laptop programs, reflecting OLPC's particular emphasis on children's personal and autonomous use of laptops in out-of-school settings, and its correspondingly limited attention to integration of laptops in instruction.

Increased student-centered, individualized, and project-based learning. Many studies reported a change toward what they described as more student-centered (e.g., Cavanaugh, Dawson, & Ritzhaupt, 2011; Danielsen, 2009; Dawson, Cavanaugh, & Ritzhaupt, 2006; Donovan, Hartley, & Strudler, 2007; Drayton, Falk, Stroud, Hobbs, & Hammerman, 2010; Dunleavy et al., 2007; Grant, Ross, Wang, & Potter, 2005; Harris, 2010; Lowther et al., 2007; Newhouse & Rennie, 2001; Sprenger, 2010) or individualized learning (e.g., Annable, 2013; Clariana, 2009; Corn, Tagsold, & Patel, 2011; Grimes & Warschauer, 2008; Gunner, 2007; Mouza, 2008; Niles, 2006; Russell et al., 2004; Storz & Hoffman, 2013; Warschauer, 2007; Zheng et al., 2014), with students having more autonomous control over their learning paths due to the resources of Internet connections. For example, Russell et al. (2004) used student surveys, teacher interviews, and classroom observations to compare teaching and learning activities between one-to-one laptop classrooms and shared laptop classrooms. They reported that teachers were more able to individualize instruction and meet students' individual learning needs when classrooms were equipped with one-to-one laptops. In addition, students were observed to work more independently of their teacher in one-to-one laptop classrooms than in shared laptop classrooms, due to the resources provided by a connection to the Internet.

Several studies also reported that laptops fostered more project-based learning, due to the capabilities of laptops for use in finding, analyzing, and sharing information (e.g., Annable, 2013; Cavanaugh et al., 2011; Corn et al., 2011; Grant et al., 2005; Jones, 2013; Mouza, 2008; Windschitl & Sahl, 2002). For example, Mouza (2008) reported that elementary school students used laptops to create electronic story books in language arts classes, conduct classroom polls, and gather and analyze data using spreadsheets in mathematics classes.

Increased quantity and genres of writing. Together with gathering information online, writing and editing was found to be among the most common uses of technology in the laptop classroom (e.g., Grimes & Warschauer, 2008; Hansen et al., 2012; Harris, 2010; Suhr et al., 2010; Trimmel & Bachmann, 2004; Wade, 2010; Zheng et al., 2013). Students were found to write more in classrooms where all students are provided with individual computers, as demonstrated by surveys, interviews, and observations. For example, in an observation study involving timed measurements, Russell et al. (2004) found that students in one-to-one laptop programs composed text on either laptop or paper at an average of 1.99 instances per 10-minute observation, whereas those in shared laptop classrooms composed texts on either medium at an average of 0.26 instances per 10-minute observation.

Additional studies found that laptops were used extensively in each stage of the writing process, from gathering information, planning, drafting, to editing, receiving feedback from others, and publishing (Warschauer, 2008, 2009). Surveys, interviews, and observations have also demonstrated that in laptop classrooms, students receive more feedback on their writing, edit and revise their papers more often, draw on a wider range of resources to write, and publish or share their work with others more often (e.g., Corn, Tagsold, & Argueta, 2012; Grimes & Warschauer, 2008; Lei & Zhao, 2008).

One-to-one laptop environments also reportedly allowed students to write in a greater variety of formats and genres and for more authentic purposes (e.g., Corn et al., 2011; Grimes & Warschauer, 2008; Lei & Zhao, 2008; Wade, 2010; Warschauer, 2009). Online writing tools, such as email, chatting software, Instant Messenger, blogs, wikis, and online discussion forums, were frequently used by students to communicate with their teachers and peers (e.g., Cowley, 2013; Lei, 2010; Lei & Zhao, 2008; Oliver & Corn, 2008).

Improved teacher–student and home–school relationship. Teachers who were interviewed in several studies reported that laptop programs helped improve both the teacher–student (e.g., Carlson, 2007; Greenwood, 2007; Gunner, 2007; Lei & Zhao, 2008; Maninger & Holden, 2009; Niles, 2006; Pogany, 2009) and home–school relationship (e.g., Corn et al., 2011; Dawson et al., 2006; Lei & Zhao, 2008; Russell et al., 2004; Rutledge, Duran, & Carrol-Miranda, 2007). In Maninger and Holden's (2009) study, teachers initially believed that computers would pose a potential hindrance to teacher–student relationships by shifting the focus from the human interaction to interaction with technology. However, they and others reported that laptops instead facilitated teacher–student communication and interaction through the use of e-mail, Google Docs, and other communicative tools and enhanced teacher–student relationships (e.g., Burns & Polman, 2006; Corn et al., 2011; Lei & Zhao, 2008; Maninger & Holden, 2009; Mouza, 2008; Rosen & Beck-Hill, 2012). In many cases, another form of positive communication took place when students provided technological assistance to teachers (e.g., Burns & Polman, 2006).

Studies also suggested that the home–school relationship was improved within one-to-one laptop environments. According to Lei and Zhao (2008), survey data indicated a significant increase in parent involvement with their children's schoolwork and homework after 1 year's implementation of a one-to-one laptop program. Interview data in another study confirmed an increased tendency by parents to pay attention to their child's schoolwork, including assignments, grades, and attendance records (Rutledge et al., 2007).

Though almost all of the 70 studies reported positive changes in teaching and learning processes, some studies cautioned that technology alone could not bring about necessary change in pedagogy. For example, Windschitl and Sahl's (2002) case study of three teachers in a one-to-one laptop environment reported that "the fact that all students had their own computers did not compel two of the participants to use the technology itself to any significant degree in their classroom" (p. 202). Warschauer et al. (2011) found a stronger counterexample in the OLPC program in Birmingham. As the program was imposed on both the district and its teachers by the mayor and city council with almost no funding or support for curriculum development, assessment reform, infrastructural support, wireless connections, laptop repair, or teacher professional development, none of these positive changes in teacher and learning processes occurred. Instead, the laptops broke down, laptops were rarely used at school, and the entire program was abandoned within 3 years of implementation.

Student and Teacher Perceptions

A total of 45 of the 96 studies investigated teachers' or students' attitudes, beliefs, and perceptions of the laptop program. Among them, nine studies provided systematic survey response data to quantitatively report student and teacher perceptions (see Bebell & Kay, 2010; Burgad, 2008; Cotten, Hale, Moroney, O'Neal, & Borch, 2011; Grant et al., 2005; Grimes & Warschauer, 2008; Lei & Zhao, 2008; Lowther et al., 2012; Mouza, 2008; Rosen & Beck-Hill, 2012). The descriptive data indicated an overall positive attitude toward laptop programs among both students and teachers (see Table 3). Next, we summarize findings of student and teacher attitudes from the 45 studies.

Students' positive attitudes toward laptop programs. Survey, interview, and observation data suggest that students had very positive attitudes regarding the effects of laptop programs on their learning (e.g., Lowther et al., 2003; Rosen & Beck-Hill, 2012; Suhr et al., 2010). A high percentage of students indicated that they preferred learning with laptops and felt that their schoolwork became

TABLE 3

A summary table of survey results on student and teacher attitudes and perceptions

Study	Grade level	Year	*N* size (response rate)	Main questions asked about laptop programs	Student perception	Teacher perception
1. Bebell and Kay (2010)	7th to 9th grade	Year 3	163 (97.6%)	Improved computer skills		83% agreement
				Improved teaching		62% agreement
				Improved student engagement		83% agreement
				Improved student motivation		73% agreement
2. Burgad (2008)	11th and 12th grades	Year 1	Student: 74 (93.7%); Teacher: 16 (100%)	Availability of the Internet simplified research for students	89% agreement	100% agreement
				Improved organization for students	80% agreement	50% agreement
				Laptops make schoolwork more interesting for students	80% agreement	94% agreement
				Laptops make schoolwork easier to do	77% agreement	56% agreement
				Students were more likely to revise or edit schoolwork when using their laptop	73% agreement	69% agreement
3. Cotten et al. (2011)	4th and 5th grades	Half a year	1,202 (41.2%)	Positive attitudes toward the impact of XO laptops on students' academic experience	A mean of 3.79 out of 8 (0–8 scale)	
4. Grant et al. (2005)	5th grade	Year 1	4 (100%)	Positive attitude toward the laptop program		A mean of 4.20 out of 5
				Positive impact on students		A mean of 4.63 out of 5
				Teacher readiness to integrate technology		A mean of 4.31 out of 5
5. Grimes and Warschauer (2008)	K–8 grade	Year 1	35 (100%)	Recommend laptop program be continued at their school		88% agreement
				Recommend other schools adopt similar laptop programs		82% agreement
			878 (86.8%)	Schoolwork has become more interesting	74% agreement	

(continued)

TABLE 3 (CONTINUED)

Study	Grade level	Year	*N* size (response rate)	Main questions asked about laptop programs	Student perception	Teacher perception
6. Lei and Zhao (2008)	7th and 8th grades	Year 1	28 (100%)	Laptops were important to both students and themselves		100% agreement
				Laptops helped them communicating with their students		96.4% agreement
			208 (87.8%)	Laptops were important to them	87.5% agreement	
				Laptops had significantly helped them with their homework	89% agreement	
				Laptops had significantly helped them increase their computer knowledge and skills	83.6% agreement	
7. Lowther et al. (2012)	K–12 (mainly in 6th grade)	Year 1	380	Laptop use has a positive impact on student learning and achievement		A mean of 4.17 out of 5
				Confident about how to meaningfully integrate laptop use into lessons		A mean of 4.11 out of 5
			5,770	Want to use laptops again next year	90% agreement	
8. Mouza (2008)	3rd and 4th grades	Year 1	50 (100%)	Laptop students' attitude toward school compared to that of non-laptop students	Significantly positive	
9. Rosen and Beck-Hill (2012)	4th and 5th grades	Year 1	283 (100%)	Positive math and reading learning motivation	A mean of 4.1 out of 5	
				Positive attitudes toward computers as tools for learning	An average 4.5 out of 5	

more interesting after they received their own laptops (Grimes & Warschauer, 2008; Kposowa & Valdez, 2013; Lowther et al., 2012; Suhr et al., 2010). In Lei and Zhao's (2008) study, 89% of the students surveyed indicated that laptops had significantly helped them with their homework. And 90% of students surveyed in Lowther et al.'s (2012) study indicated that they wanted to use laptops again in the following year.

A number of studies report higher student engagement, motivation, and persistence in one-to-one laptop environments than in non-laptop or shared laptop classrooms (e.g., Khambari, Moses, & Luan, 2009; Mouza, 2008; Niles, 2006; Russell et al., 2004; Trimmel & Bachmann, 2004; Whiteside, 2013). For example, based on interviews and systematic classroom observations, Russell et al. (2004) found that students in one-to-one laptop environments demonstrated greater motivation and engagement toward learning than students who shared laptops. According to studies by Corn et al. (2012) and Cowley (2013), this increased engagement and motivation among laptop users also extended to special needs students.

However, several studies suggest some caveats. A student survey by Cotten et al. (2011) in Birmingham suggests disagreement with the idea that the OLPC program there positively affected academic achievement. That is not surprising given the limited integration of the laptops in classroom instruction in that program. In addition, an observational study by Donovan, Green, and Hartley (2010) reported increased off-task behavior in supposed one-to-one classrooms where a number of students did not have functioning laptops. Another two studies (Hur & Oh, 2012; Zuber & Anderson, 2013) reported a high degree of engagement and excitement among students at the beginning of the laptop program; however, this initial enthusiasm was found to decrease as the program continued. These studies reinforce the idea that technical, curricular, and pedagogical support for laptop use is an important component of program success.

Teachers' changing perception toward laptop programs. Teachers' beliefs and instructional approaches are believed to be crucial to the effective integration of technology in teaching and learning (Clariana, 2009; Inan & Lowther, 2010; Mouza, 2008; Windschitl & Sahl, 2002). In contrast to students' overall positive attitudes toward technology use, a number of studies suggested that teachers had initial concerns about use of laptops for instruction, either due to limited technology skills, lack of sufficient technical support, uncertainty about ways in which the technology would affect them, or fear of losing control in the classrooms (e.g., Carlson, 2007; Gunner, 2007; Khambari et al., 2009; Maninger & Holden, 2009; McGrail, 2006, 2007; Windschitl & Sahl, 2002; Zuber & Anderson, 2013). As a result, some teachers reportedly had difficulties creating a learning environment "where learning drives the use of technology, instead of the other way around" (Maninger & Holden, 2009, p. 7). According to one study, this led to some teachers to become frustrated when facing barriers to integrating technology into instruction (Dunleavy et al., 2007).

When technical support and professional development were not sufficiently offered, teachers' negative perceptions of laptop programs persisted. In Lei's (2010) 4-year longitudinal study, teachers reported that their need for timely and adequate technology support was not well addressed. An increase in teachers' technology use led to increased demand for technology support; this in turn increased the workload for technology support staff and made addressing each teacher's technology support needs a more difficult and lengthy process. In another study, Corn et al. (2011) found that the "schools with the highest proportion of teachers who reacted negatively to the laptop initiative were those who had ill-planned professional development" (pp. 19–20).

However, when sufficient training and support were provided, teachers became more confident about their ability to solve minor technical problems and more efficient in their use of technology over time (Burns & Polman, 2006; Howard et al., 2015; Inan & Lowther, 2010; Murphy, King, & Brown, 2007; Zuber & Anderson, 2013). Teachers' preparedness to use technology was also improved when a sufficient amount of professional development was provided (Danielsen, 2009), enabling teachers to use technology more frequently in the classroom (Inan & Lowther, 2010; Lowther et al., 2012; Zuber & Anderson, 2013) and to integrate technology into their instruction (e.g., Chandrasekhar, 2009; Drayton et al., 2010; Grimes & Warschauer, 2008; Lei, 2010). Most studies that analyzed teachers' attitudes longitudinally reported that after at least a year of use, teachers had very positive attitudes toward the laptop programs. For example, Grimes and Warschauer's (2008) study of a laptop program in three California middle and elementary schools found that 88% of teachers agreed with the statement "I recommend that the laptop program be continued at my school" on an anonymous survey, and 82% recommended that other schools adopt similar laptop programs.

Finally, a number of studies mentioned the importance of including teachers' voices in whether and how to adopt laptop programs (Donovan et al., 2007; Maninger & Holden, 2009; Murphy et al., 2007; Skevakis, 2010). At least two of the papers reported that decisions were made about programs without teacher input and that, as a result, teachers' commitment to the one-to-one laptop programs was weakened, thereby harming program implementation (McGrail, 2006; Warschauer et al., 2011).

Twenty-First-Century Skills: Broad But Weak Evidence

There is a wide-scale belief that the types of outcomes measured by today's standardized tests do not fully capture the kinds of thinking and learning skills required for a knowledge economy (see, e.g., Grimes & Warschauer, 2008). Furthermore, many view one-to-one laptop programs as a fertile ground for developing these broader *21st-century learning skills* (Bernard et al., 2007; Russell et al., 2004). A broad national coalition suggests that these skills fall into three areas: Learning and Innovation; Information, Media, and Technology; and Life and Career (Partnership for 21st Century Skills, 2010). Though operationalization of these three areas as skills sets is challenging (Warschauer & Matuchniak, 2010), the studies we reviewed suggested that laptop use supported development in at least the first two of these three areas, though evidence provided was often weak.

Several studies indicated the impact of one-to-one laptop programs on students' information, media, and technology skills, including increased technological proficiency (see findings in Corn et al., 2011; Greenwood, 2007; Lei & Zhao, 2008; Mo et al., 2013; Warschauer, 2007) and enhanced ability to locate and use Internet resources (e.g., Harris, 2010; Wade, 2010; Warschauer, 2008). For the most part, these findings reflected researchers' observations about what was occurring in the classroom or reports in teacher or student surveys about experiences in the laptop classroom. Lei and Zhao (2008) evaluated students' ability to make appropriate choices about how to use technology to solve practice problems. Pre- and post-tests indicated that students in a one-to-one laptop program made significant progress on this measure over the course of a year. However, since the study included no control students, it is difficult to draw any substantive conclusions about whether these gains can be attributed to laptop program participation.

A number of studies suggested that laptop environments promoted students' learning autonomy, improving their individual and collaborative learning skills, including the ability to independently organize and maintain their schoolwork (e.g., Cowley, 2013; Grimes & Warschauer, 2008; Lei & Zhao, 2008; Maninger & Holden, 2009; Mouza, 2008; Oliver & Corn, 2008; Pogany, 2009; Rosen and Beck-Hill, 2012; Shapley et al., 2011). Again, these findings were arrived upon through analysis of observation, survey, and interview data, but without any attempt to operationalize these constructs and measure the skills developed by laptop users as compared with control students.

Additionally, a number of studies reported that laptops were used extensively for problem-solving tasks and suggested that this use could help improve students' problem-solving skills (e.g., Maninger & Holden, 2009). One study went beyond this general observation to assess the impact of laptop use on these skills (Lowther et al., 2003). In this study, students in laptop classrooms and in comparison classrooms in the same schools were asked to consider the problem of used soda-can accumulation in city parks and then answer specific related questions. Their blinded answers were scored on a number of dimensions related to problem-solving ability by a team of trained reviewers. The study found that laptop students exhibited higher problem-solving skills than their comparison peers in completing this task. The authors suggest that the enhanced problem-solving ability they found in the laptop students might be attributable to laptop students' increased experience with research- and project-based activities in which they had used technology to find background information on specific topics, identify approaches to solve problems, and present results to others. However, whether the laptop and comparison students were equivalent in their problem-solving ability before the initiation of the laptop program was not well established. Another study reported that students' abstract reasoning skills were significantly improved with the use of laptops, compared with a control group, using a validated and standardized test (see Hansen et al., 2012). However, this significant effect was only detected among upper elementary grades, but not among younger students.

Several studies also suggested that one-to-one laptop programs better prepare students for college and career readiness (e.g., Danielsen, 2009; Niles, 2006; Zheng et al., 2014). All of the three school districts studies in Danielsen's study implemented the laptop initiative so that "students would be more prepared for postsecondary and work opportunities" (Danielsen, 2009, p. 69). Students' real-world learning experience was observed by Danielsen in high school classrooms, such as an art class running a graphic design business. In another study (Zheng et al., 2014) that investigated laptop use in upper elementary students' science learning, both teachers and students indicated that having access to online resources expanded students' motivation and interest in pursuing science-related study and careers.

In summary, there was a wide consensus in the studies we reviewed that use of laptops promotes 21st-century learning skills. Studies present a substantial amount of observation data, reporting examples of these skills being practiced or exhibited in the laptop classroom, as well as survey and interview data confirming that teachers and students perceive these skills as being developed through laptop program participation. However, studies rarely attempted to operationalize and systematically measure the growth of 21st-century skills in laptop students compared with control students.

Overcoming Inequity: Mixed Findings

One goal of many educational technology programs is to reduce educational and social inequity by providing access to digital resources that is lacking in low-income homes (Culp, Honey, & Mandinach, 2005; Mo et al., 2013; Rosen & Manny-Ikan, 2011). One-to-one laptop programs, by providing individual access to computers, may help lessen the digital divide in the most practical sense, that is, access to technology (Pittaluga & Rivoir, 2012). The more important question is whether use of laptops by diverse learners helps bridge inequities in skills, knowledge, and attitudes.

A number of the studies suggest that, in comparison with high-socioeconomic status (SES) peers, low-SES students gain more technological proficiency from laptop environments, presumably because they started with less experience with digital media outside the classroom (e.g., McKeeman, 2008; Shapley et al., 2011). For example, Shapley et al. (2011) reported that economically disadvantaged students in laptop schools reached the same proficiency in technology skills as advantaged students in control schools after 3 years of participation in a laptop program. However, at least one study found the broader development of information literacy skills in one low-SES school in Maine woefully inadequate compared to a high-SES school in the state's one-to-one laptop program (Warschauer, 2007). This disparity was due both to the unequal distribution of resources available to the two schools as well as to the lesser focus on critical thinking skills in the low-income school. The same study pointed to a positive example of how a low-SES school in Maine developed information literacy, suggesting that the socioeconomic context may influence laptop implementation but does not determine it.

Whether laptop programs can reduce educational gaps in academic achievements is still unclear. The positive impact of laptop programs on disadvantaged students was identified in a number of studies (e.g., Cottone, 2013; Cowley, 2013; Kay, 2010; Rosen & Manny-Ikan, 2011; Weber, 2012; Zheng et al., 2013; Zheng et al., 2014). For example, Kay (2010) measured students' standardized ELA test scores and found that a laptop program helped shrink the achievement gap between low-income students and their peers. Similarly, Bernard et al. (2007) found that a laptop initiative helped low-achieving students more than high-achieving students in improving their achievement in language and mathematics. Further confirmatory evidence comes from Zheng et al.'s (2013) study of elementary school laptop programs in two school districts in Colorado and California. Their analysis found that low-income and Hispanic students in each district improved their writing test scores significantly more than their non-at-risk peers. In another study by Zheng et al. (2014), it was found that although the laptop program did not have an overall positive effect on upper elementary students' science achievement, it did significantly improve at-risk students' science test scores when compared to their counterparts.

However, these positive goals for at-risk learners are not achieved in all one-to-one laptop programs. Bebell and Kay (2010) found that eighth-grade laptop students who reported more frequent use of computers for recreation at home had higher ELA achievement; the positive effect diminished greatly after controlling for students' SES. Smith (2012) found that although Black students had significantly higher ELA and mathematics scores after 2 years' participating in a laptop program, the test score improvement of White students was comparatively higher. Several studies suggested that disadvantaged students typically face more difficulty in using technology, due to less prior literacy or technology skills, which thus places an extra load on these already challenged students (e.g., Warschauer, 2008; Zuber & Anderson, 2013). In contrast, teachers and students from high-SES schools usually were more tech-savvy so that they could focus their teaching and learning time on how to maximize the educational benefits of technology, instead of teaching and learning basic technology skills (Rousseau, 2007).

The relationship between technology and inequality is quite complex, and it will take far more than distribution of computers to address this issue (see Warschauer & Matuchniak, 2010, for a discussion). Laptop programs that include sufficient technical and curricular support and that focus on the particular needs of low-SES learners, such as by emphasizing writing skills, are likely to be more successful in bridging divides than programs that lack support and focus.

Conclusion

Contrary to Cuban's (2003) argument that computers are "oversold and underused" (p. 179) in schools, laptop environments are reshaping many aspects of education in K–12 schools. The most common changes noted in the reviewed studies include significantly increased academic achievement in science, writing, math, and English; increased technology use for varied learning purposes; more student-centered, individualized, and project-based instruction; enhanced engagement and enthusiasm among students; and improved teacher–student and home–school relationships. Contrary to Mayer's argument that educational technology is a neutral tool indifferent to its use (Veronikas & Shaughnessy, 2005), laptop computers have specific affordances that make certain uses and outcomes likely, such as the ease with which they can be used for drafting, revising, and sharing writing, and for personal access of information.

Though our analysis corroborates and extends many of the positive conclusions from earlier syntheses of one-to-one computing, it is far from the last word on this topic, in part because a disproportionate amount of the research to date on this topic consists of small case studies in one or a handful of schools. The number of studies identified that deployed rigorous experimental or quasi-experimental methods was small, making meta-analysis difficult, and making it impossible for us to conduct moderator analyses. In addition, studies on this topic have largely done a poor job of assessing learning outcomes that are not well-captured by current iterations of standardized tests. As the United States and other countries move to more sophisticated forms of standardized assessment, these new measures may be better aligned with the learning goals believed to be associated with laptop use.

The falling price of hardware, software, and wireless access; the increasing digital literacy of teachers, students, and parents; the growing sophistication of educational technology applications; and the rising need for computers to be used in student assessment all suggest that one-to-one laptop programs are going to continue to expand in K–12 schools. This, in turn, should encourage larger, better-funded, and longer studies that can more systematically identify what works, what does not, for what purposes, and for whom in the one-to-one laptop classroom.

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Studies marked with an asterisk are included in the meta-analysis. Studies marked with "+" report academic achievements but are not included in the meta-analysis. Those marked with "a" report teaching and learning processes; those marked with "b" report teaching and learning perceptions; those marked with "c" report 21st century skills; and those marked with "d" report on the digital divide.

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