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Ubiquitous Computing in K-12 Classrooms: A Systematic Review

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Abstract: As technology use in education increases, interest in and implementations of ubiquitous computing initiatives have also increased. One-to-one laptop initiatives have sprung up throughout North America at the school, district, and state or province levels. This paper is an attempt to synthesize available studies of one-to-one initiatives at the K-12 level using both quantitative and narrative techniques. Meta-analysis yielded a small positive average effect size that seems to be due largely to the impact of laptops on students' writing.

Technology in Education

Welcomed or spurned, technology use in education is increasing. On the one hand, some advocate the educative potential of computers (Harasim, Hiltz, Teles & Turoff, 1995; Lou, Abrami & d'Apollonia, 2001; Scardamalia & Bereiter, 1996). This enthusiasm is evidenced by the spread of technology initiatives in K-12 classrooms. Of particular interest are new, rigorously designed studies reporting the success of web-based basic literacy tools (Savage, Abrami, Piquette-Tomei, Wood, & Deleveaux, 2008; Savage & Abrami, 2007; Schmid, Miodrag, Di Francesco, 2008), and the impact of computers in one-to-one settings on broader conceptions of literacy (Warschauer, 2006: Warschauer, 2007; Warschauer, Grant, Del Real, & Rousseau, 2004). On the other hand, there are doubts (Healy, 1998; Russell, 1999) that technology can improve learning and concerns that it can in some ways hinder learning. It is argued that overuse of technology can actually be harmful: computer skills may be developed at the expense of essential literacy; or that technology overuse will foster dependant and isolated rather than independent and interdependent learners; or that faulty equipment may frustrate and de-motivate learners (Clark & Sugrue, 1995; Cuban, 2001; Healy, 1998; Noble, Sheiderman, Herman, Agre, & Denning, 1998; Russell, 1999). Given the debate, there is a continuing need for the study of technology use in education.

One-to-one computer implementations

Until recently, studies of technology integration in K-12 schools have reported limited student access to technology: students learn in dedicated computer labs for select periods during the week, or in classrooms where computers are available but at ratios of several students per computer, or even in classrooms using "laptop carts" where a cart with enough laptops for a one to one ratio is shared by several classrooms so that students can use their own computer in their own classroom for select periods during the week. Now, interest is shifting to more widespread and ubiquitous technology use, that is, when each student is provided with a computer for use throughout the day. Underpinning this interest is the belief that increased access to technology will lead to increased technology use, which will in turn lead to improvements in a variety of educational outcomes (Russell, Bebell & Higgins, 2004). It is unsurprising that particular interest is being given to laptop initiatives where students are allowed to take their laptops home.

K-12 one-to-one computer implementations that provide students with internet access and laptop computers for use at school and home are rapidly increasing in number. Decreasing costs, increased portability, and availability of wireless networking all contribute to making broad implementations feasible (Apple, 2005; Penuel, 2006). In two separate research syntheses, Penuel reports that not only does research lag behind such rapid expansion, but of the research studies that have been done, few analyze implementation outcomes in a rigorous manner (Penuel et el., 2001 & Penuel, 2006).

In this review we update those earlier reviews by including more recent evaluations and intervention studies. In particular we took pains to locate well-designed studies to provide more concrete support for the analysis. Specifically this review attempts to determine to what extent, and under what circumstances one-to-one computing impacts K-12 student achievement, student and teacher technology use, and student and teacher attitudes by synthesizing in a systematic manner, the findings of K-12 one-to-one laptop studies. Where quantitative data are available they will be aggregated using accepted meta-analytic techniques. We hope that by aggregating findings in this way, a clearer picture of best practices for one-to-one computer implementations will emerge. Qualitative studies and quantitative studies with insufficient data for effect size calculation will be synthesized in a prose summary. Reviews or other research syntheses will be included in the prose summary.

Methodology

We identified the key terms used as a basis for document searches. We studied abstracts to determine whether the document would be retrieved. We recorded all key terms and definitions; search strategies, decisions and results; retrieval, inclusion/exclusion criteria and decisions in the study codebook.

Terms and Definitions

Our key terms were identified and defined as follows:

- One-to-one computing – each student has a computer to use for every class, every day for no less than one academic term (13 weeks). In some one-to-one programs students have full time access to the computers: that is they are allowed to take them home; in others, students can only use the computers at school. Though these two types of programs will exhibit unique characteristics, for the purpose of this study they will be both be classified as one-to-one programs and included in the study. This difference will be recorded as a study feature.
- Student achievement – the assessed performance of a student on a particular assignment, a group of assignments, or the composite or average score over a series of assignments.
- Technology use – how and to what extent the computers (and other related technologies) are used by teachers and by students. Whether technology use was self-reported or observed was coded as a study feature.

- Student and teacher attitudes – how students and teachers perceive technology. By definition, this measure is self-reported.

Search strategy

We used the following keywords and descriptors for the search: one-to-one, ubiquitous computing, laptop initiative, K-12, school, education, pda, handheld, mobile, portable, technology integration, personal digital assistant, computers. The following databases were searched using some combinations of the search terms: ERIC, ProQuest full text, ProQuest dissertations, ProQuest CBCA Education, Educational Technology Abstracts, Academic Search Premier. In addition, using the same search terms, we searched the internet using the Google search engine. We accessed additional web resources using several online one-to-one clearinghouses: One-to-One Information Resource (http://www.k12one2one.org/), Ubiquitous Computing Consortium – Literature Review and Resources (http://ubiqcomputing.org/lit_review.html), One-to-One Institute (http://sparty.crt.net/121/research.cfm), BC Ministry Education – Laptop Initiative (http://www.bced.gov.bc.ca/onetoone/resources.htm), Govt of Western Australia, Dept of Education and Training, Notebooks for students 1:1 (http://www.det.wa.edu.au/education/cmis/eval/curriculum/ict/notebooks/). When we encountered dead links, we attempted to locate documents using the Internet Archive's WayBackMachine (http://www.archive.org). Finally, when there was evidence of the existence of a K-12 one-to-one implementation but no report can be located by other means, we contacted schools, school boards, school district offices, or other relevant governing bodies directly to request access to reports of any evaluation studies.

Inclusion/Exclusion Criteria

Quantitative comparison

To be included for retrieval, studies must compare one to one computing in K-12 with a control condition (one to many, computer lab time, no technology, a pre-treatment condition). One to one initiatives must be school based and evaluate at least one full term (13 weeks) of instruction. Outcomes must include one or more of the following: student/teacher attitudes toward technology, student/teacher technology use, or student achievement data. Measures must be reported in a way that enables effect size extraction or estimation (quantitative data sufficiency criterion). Other reasons for exclusion are noted below.

We retrieved studies that satisfy inclusion criteria for full text review, regardless of the type of study design: experimental (randomly assigned group comparison), quasi-experimental (comparison of pre-existing groups) or pre-experimental (one group pre-test and post-test). If the study failed to meet one or more of these criteria, we did not include that study in the quantitative analysis. The reasons for exclusion are organized according to the major criteria described above as follows:

- N121 (Not a One-to-One study): Conditions do not fit the One-to-One definition.
- DUR (Duration): The analysis does not consider studies in which the duration of one-to-one lasted for less than one term (13 weeks).

- NSB (Not school based): One-to-one initiative not in K-12 school environment.
- DOA (Description or opinion article): An article that reflects personal opinion or a description of a specific implementation that does not report outcomes.
- RA (Review article): An article that includes a general review of findings or studies in the field will be excluded from the quantitative analysis but will be included in the narrative summary.
- QLR (Qualitative research): A qualitative study will be excluded from the quantitative analysis but may be included in the narrative summary if the study reports one or more outcomes identified for this review.
- ATT (Attitudes or Perceptions): The study reports quantitative data about attitudes towards or perceptions of one-to-one computing, usually as survey data.
- MA (Meta-analysis): Meta-analyses addressing one-to-one initiatives will be excluded from the quantitative analysis but will be included in the narrative summary.
- ISD (Insufficient Statistical Data): Articles that do not fit the quantitative data sufficiency criterion will not be included for quantitative analysis, but may be included in the narrative summary.

We coded studies according to the level of confidence about the decision made using a 5 point scale: (1) almost definitely unsuitable; (2) probably unsuitable; (3) doubtful, but possibly suitable; (4) most likely suitable; and (5) almost definitely suitable. Since study abstracts in general may not provide all necessary information about the study design and outcomes, we took a deliberately inclusive approach at this stage of the project. Abstracts rated (3) or higher were retrieved.

Attitude outcomes, qualitative studies, reviews

In addition to studies reporting achievement outcomes, we retrieved studies reporting quantitative data about attitudes or perceptions for review. For this preliminary report we did not include them in the meta-analysis. Instead we summarize their findings by vote count. That is we summarized studies reporting data on perceptions according to the positive findings they reported. Note that this type of summary highlights the prevalence of certain program goals as much as it does actual outcomes. A meta-analysis of attitude data will follow in future reports.

Synthesis of the qualitative studies presents a more complex challenge. Narrative summary is a flexible approach that allows for the integration of diverse sources, but lacks methodological transparency and is hence vulnerable to researcher bias (Dixon-Woods, Agarwal, Young, Jones, & Sutton, 2004; Mays, Pope, & Popay, 2005). In future reports we will investigate and integrate more systematic and transparent methods for qualitative and diverse evidence synthesis into our findings.

Finally, we have briefly summarized existing reviews of one-to-one laptop programs. This summary is not intended to be comprehensive or detailed. Rather it compares the findings of this study to those of other reviews.

Outcomes and effect size extraction

Outcomes

We read Retrieved studies for final inclusion decisions and for effect size and study features coding. In effect size coding, we identified and coded statistical data from which effect sizes could be extracted according to outcome type (standardized measure, researcher-produced test, teacher-produced test) and type of statistics that will allow for effect size extraction. The unit of analysis was independent effect size rather than study, so it was possible that one study could yield more than one effect size. By the same token, because several included studies were annual evaluation reports of the same program, we verified that effect sizes from each of these studies were in fact independent. In some cases, after this verification process, we excluded effect sizes from multiple year studies because independence could not be established.

In study features coding, we identified and coded characteristics of the study that could explain effect size variability, for example, study design, sample size, and implementation features.

Effect size extraction

We extracted effect sizes from included studies. For this study, we used standardized mean difference as a measure of effect size, that is, the mean for the treatment minus the mean for the control divided by the pooled standard deviation (Cohen, 1988):

$$d = \frac{Y_E - Y_C}{s_{Pooled}} \quad (1)$$

To account for small sample bias, we calculated Hedges *g* (unbiased estimator) from equation (1) using equation (2) (Hedges & Olkin, 1985):

$$g \approx \left(1 - \frac{3}{4N - 9}\right) d \quad (2)$$

Data analysis

Mean estimate of treatment effect

We weighted effect sizes to reflect sample size – more weight was given to studies with larger sample sizes. Weighted effect sizes were then averaged to determine the overall weighted mean estimate of the treatment effect size ($g+$). We used the 95% confidence interval of the mean effect size and a z-test to evaluate significance of the mean effect size.

Exploring heterogeneity

One of the challenges to interpreting the results of meta-analysis is that while on the surface interventions may appear to be similar, underlying differences of the studies or the implementation of the interventions themselves influence the study outcomes enough to make effect sizes incomparable. If effect sizes are similar or *homogeneous*, then they are estimating a shared treatment effect and will vary around a single value. In practical terms, estimated confidence intervals should all contain this shared treatment effect. Visual inspection of confidence intervals gives a good idea of whether or not a sample of studies is estimating the same treatment effect. Conversely, *heterogeneous* effect sizes may be estimating different treatment effects. If effect sizes are found to be heterogeneous, alternative analyses must be employed (The Cochrane Collaboration, 2002). To test for heterogeneity we calculate the Q statistic and evaluate it using a χ^2 distribution. A significant Q indicates heterogeneity of effect size. If the sample is found to be heterogeneous, there are three common solutions:

- Subgroup analysis – The sample is divided into a small number of subgroups, each of which is then analyzed separately. Researchers should have strong theoretical justification for subgroup analysis (Cochrane, 2002).
- Random effects model for aggregating studies – The random effects model assumes heterogeneity, in other words that different effect sizes are estimating different treatment effects and that these effects form a distribution. This model estimates the central value of the distribution and explores how effects vary over studies (Hedges & Vevea, 1998).
- Moderator analysis (meta-regression) – In this approach differential effects of subgroups are formally tested by treating them as multiple independent variables and *g* as the dependent variable and entering them into regression to assess their relative contributions (Bernard et al., 2004).

Preliminary findings

Nature of the evidence

As of March 2008, we identified 821 documents, of which 114 impact studies reporting on 72 unique K-12 one-to-one laptop implementations have been retrieved and included for synthesis. These numbers represent both scholarly articles and "grey literature" and as such warrant discussions on methodological quality, and selection and publication bias. Table 1 summarizes the types of documents we retrieved and ultimately included in the analysis.

Table 1 - Types of documents identified and included in the analysis

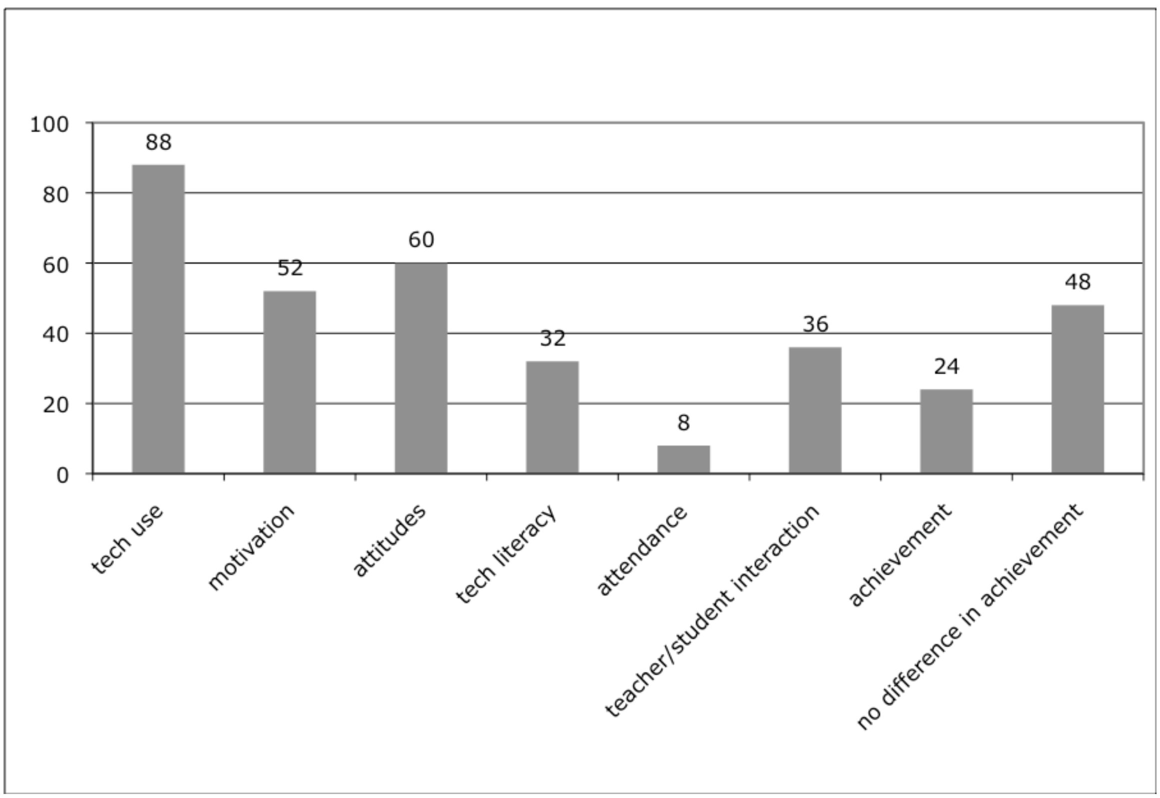
Article type	Hits by article type	Includes by article type	%age of total hits	%age of total includes
Book, Section	5	0	0.6%	0.0%
Book, Whole	6	1	0.7%	0.9%
Conference Proceedings	82	15	10.0%	13.2%
Dissertation/Thesis	16	2	1.9%	1.8%
Generic	48	4	5.8%	3.5%
Journal Article	460	26	56.0%	22.8%
Magazine Article	10	0	1.2%	0.0%
Newspaper Article	6	0	0.7%	0.0%
Report	185	66	22.5%	57.9%
Web Page	3	0	0.4%	0.0%

As noted earlier, the diversity of research frameworks employed will require us to investigate alternative synthesis methods to include as much of the evidence as possible in the synthesis. Of these retrieved studies only 22 report achievement data and 65 report data on perceptions from which only 18 independent effect sizes could be extracted using commonly used techniques for meta-analysis.

Vote count of survey based perceptions data

We summarized the 65 included studies reporting data on perceptions according to the positive findings they reported. As noted earlier this summary highlights the goals of the separate programs as much as anything else. Implementation goals included increasing technology use, increasing technology literacy, improving quality of teaching and learning, reduction in dropout rates/improving attendance, improving motivation and behavior, and improving academic achievement.

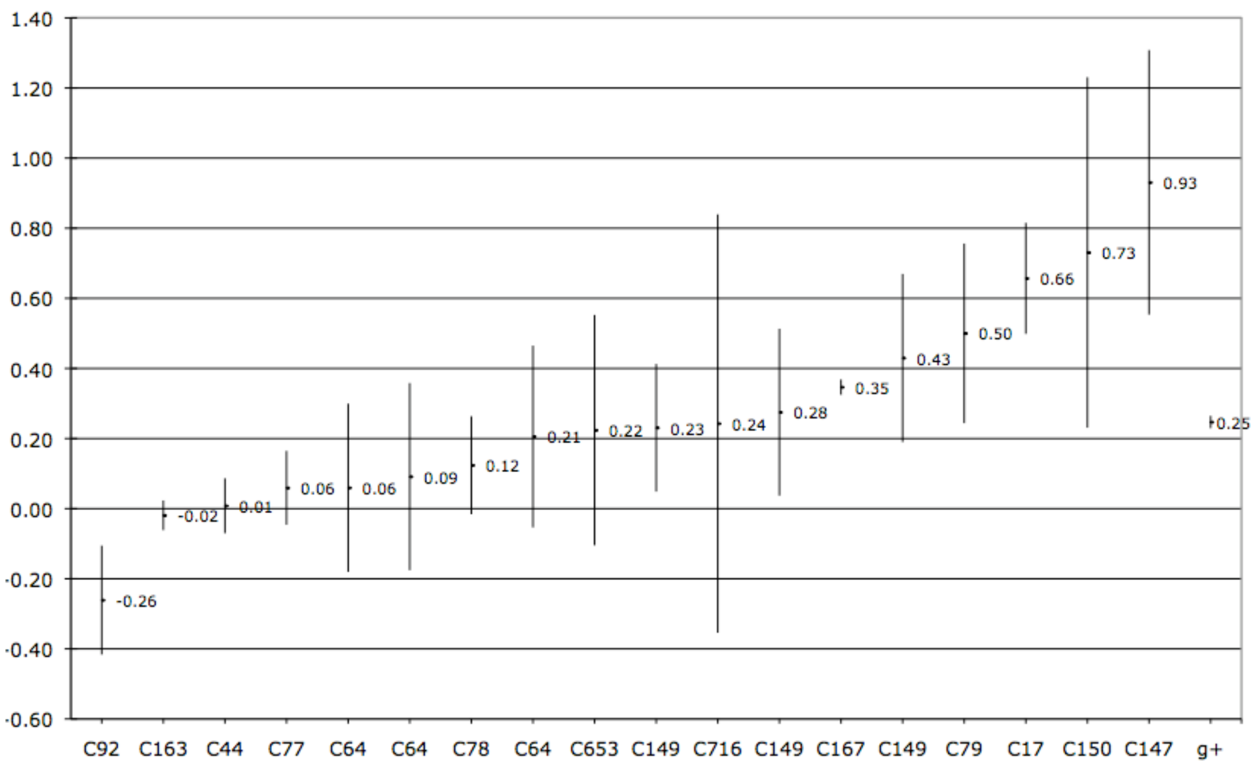
Figure 1 - Perceptions survey data: Gains in outcomes reported (%)



Meta-analysis of effect sizes

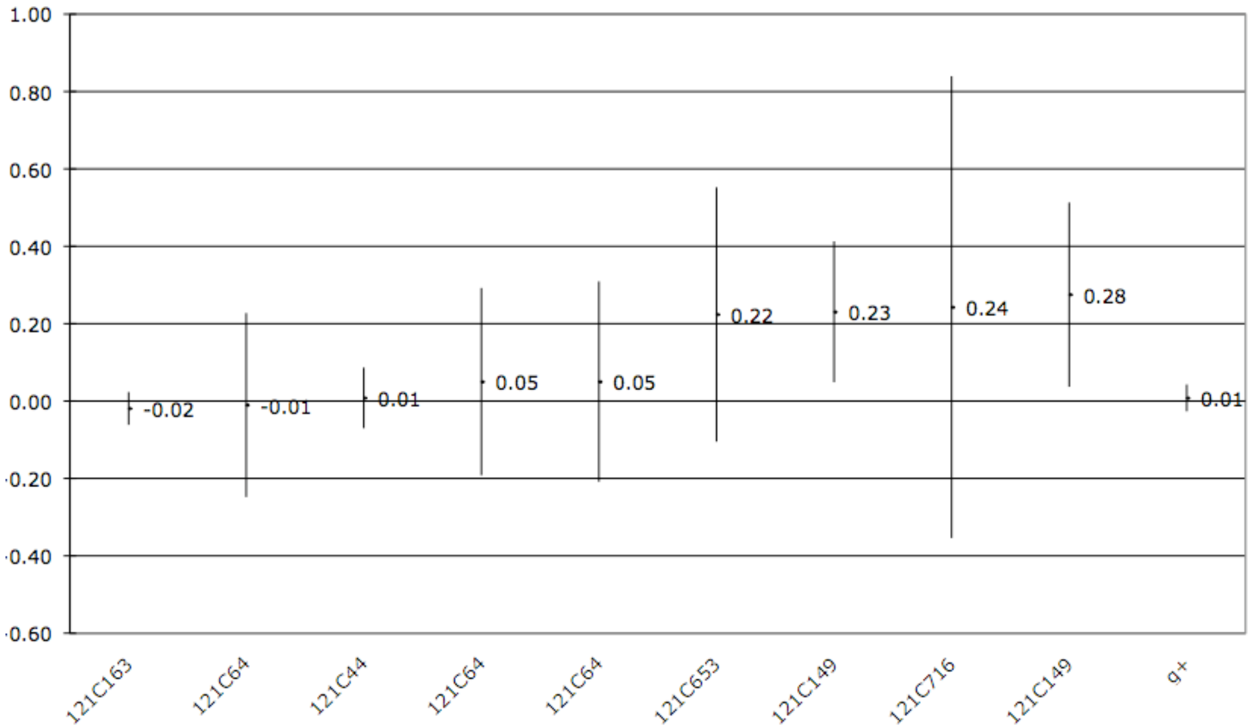
Justifiably or otherwise, the success of any educational innovation is more often than not evaluated in terms of student achievement gains, usually measured by standardized testing. As far as one-to-one initiatives are concerned, the results are not straightforward. From the 22 studies with achievement data, we were able to extract18 independent effect sizes. Meta-analysis of these 18 effect sizes yielded an average effect size of $g+ = 0.25$. The Q statistic of 374.63 (df =17) was significant, indicating that this data set is heterogeneous. From the plot of effect sizes and confidence intervals (Figure 2) we can see that $g+$, the treatment effect estimate, falls well outside the confidence intervals of several of the calculated effect sizes.

Figure 2 - Effect sizes and confidence intervals - all



Of the three methods for dealing with heterogeneity, we chose subgroup analysis as the most appropriate method for two reasons. First, because of the small sample of effect sizes (18) there may have been too few degrees of freedom to conduct meta-regression. Moreover with sample sizes of smaller than 20, random effects models produce biased estimates. Second, there is strong theoretical support for subgroups: according to the literature, one of the most consistently observed effects was the impact of one-to-one computing on student writing (Goldberg, Russell, & Cook, 2003). We divided the set of studies into two subsets: writing and non-writing studies. Additionally, we removed effect sizes from two studies with low quality research designs from the analysis as study design has been noted in the literature as a source of heterogeneity (Bernard et al., 2004, Cochrane, 2002). The two resulting sub-sets of studies (writing and non-writing) were considerably less heterogeneous. The non-writing studies yielded a non-significant average effect size of $g = 0.02$. The homogeneity statistic was calculated at $Q = 15.16$, p=0.06. Visual inspection of the effect sizes and confidence intervals is much more encouraging – g+ seems to fall within the confidence intervals, if only barely (Figure 3).

Figure 3 - Effect sizes and confidence intervals - general achievement (writing and low quality studies removed)

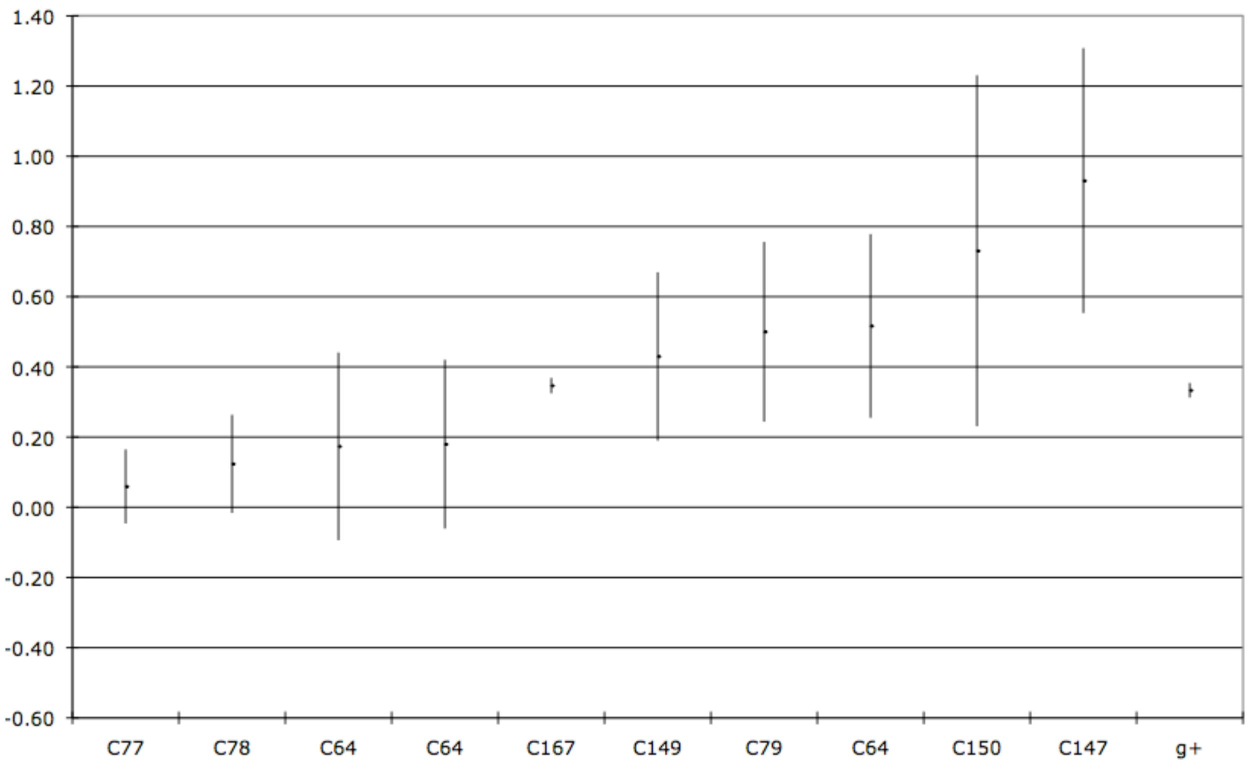


The second sub-group – effect sizes from studies of laptops on student writing – still showed a degree of heterogeneity, though again considerably less that the original set combining writing and non-writing studies. The writing studies yielded a significant average effect size of g = 0.33, with Q = 55.06, p = 0.00. Visual inspection shows that confidence intervals are more tightly bunched than the original analysis, though follow-up analyses with larger sample sizes is desirable (see Figure 4).

Synthesis of syntheses

The six research syntheses reviewed echo the findings described above: they report consistent findings of increases in technology use and technology literacy, while reporting little evidence of a generalized "technology effect" on student achievement, though they note that one-to-one programs enhance learning in some areas more than others. The syntheses report several factors contributing to the success of any one-to-one implementation: teacher beliefs, teacher training, technical support, comprehensive curriculum review that meaningfully integrates technology rather than forces into existing pedagogy, change management strategies. These findings were particularly useful for determining categories of study features for the meta-analysis. Most importantly, though, the syntheses emphasize the need for more research into one-to-one implementations to tease out exactly how, when, and under what conditions they are the most effective. It is hoped that by combining the meta-analysis results with a more comprehensive and systematic review of attitude data and the qualitative data, greater insight into contextual variables can be gained.

Figure 4 - Effect sizes and confidence intervals for writing studies



Preliminary Conclusions

The results of twenty years of laptop programs have been mixed. Results from the meta-analysis suggest that laptops alone are not a panacea for educational reform. When targeted toward specific purposes, they can produce gains, though these need to be studied further. It would be interesting to see what sort of learning gains can be achieved if the new literacy approaches mentioned above are integrated into the curricula of schools and boards with laptop programs in place. The survey evidence echoes these mixed findings: laptop initiatives have shown improvements in writing, technology integration, use, and proficiency, in attitudes towards technology and the promise of technology for learning, and to some extent increased engagement and motivation. What seems clear, however, is that research does not support the premise that one-to-one initiatives automatically lead to increased student achievement. Technology seems better suited to affecting improvements in some areas and with some students more than with others. Improving students' writing seems to be a particularly successful application of one-to-one technology. Moreover as the results reported in Lowther et al. (2003) seem to suggest, the best results are obtained when one-to-one computing is one part of a well-planned technological integration strategy that includes specific guidelines and training in pedagogically sound uses of computers in the classroom. Along these lines, we can speculate that if one-to-one programs are combined with faithful implementation of proven technology assisted learning tools, technology advocates may finally see the long-hoped-learning gains.

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Note

The references listed above are those referred to in-text only. A complete list of studies included in the review is available upon request.