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Abstract:

Meta-analyses were performed including 26 studies conducted between 1992–2002 focused on the comparison between K–12 students writing with computers vs. paper-and-pencil. Significant mean effect sizes in favor of computers were found for quantity of writing (d=.50, n=14) and quality of writing (d=.41, n=15). Studies focused on revision behaviors between these two writing conditions (n=6) revealed mixed results. Other studies collected for the meta-analysis which did not meet the statistical criteria were also reviewed briefly. These articles (n=35) indicate that the writing process is more collaborative, iterative, and social in computer classrooms as compared with paper-and-pencil environments. For educational leaders questioning whether computers should be used to help students develop writing skills, the results of the meta-analyses suggest that, on average, students who use computers when learning to write are not only more engaged and motivated in their writing, but they produce written work that is of greater length and higher quality.

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The Effect of Computers on Student Writing: A Meta-analysis of Studies from 1992 to 2002

Introduction

Over the past two decades, the presence of computers in schools has increased rapidly. While schools had one computer for every 125 students in 1983, they had one for every 9 students in 1995, one for every 6 students in 1998, and one for every 4.2 students in 2001 (Glennan & Melmed, 1996; Market Data Retrieval, 1999, 2001). Today, some states, such as South Dakota, report a student to computer ratio of 2:1 (Bennett, 2002).

Just as the availability of computers in schools has increased, their use has also increased. A national survey of teachers indicates that in 1998, 50 percent of K–12 teachers had students use word processors, 36 percent had them use CD ROMS, and 29 percent had them use the World Wide Web (Becker, 1999). More recent national data indicates that 75 percent of elementary school-aged students and 85 percent of middle and high school-aged students use a computer in school (U.S. Department of Commerce, 2002). Today, the most common educational use of computers by students is for word processing (Becker, 1999; inTASC, 2003). Given that, it is logical to ask: Do computers have a positive effect on students' writing process and quality of writing they produce?

As is described more fully below, the study presented here employs meta-analytic techniques, commonly used in fields of medicine and economics, to integrate the findings of studies conducted between 1992–2002. This research synthesis allows educators, administrators, policymakers, and others to more fully capitalize on the most recent findings regarding the impact of word processing on students' writing.

Word Processing and Student Writing

Over the past two decades, more than 200 studies have examined the impact of word processing on student writing. Over half of these studies, however, were conducted prior to the presence and wide-scale use of current menu-driven word processors. In addition, these early studies focused on students who were generally less accustomed to working with computer technologies compared to students today.

Regardless of these obstacles, syntheses of early research provide some evidence of positive effects. For example, important findings emerged from Cochran-Smith's (1991) qualitative literature review on word processing and writing in elementary classrooms. Among them, Cochran-Smith found that students of all ages had positive attitudes toward word processing and were able to master keyboarding strategies for use in age-appropriate writing activities. Cochran-Smith also found that students who used word processors spent a greater amount of time writing and produced slightly longer, neater, and more technically error-free texts than with paper and pencil. However, this review of the literature also indicated that word-processing, in and of itself, generally did not impact overall quality of student writing.

Other early research, however, such as Bangert-Drowns' (1993) quantitative meta-analysis of 28 individual studies spanning elementary through post-secondary school levels, indicates that word processing contributed to a modest but consistent improvement in the quality of students' writing: Approximately two-thirds of the 28 studies' results favored the word processor over handwritten text.

In general, the research on word processors and student writing conducted during the 1980's and early 1990's suggests many ways in which writing on computers may help students produce better work. Although much of this research was performed before large numbers of computers were present in schools, formal studies report that when students write on computer they tend to produce more text and make more revisions (Dauite, 1986; Vacc, 1987). Studies that compare student work produced on computer with work produced on paper find that for some groups of students, writing on computer also had a positive effect on the quality of student writing (Hannafin & Dalton, 1987; Owston, 1991;). This positive effect is strongest for students with learning disabilities, early elementary-aged students and college-aged students (Hass & Hayes, 1986; Phoenix & Hannan, 1984; Sitko & Crealock, 1986). Additionally, when applied to meet curricular goals, education technology provides alternative approaches to sustaining student interest, developing student knowledge and skill, and provides supplementary materials that teachers can use to extend student learning. Although earlier research syntheses reveal just modest trends, individual studies of that era have shown that writing with a computer can increase the amount of writing students perform, the extent to which students edit their writing (Dauite, 1986; Etchinson, 1989; Vacc, 1987), which, in turn, leads to higher quality writing (Hannafin & Dalton, 1987; Kerchner & Kistinger, 1984; Williamson & Pence, 1989).

Throughout the 1990's, however, technology has and continues to develop at an astonishing pace. Word processing technologies, are easier to use and are no longer the classroom novelty they once were. A new generation of studies that examine the impact of word processing on writing fills today's journals. In response to improvements in word processing and students comfort with technology, the study presented here builds on Cochran-Smith's (1991) and Bangert-Drowns' (1993) work by integrating research conducted since 1991 that has focused on the impact of word processors on the quantity and quality of student writing.

The study presented here differs in two ways from the two previous meta-analyses described above. First, while Cochran-Smith's (1991) study was qualitative in nature and Bangert-Drowns' (1993) employed a quantitative meta-analytic technique, this study combines quantitative and qualitative methods in order to provide a richer, more encompassing view of all data available for the time period under study.

Secondly, the quantitative component provides an expanded scope on student- and learning environment-level variables in relation to writing performance. These supplemental analyses include factors such as: students' grade level, keyboarding skills, school setting (urban, suburban, rural), etc.

The specific research questions addressed in this study are:

- Does word processing impact K–12 student writing? If so, in what ways (i.e., is quality and/or quantity of student writing impacted)?
- Does the impact of word processing on student writing vary according to other factors, such as student-level characteristics (as described above)?

Methodology

Meta-analytic procedures refer to a set of statistical techniques used to systematically review and synthesize independent studies within a specific area of research. Gene Glass first proposed such methods and coined the term "meta-analysis" in 1976. "Meta-analysis refers to the analysis of analyses ... it ...refer[s] to the statistical analysis of a large collection of results from individual studies for the purpose of integrating the findings. It connotes a rigorous alternative to the casual, narrative discussions of research studies which typify our attempts to make sense of the rapidly expanding research literature" (p. 3). The meta-analytic portion of the study was conducted using procedures set forth by Lipsey and Wilson (2001) and Hedges and Olkin (1985). The methodology followed five phases:

- identification of relevant studies,
- determination for inclusion,
- coding,
- effect size extraction and calculation, and
- data analyses.

Each of these phases is described separately below.

Identification of Relevant Studies

The search for relevant studies was as exhaustive as possible. Methods used to find studies that focused on word processing included:

- Searching online databases such as ERIC, Educational Abstracts, PsychLit, and Dissertation Abstracts,
- Searching web sites known to reference or contain research related to educational technology such as the US Department of Education, and technology and educational research organizations.
- Searching scholarly e-journals that may not be indexed
- Employing general search engines (e.g., Google) in keyword searches for additional manuscripts that either had not yet been catalogued in ERIC or were currently under refereed journal review (yet posted on the researcher's own web page), and
- Directly inquiring with researchers known to be actively studying educational technology about relevant work.

To maximize the pool of studies for consideration, search strategies varied slightly depending on the structure of the source, and included a variety of combinations of terms in each search. Search terms included different forms of such words as: computer, writing, word processing, pencil-and-paper, and handwritten (i.e. *computerized* and *computer*; *word process* and *word processing*, etc.).

If, based on the article's abstract/description, relevancy to the present study could not be determined, it was collected for possible inclusion. The resulting collection included 99 articles (see Appendix C).

Determination for Inclusion

The inclusion criteria for the meta-analysis were stringent. Each study had to consist of the following:

- A quantitative study, conducted between the years of 1992–2002, in with results reported in a way that would allow an effect size calculation, have a research design that employed a measure of word-processing's impact on writing over time, OR be a direct comparison between paper-and-pencil writing and computerized writing,
- have 'quality of student writing' and/or 'quantity of student writing' and/or 'revision of student writing' as its outcome measure(s),
- not specifically focus on the effects of grammar and spell-checkers or heavily multimedia-enhanced word processing software,
- not examine differences in writing within the context of a test administration (i.e, focused on the mode of test administration rather than the mode of learning), and
- focus on students in Grades K–12.

Independently, two researchers read all collected studies to determine eligibility for inclusion based on the above criteria. Any discrepancies between researchers were discussed and resolved. In total, 26 studies met all inclusion criteria. An additional 35 studies/articles were on target regarding the topic, but were either qualitative, insufficient in reporting quantitative data (to enable effect size extraction), or were conceptual or commentary papers that focused on how word processors could be used for instruction. These studies were set aside for separate analysis. The research focus of the remaining 38 articles did not match the purposes of this study. Figure 1 illustrates the results of the literature search and criteria screening, and Figure 2 depicts the studies included in the meta-analysis classified by their measured outcomes.

Figure 1: Articles Collected in Literature Search by Type

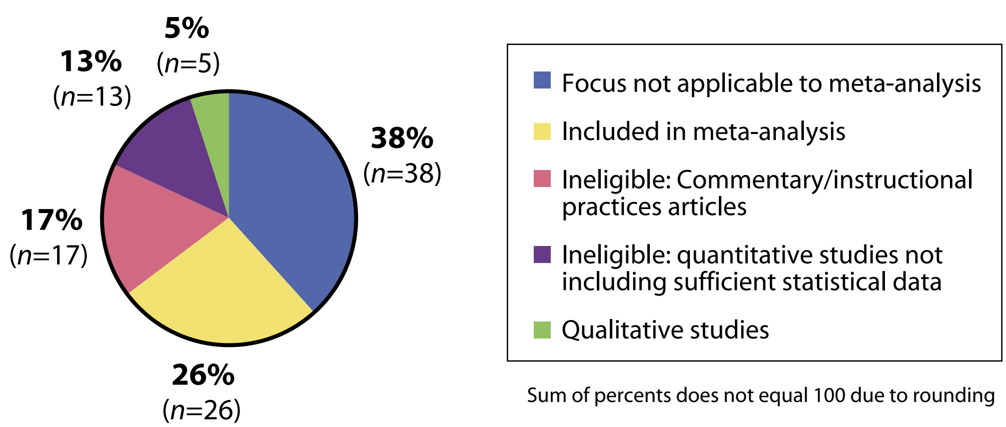
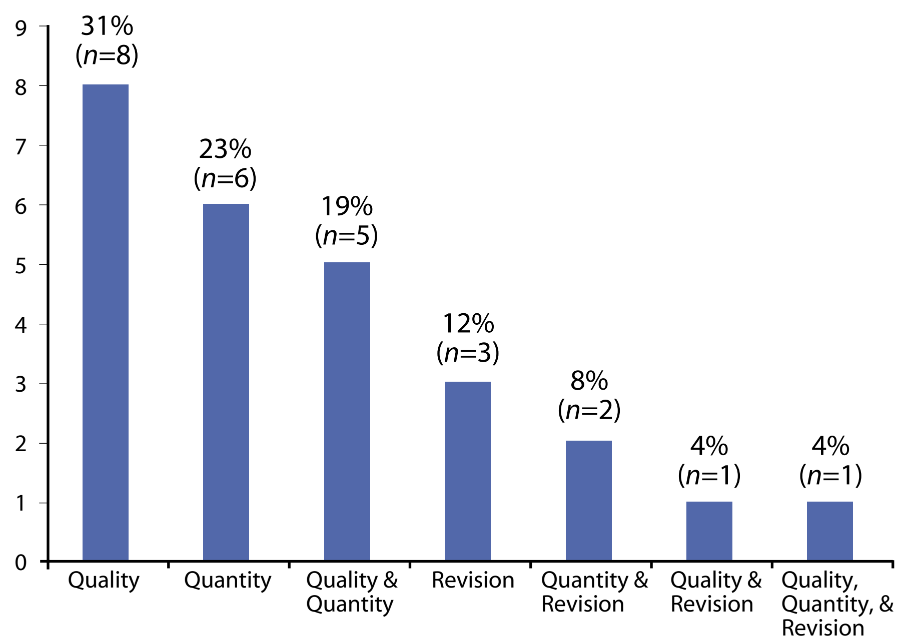


Figure 2: Studies Included in Meta-analysis by Outcomes Measured



Coding of Study Features and Outcome Measures

Study features were coded to aid examination of methodological and substantive characteristics that may contribute to variations in results among studies.

Based on a review of the literature, a coding framework was constructed to encompass salient features of each study. According to this coding scheme, two researchers independently coded each study. Afterwards, coding was discussed between researchers on a study-by-study basis. Coding discrepancies, which occurred infrequently, were discussed and resolved after consulting the original research study.

The final coding frame encompasses seven categories of study descriptors including: publication type, research methodology, student characteristics, technology related factors, writing environment factors, instructional support factors, and outcome measures. Appendix A contains a full description of the variables and all 33 levels included in the coding framework.

In terms of the outcome measures, "quality," "quantity," and "revision" of writing were operationally defined in a variety of ways across studies. Specifically, for quality of writing, most studies (*n*=10), employed one or more rubrics to score students' writing, which resulted in an overall holistic quality rating. In the remaining five studies, individual scores for dimensions of writing were reported. In these cases, these individual scores were averaged to arrive at a single holistic measure of quality of writing. Across the studies, the following writing dimensions were included:

- Mechanics
- Style
- Structure/Language Use
- Content
- Coherence/Competence
- Unity/Focus
- Purpose
- Word Choice/Vocabulary
- Grammar
- Organization
- Voice
- Tone
- Audience
- Commitment
- Creativity
- Punctuation
- Theme
- Setting
- Characterization
- Emotion

In calculating the holistic measure of quality, measures of "neatness" or "spelling" were not included.

For quantity of writing, each of the 12 studies in the meta-analysis used number of words as its metric. Not included in the meta-analysis were an additional four studies that measured quantity as number of sentences, and an additional one study each that used mean clause length and t-units.

Revision of writing was operationally defined in diverse ways across studies. For example, some studies measured revisions in terms of the number of words or sentences inserted and deleted or sentence fragments/run-ons corrected (Grejda &

Hannafin, 1992; Peterson, 1993), while other studies were more qualitative in the ways in which they measured revision. The latter of these studies (Hagler, 1993; Head, 2000; Olson, 1994; Peterson, 1993; Seawel, 1994) measured 'surface' and format revisions (spelling, grammar, punctuation, etc.) as well as revisions that resulted in changes in content and meaning.

After all studies were coded, a variable representing "methodological quality" (Moher & Olkin, 1995, Shadish & Haddock, 1994) was derived from a subset of the coded variables. For each study, methodological quality was based on a 16-point scale. This scale was based on the following formula:

- one point for each dichotomous variable coded as "yes" in the "Research Methodology" category,
- one point for studies obtained from refereed journals ("Publication Type"),
- a maximum of three points for the "Intervention time/Duration of study" and "Sample size" variables,
- Heterogeneity of the sample's gender and race/ethnicity were each awarded one point ("Student Characteristics"), and
- Mention of at least one demographic descriptor for the study's sample (i.e., gender, race, geographic setting (rural, urban, suburban) was awarded one point.

Finally, there was some ambiguity in study reporting which sometimes made coding study features a challenge. Where the presence or absence of a feature could not be reasonably detected (explicitly or by implication), an additional code, "no information available," was employed.

The codes assigned to each study along with all data used to calculate effect sizes are presented in the data file that accompanies this paper.

Extracting and Calculating Effect Sizes

The meta-analytic portion of the data analysis requires the calculation of effect sizes. Conceptually, an effect size represents the standardized difference between two groups on a given measure. Mathematically, it is the mean difference between groups expressed in standard deviation units. In this study, for example, effect sizes were calculated taking the mean performance difference between computerized and paper-and-pencil groups and dividing it by a pooled standard deviation. Generally speaking, effect sizes between .2 and .5 standard deviation units are considered small. Those between .5 and .8 standard deviation units are medium, and effect sizes .8 or greater are considered large.

In order to decrease the probability of falsely concluding that word processing has an effect on student writing (i.e., committing a Type 1 error), the unit of analysis is an "independent study finding." For each of the three outcome measures, an independent effect size was calculated. For studies that reported more than one measure for a particular outcome for the same sample (i.e., "writing quality" was often measured in more than one way per study; mechanics, content, organization, etc. were frequently encountered sub-domains), overall means and standard deviations across these measures were calculated and used to calculate a single effect size. In this way, the assumption of independence was preserved and inflated Type 1 error rates were controlled for, yet no study findings were ignored.

At the outset of the study, we had hoped to base the calculation of effect sizes using gain scores (the difference between scores on post-test and pre-test measures). Unfortunately, a considerable number of studies either lacked a pre-post design or failed to report pre-test data. This precluded the most compelling perspective from being meta-analyzed: comparing gain scores between paper-and-pencil and computer writing groups.

In order to maximize the number of studies included in the analysis, the few pre- and post-test designs were analyzed only in terms of post-test data. This enabled results from the pre/post studies to be analyzed with post-only design data. For all three outcomes (i.e., quantity of writing, quality of writing, and revisions), the standardized mean difference effect size statistic was employed. Since it has been documented that this effect size index tends to be upwardly biased when based on small sample sizes, Hedges (1981) correction was applied.

Effect sizes from data in the form of *t*- and *F*-statistics, frequencies, and p-values were computed via formulas provided by Lipsey & Wilson (2001).

Adjusting for Bias and Applying Inverse Variance Weights

Following standard meta-analytic procedures, an inverse variance weight was applied to each effect size. Essentially, this procedure weights each effect size by the inverse of its sampling variance in order to give more weight to findings based on larger sample sizes. Thus, all inferential statistical analyses were conducted on weighted effect sizes.

Outlier analyses of the sampling weights and effect sizes were also performed. No outliers were identified for effect sizes. However, for the "Quantity of Writing" analyses, two sampling weights were more than two standard deviations from the mean sampling weight. Following a procedure originally employed by Lipsey (1992), the inverse variance weights in this study were adjusted so that they did not over weight the effects found in these two studies.[1]

Data Analysis

Three types of data analyses were performed. First, using the effect size extracted from each study, an overall effect size across studies was calculated and tested for statistical significance. Second, analyses were performed to investigate the potential effects of publication bias. Finally, to investigate the extent to which study features moderated the effect on outcome measures, regression analyses were performed. Below, we describe the methods used to explore publication bias and moderating effects.

Publication Bias

Publication bias analyses were performed via Forest plots, funnel plots, and the fail-safe *N* analysis. Forest plots were used to visually convey the contribution of each study to its meta-analysis, by plotting study effect sizes and corresponding confidence interval bars in a single display. Funnel plots, another widely-used technique for detecting publication bias, were also employed. These plots graphically investigate possible gaps among the studies' findings by simply plotting effect sizes against sample sizes. Finally, a fail-safe *N* analysis (Orwin, 1983) was conducted for each meta-analysis. This analysis addresses the "file-drawer" problem in meta-analytic research and provides an estimate of the number of insignificant, unpublished studies that would have to exist in order to render a statistically significant meta-analytic finding insignificant.

Significance and Homogeneity Analysis

For each meta-analysis, an independent set of effect sizes were extracted, weighted, and then aggregated. Prior to exploring the extent to which other factors, such as grade level or publication type influence the effect sizes, a test for homogeneity was conducted. In essence, the test of homogeneity examines whether the group of effect sizes are part of the same population of effect sizes and thus are not influenced by any other variable. As Table 1 indicates, the effect sizes included in the quantity and quality meta-analyses are heterogeneous. For this reason, additional analyses were conducted in an attempt to identify other factors that may influence the study findings. Due to the small number of studies that included measures of revisions, a formal test for homogeneity was not possible.

Table 1: Results of Tests for Homogeneity

Quantity of Writing (*n*=14)					
Min ES	Max ES	Weighted SD	Homogeneity (Q)	Df	P
-1.617	11.971	4.913	4120.6571	13	.0001
Quality of Writing (*n*=15)					
Min ES	Max ES	Weighted SD	Homogeneity (Q)	Df	P
-2.897	30.117	10.801	24396.9961	14	.0001

Moderator Variable Multiple Regression Models

To explore factors that may influence the effect of word processing on the quantity and/or quality of student writing, regression analyses were conducted in which the coded study features were independent variables. These analyses were limited by two conditions. First, these analyses could only include study features that were reported by most researchers. Second, for each study feature included in the regression analyses, there had to be variation among studies. For several study features, all studies received the same code and thus did not vary. These two conditions severely limited moderator analyses.

For each outcome variable, frequencies of study feature variables were examined. After suitable independent variables were identified, variables with more than two levels were recoded into dummy variables. These variables were then categorized into groups by theme. For example, variables such as "presence of control group," "length of intervention," "type of publication," and "conversion of handwritten student work to word processed format" fell under the theme labeled "Study's Methodological Quality." Variables such as: "technical assistance provided to students," "student participation in peer editing," "students receive teacher feedback," were included in the "Student Support" theme.

Ideally, for each outcome, each themed group of variables would be entered as a single block and themed groups would be entered step wise into a single regression model. However, this was not statistically possible due to the small number of effect sizes. Instead, each themed group of variables was entered as a single block of independent variables and each theme was analyzed in separate regression models.

Summary of Findings

In this section, we present a summary of the findings. Readers who are familiar with meta-analytic techniques or who desire a more technical presentation of the findings are encouraged to read Appendix B.

The analyses focused on three outcome variables commonly reported by studies that examine the impact of word processors on student writing. These variables include: Quantity of Writing, Quality of Writing, and Number of Revisions. Below, findings for each of these variables are presented separately.

Quantity of Writing

Fourteen studies included sufficient information to calculate effect sizes that compare the quantity of writing, as measured by word count, between computer and paper-and-pencil groups.

Figure 3 depicts the effect sizes and the 95 percent confidence interval for all 14 studies sorted by publication year. The fifteenth entry depicts the mean weighted effect size across all fourteen studies, along with the 95 percent confidence interval.

Figure 3: Forest Plot of Quantity of Writing Meta-analysis

Author	Publication Year	Grand N*	Adjusted Effect Size	Lower 95%CI	Upper 95%CI
Owston, et al.	1992	136	0.00	-0.34	0.34
D'Odorico & Zammuner	1993	51	0.56	0.00	1.12
Snyder	1993	51	0.78	0.21	1.35
Peterson	1993	36	1.31	0.59	2.03
Hagler	1993	76	0.47	0.01	0.93
Olson	1994	14	0.02	-1.03	1.07
Jones	1994	20	0.48	-0.41	1.37
Brigman	1994	12	1.23	0.00	2.46
Wolfe, et al.	1996	60	-0.05	-0.41	0.3
Nichols	1996	60	0.87	0.34	1.4
Dybahl, et al.	1997	41	-0.14	-0.77	0.48
Godsey	2000	44	1.31	0.66	1.96
Padgett	2000	32	0.52	-0.18	1.23
Barrera, et al.	2001	36	0.21	-0.44	0.87
mean		669	0.541	0.380	0.702

*Grand N $= n_{paper} + n_{computer}$

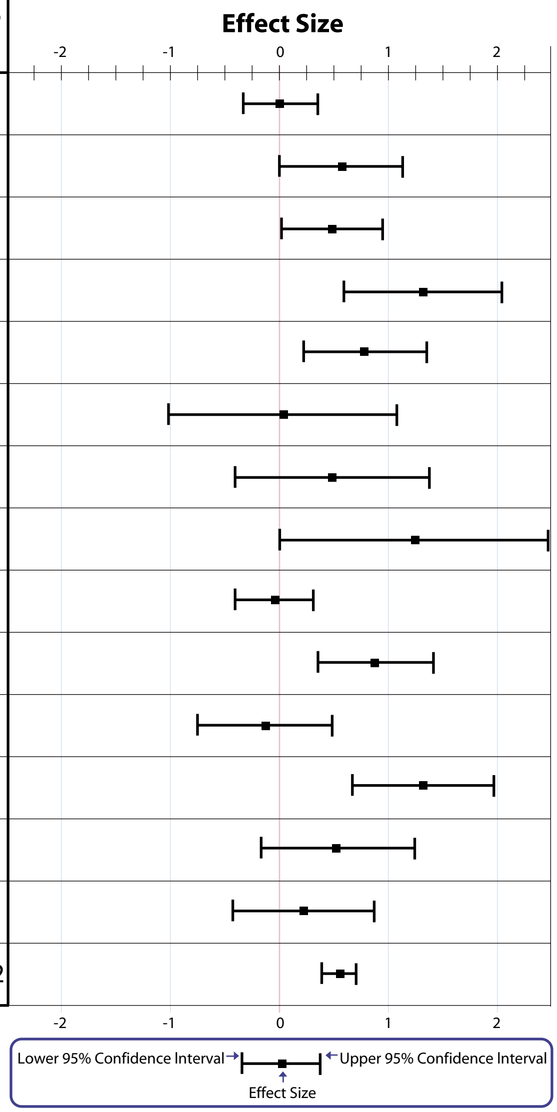


Figure 3 indicates that 4 of the 14 studies had effect sizes that were approximately zero or negative, but which did not differ significantly from zero. Figure 1 also shows that 4 of the 14 studies had positive effect sizes that differed significantly from zero. In addition, the mean weighted effect size across all 14 studies is .50, which differs significantly from zero. Thus, across the fourteen studies, the meta-analysis indicates that students who write with word processors tend to produce longer passages than students who write with paper-and-pencil.

Recognizing that our search for studies may have missed some studies that have not been published, a "fail-safe *N*" analysis (Orwin, 1983) was conducted to estimate the number of studies that report no effect needed to nullify the mean adjusted effect size. This analysis indicates that in order to reverse the effect size found, there would need to be 24 unpublished studies that found no effect. Given that only 14 studies that fit the selection criteria were found and that only four of these had non-positive effect sizes, it seems highly unlikely that an additional 24 studies that found non-positive effects exist. This suggests that our meta-analytic findings are robust to publication bias.

As described above, regression analyses were performed to explore factors that may influence the effect of word processing on the quantity of student writing. These analyses indicated that student supports (i.e., keyboard training, technical assistance, teacher feedback, and peer editing) were not significant factors affecting the quantity of student writing. Similarly, student characteristics (i.e., keyboard experience prior to the study, student achievement level, school setting, and grade level) also were not significant factors affecting the quantity of student writing, although grade level did approach statistical significance. Finally, the study characteristics (i.e., publication type, presence of control group, pre-post design, length of study) were not related to the effect of word processing on the quantity of student writing.

Recognizing that studies that lasted for less than six weeks may not provide enough time for the use of word processors to impact student writing, a separate set of regression analyses were performed for the sub-set of studies that lasted more than six weeks. For this sub-set of studies, a significant relationship between school level and effect size was found. On average, effect sizes were larger for studies that focused on middle and high school students as compared to elementary students. All other factors remained insignificant.

In short, the meta-analysis of studies that focused on the effect of word processing on the quantity of student writing found a positive overall effect that was about one-half standard deviation. This effect tended to be larger for middle and high school students than for elementary students

Quality of Writing

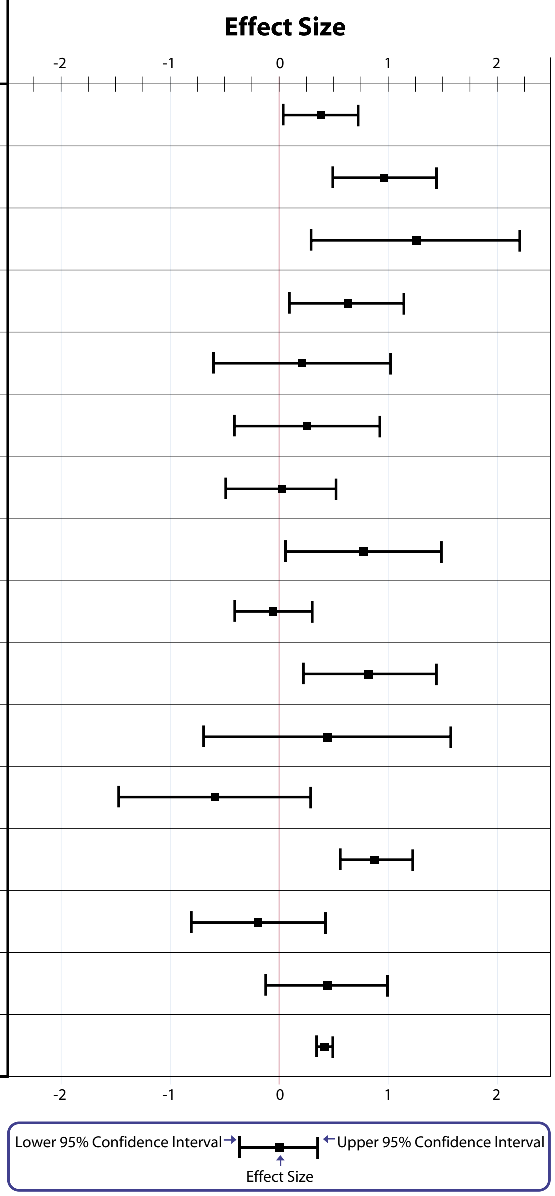
Fifteen studies included sufficient information to calculate effect sizes that compare the quality of writing between computer and paper-and-pencil groups.

Figure 4 depicts the effect sizes and the 95 percent confidence interval for all 15 studies sorted by publication year. The 16th entry depicts the mean weighted effect size across all fifteen studies, along with the 95 percent confidence interval.

Figure 4 indicates that 4 of the 15 studies had effect sizes that were approximately zero or negative, but which did not differ significantly from zero. Since the power in meta-analysis is the aggregation of findings across many studies, it is not unusual to find a subset of studies that contradict the overall trend of findings. In this case, a qualitative examination did not reveal any systematic differences among these studies' features as compared with those studies reporting positive effect sizes. Figure 4 also shows that the 11 remaining studies had positive effect sizes and that seven of these effect sizes differed significantly from zero. In addition, the mean adjusted effect size across all 15 studies is .41, which differs significantly from zero. According to Cohen's criteria for effect sizes, this is considered a small to moderate effect. Thus, across the 15 studies, the meta-analysis indicates that students who write with word processors tend to produce higher quality passages than students who write with paper-and-pencil.

Figure 4: Forest Plot of Quality of Writing Meta-analysis

Author	Publication Year	Grand N*	Adjusted Effect Size	Lower 95%CI	Upper 95%CI
Owston, et al.	1992	136	0.38	0.04	0.72
Hagler	1993	38	0.96	0.49	1.44
Jones	1994	20	1.25	0.29	2.21
Jackiewicz	1995	58	0.62	0.09	1.15
Keetley	1995	23	0.20	-0.62	1.02
Lam & Pennington	1995	34	0.25	-0.42	0.93
Nichols	1996	60	0.01	-0.5	0.52
Lichetenstein	1996	32	0.77	0.05	1.49
Wolfe,et al.	1996	120	-0.06	-0.42	0.3
Breese, et al.	1996	44	0.83	0.21	1.44
Langone et al.	1996	12	0.43	-0.71	1.58
Jones & Pellegrino	1996	20	-0.61	-1.5	0.29
Lerew	1997	150	0.88	0.55	1.22
Dybdhal, et al.	1997	41	-0.20	-0.83	0.42
Head	2000	50	0.43	-0.13	0.99
mean		838	0.410	0.340	0.481



*Grand N $= n_{paper} + n_{computer}$

Recognizing that our search for studies may have missed some studies that have never been published, the "fail-safe *N*" analysis was again conducted. This analysis indicates that in order to reverse the effect size found, there would have to be 16 unpublished studies that found no effect. Given that only 15 studies that fit the selection criteria were found and that only four of these had non-positive effect sizes, it seems highly unlikely that an additional 16 studies that found non-positive effects exist.

As described above, regression analyses were performed to explore factors that may influence the effect of word processing on the quality of student writing. These analyses indicated that student supports (i.e., keyboard training, technical assistance, teacher feedback, and peer editing) were not significant factors affecting the quality of student writing. Similarly, the study characteristics (i.e., type of publication, employment of random assignment, employment of pre-post design, single vs. multiple classroom sampling, length of study, etc.) were not related to the effect of word processing on the quality of student writing. However, when examining student characteristics (i.e., keyboard experience prior to the study, student achievement level, school setting, and grade level), a statistically significant relationship was detected between grade level and quality of writing: as school level increased, the magnitude of the effect size increased.

Recognizing that studies that lasted for less than six weeks may not provide enough time for the use of word processors to impact student writing, a separate set of regression analyses were performed for the sub-set of studies that lasted more than six weeks. For this sub-set of studies, no significant relationships were found. This suggests that the relationship between school level and quality of writing occurred regardless of the length of study.

In short, the meta-analysis of studies that focused on the effect of word processing on the quality of student writing found a positive overall effect that was about four tenths of a standard deviation. As with the effect for quantity, this effect tended to be larger for middle and high school students than for elementary students.

Revisions

Only 6 of the 30 studies that met the criteria for inclusion in this study included measures related to revisions. Of these six studies, half were published in refereed journals, half took place in elementary schools, and only one employed a sample size greater than 30.

Because of the small sample size (only 6) coupled with the reporting of multiple measures of revisions which could not be combined into a single measure for each study, it was not possible to calculate an average effect size. Nonetheless, these six studies all report that students made more changes to their writing between drafts when word processors were used as compared to paper-and-pencil. In studies that focused on both revision and quality of writing, revisions made by students using word processors resulted in higher quality writing than did students revising their work with paper and pencils. It should also be noted that one study found that students writing with paper-and-pencil produced more content-related revisions than did students who used word processors.

In short, given the small number of studies that compared revisions made on paper with revisions made with word processors coupled with the multiple methods used to measure revisions, it is difficult to estimate the effect of computer use on student revisions.

Qualitative Analysis of Excluded Studies

In total, 65 articles published between 1992 and 2002 that focused on the effects of computers on student writing were found during our search (see Appendix C). Of these, 26 met our criteria for inclusion in the quantitative portion of the meta-analyses. In many cases, the studies that were excluded contained information about the effect of computers on student writing, but did not report sufficient statistics to calculate effect sizes. In several cases, the excluded studies did not focus on the three variables of interest – quantity of writing, quality of writing, and revisions – but instead provide information about the effect of computers on other aspects of student writing. In still other cases, excluded studies employed qualitative methods to explore a variety of ways in which computers may impact student writing.

In this section, we summarize the findings across the excluded studies. We do this both to supplement the findings of our quantitative meta-analysis and to check that our criteria for inclusion in the meta-analysis did not systematically bias our analysis. It is important to remember that the studies summarized below were selected as possible candidates for inclusion in our meta-analyses and were selected because it was believed they included information about the effect of computers on the quantity of writing, quality of writing, and the amount of revisions made while writing. Thus, the sample of studies summarized here is not representative of all studies that focus on computers and writing.

Writing as a Social Process

Several of the excluded studies examined how interactions among students were effected when students wrote with computers. These studies describe in rich detail the social interactions between students as they engage in the writing process. In general, these studies find that when students use computers to produce writing, the writing process becomes more collaborative and includes more peer-editing and peer-mediate work (Baker & Kinzer, 1998; Butler & Cox, 1992; Snyder, 1994). As an example, Snyder (1994) describes changes in classroom-talk when students use computers rather than paper-and-pencil. In Snyder's study, teacher-to-student communications was predominant in the "pens classroom" while student-to-student interactions occurred more frequently in the "computers classroom." In addition, Snyder describes how the teacher's role shifted from activity leader in the "pens classroom" to that of facilitator and "proof-reader" in the "computers classroom." Snyder attributed this change to students increased motivation, engagement and independence when writing with computers.

Writing as an Iterative Process

One study focused specifically on how the writing process changed when students wrote on computers versus on paper (Baker & Kinzer, 1998). This study found that when students wrote on paper, the writing process was more linear. Students generally brainstormed, outlined their ideas, wrote a draft, then revised the draft, produced a second draft, and then proof read the draft before producing the final version. When students produced writing on computers, however, the process of producing and revising text was more integrated. Students would begin recording ideas and would modify their ideas before completing an entire draft. Students also appeared more willing to abandon ideas in mid-stream to pursue a new idea. In this way, the process of revision tended to begin earlier in the writing process and often was performed as new ideas were being recorded. Rather than waiting until an entire draft of text was produced before beginning the revision process, students appeared to critically examine and edit their text as ideas flowed from their mind to written form.

Computers and Motivation

A few of the excluded studies noted that computers seemed to motivate students, especially reluctant writers. In her case study of two third grade "reluctant writers," Yackanicz's (2000) found that these students were more willing to engage and sustain in writing activities when they used the computer. As a result, these students wrote more often, for longer periods of time, and produced more writing when they used a computer instead of paper-and-pencil.

Keyboarding and Computers

One study that focused on a range of middle school students found that it tended to take students longer periods of time to produce writing on computers as compared to on paper (Jackowski-Bartol, 2001). Although no formal measures of keyboarding skills were recorded, Jackowski-Bartol attributed this difference to a lack of keyboarding skills and inferred that as students keyboarding skills improve, the amount of time required to produce writing on computers would decrease.

Effects on Student Writing

Several of the excluded studies examined the effect of computers on various aspects of students' final written products. Examining writing produced by high school students who participated in a computer technology infusion product, Allison (1999) reported improvement in students' literacy skills, attitudes toward writing, and an increase in the number of students who demonstrated high-order thinking skills in their writing. In a three-week study of 66 sixth graders who were randomly assigned to write on computer or paper, Grejda and Hannafin (1992) found that the quality of student writing was comparable, but students who used word-processors introduced fewer new errors when revising their text as compared to students who re-wrote their work on paper.

In a three year study that examined the effect of computers on student writing, Owston and Wideman (1997) compared changes in the quantity and quality of writing of students attending a school in which there was one computer for every fifteen students versus a school in which there was 1 computer for every 3students. After three years, Owston and Wideman found that the quality of writing improved at a faster rate in the high access school and that the mean length of composition was three times longer in the high access school. The researchers, however, acknowledged that their findings do not take into account differences between teachers or the demographics of the students. Nonetheless, the researchers state that these variables did not appear to explain the superior writing produced by students in the high access school.

Not all studies, however, report positive effects of computers on student writing. In a three year study in which 72 third-grade students wrote on computer and paper, Shaw, Nauman, and Burson (1994) report that the length and quality of writing produced on paper was higher than writing produced on computer. This finding occurred even though students who wrote on computer had received keyboarding instruction. The authors described writing produced on computer as "stilted" and less creative.

Discussion

This study employed meta-analytic techniques to summarize findings across multiple studies in order to systematically examine the effects of computers and student learning. Although a large number of studies initially identified for inclusion in the meta-analysis had to be eliminated either because they were qualitative in nature or because they failed to report statistics required to calculate effect sizes, the analyses indicate that instructional uses of computers for writing are having a positive impact on student writing. This positive impact was found in each independent set of meta-analyses; for quantity of writing as well as quality of writing.

Early research consistently found large effects of computer-based writing on the length of passages and less consistently reported small effects on the quality of student writing. In contrast, although our meta-analyses of research conducted since 1992 found a larger overall effect size for the quantity of writing produced on computer, the relationship between computers and quality of writing appears to have strengthened considerably. When aggregated across all studies, the mean effect size indicated that, on average, students who develop their writing skills while using a computer produce written work that is .4 standard deviations higher in quality than those students who learn to write on paper. On average, the effect of writing with computers on both the quality and quantity of writing was larger for middle and high school students than for elementary school students.

Glass is quoted in Morton Hunt's (1997), *How Science Takes Stock: the Story of Meta-analysis* as saying,

> What I've come to think meta-analysis really is – or rather, what it ought to be – is not little single-number summaries such as 'This is what psychotherapy's effect is' but a whole array of study results that show how relationships between treatment and outcome change as a function of all sorts of other conditions – the age of the people in treatment, what kinds of problems they had, the training of the therapist, how long after therapy you're measuring change, and so on. That's what we really want to get – a total portrait of all those changes and shifts, a complicated landscape rather than a single central point. That would be the best contribution we could make. (p. 163)

Following this purpose, regression analyses were conducted in order to investigate key factors that may affect the relationship between computers and writing. These analyses indicated that computers had a greater impact on writing for middle and high school students than for elementary school students, for both quantity and quality of writing. Other factors investigated, such as students' keyboarding experience and students' academic achievement level, were not found to play a significant role for either quantity or quality of writing. However, it is important to note that these additional analyses were conducted with a small number of studies, which often makes detecting effects difficult.

In addition, the findings reported in the excluded studies are consistent with both the findings of our quantitative meta-analyses and many of the findings presented in Cochran-Smith's (1991) and Bangert-Downs (1993) summaries of research conducted prior to 1992. In general, research over the past two decades consistently finds that when students write on computers, writing becomes a more social process in which students share their work with each other. When using computers, students also tend to make revisions while producing, rather than after producing, text. Between initial and final drafts, students also tend to make more revision when they write with computers. In most cases, students also tend to produce longer passages when writing on computers.

For educational leaders questioning whether computers should be used to help students develop writing skills, the results of our meta-analyses suggest that on average students who use computers when learning to write produce written work that is about .4 standard deviations better than students who develop writing skills on paper. While teachers undoubtedly play an important role in helping students develop their writing skills, the analyses presented here suggest that when students write with computers, they engage in the revising of their work throughout the writing process, more frequently share and receive feedback from their peers, and benefit from teacher input earlier in the writing process. Thus, while there is clearly a need for systematic and high quality research on computers and student learning, those studies that met the rigorous criteria for inclusion in our meta-analyses suggest that computers are valuable tools for helping students develop writing skills.

Endnote

1 The smallest grand sample size among the 14 studies measuring "quantity of writing" was 12, while the largest grand sample size was 136. This variation in sample size resulted in a mean inverse variance weight of 12.30 (*SD* = 8.75), and a range from 2.52 through 31.03. The two largest weights were slightly greater than two standard deviations above the mean in value, and therefore were winsorized down to the value of two standard deviations above the mean, 29.80.

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Appendix A: Coding Framework

1) **Publication type** (one variable)
   - Refereed journal article
   - Conference presentation
   - Manuscript under journal review
   - Doctoral dissertation
   - Master's thesis
   - Research organization study/technical report

2) **Research methodology** (eight variables, unless otherwise indicated, dichotomous: yes/no)
   - Random assignment of students
   - Direct comparison to paper/handwritten writing
   - Presence of pre- and post-test
   - Standardized/controlled writing conditions
   - Intervention time/duration of study
     - Less than six weeks
     - Between six weeks and one semester
     - More than one semester
   - Sample size
     - Thirty or less
     - Between 31 and 100
     - More than 100
   - In the case of handwritten samples: Were they converted to computerized form to ensure blindness of scorers/raters?
   - Other indicators of sound design (i.e., treatment vs. control groups, counterbalanced design, absence of confounding variables, etc.)

3) **Student characteristics** (six variables)
   - Grade level
     - Elementary
     - Middle
     - Secondary

- Gender description
  - Heterogeneous
  - Homogeneous
- Race/ethnic description
  - Heterogeneous
  - Homogeneous
- School-setting
  - Rural
  - Suburban
  - Urban
- Type of students
  - Mainstream
  - SPED/At-risk
  - Gifted
  - ESL/ESOL
- Writing ability of students
  - Low
  - Average
  - High

4) **Technology-related factors** (seven variables)

- Type of hardware used
- Type of software used
- Description of students' prior keyboarding skills
  - No mention
  - Minimal
  - Adequate
  - Advanced
- Description of students' prior word-processing skills
  - No mention
  - Minimal
  - Adequate
  - Advanced
- Keyboarding training provided as part of study (yes/no)
- Word processing training provided as part of study (yes/no)
- Technological assistance provided to students during study (yes/no)

5) **Writing environment factors** (two variables)

- Writing within Language Arts/English discipline?
- Type of student writing
  - Collaborative
  - Individual

6) **Instructional factors** (six variables; all dichotomous: yes/no)

- Did students receive writing instruction during the intervention period?
- Receipt of teacher-feedback/editing
- Receipt of peer-feedback/editing
- Were students allowed to revise without any kind of feedback
- Internet or distance editors
- Did students make use of spell-checkers

7) **Outcome measures** (three variables)

- Quantity of writing
  - Number of words
  - Number of t-units
  - Number of sentences
- Quality of writing
- – Holistic, judgmental (no rubric)
  - Mechanics, rubric
  - Grammar, rubric
  - Style, rubric
- Revision of writing
  - Number of revisions
  - Nature of revisions

Appendix B: Results

Computers and Writing: Quantity

Fourteen independent effect sizes were extracted from 14 studies that compared quantity of writing, as measured by word count, between computer and paper-and-pencil groups. Below we present descriptive highlights of the fourteen studies followed by an analyses of effect sizes and regression analyses that explore moderating variables.

Descriptive Highlights

As detailed in Table B1, 64 percent of the studies (*n*=9) were published in refereed journals, 14.3 percent (*n*=2) employed random assignment, and more than half (*n*=8) sampled from multiple classrooms. For 57 percent of the studies (*n*=8), the research duration lasted between six weeks and one semester, and 86 percent (*n*=12) utilized standardized writing tasks across groups. In 43 percent (*n*=6) of the studies, students were provided with keyboarding training. Individual writing (as opposed to collaborative writing) was the focus in all 14 studies, and peer editing, teacher feedback, and technical assistance were available to students in 21 percent (n=3) of the studies. It was inconclusive whether or not teacher feedback and/or technical assistance were study features in *n*=5 and *n*=9 studies, respectively.

With respect to student demographics, only three studies (21 percent) provided sufficient information that indicated that the sample was gender diverse and four studies (29 percent) indicated that they had racially/ethnically-diverse student samples. Over half of the studies did not provide sufficient information about the participating students to classify their gender or racial/ethnic diversity. All but two studies (*n*=12) focused on mainstream education samples, and half (*n*=7) of the studies were conducted with elementary school students. Finally, two studies occurred in rural, three in urban, and four in suburban settings, while the three studies lack any geographic information.

Table B1: Characteristics of Studies Included in Quantity of Writing Meta-analysis

Study Characteristics	***n* of studies (%)**		
	Refereed journal article	**Doctoral dissertation**	**Master's thesis**
Publication type	9 (64.3%)	3 (21.4%)	2(14.3%)
	Yes	**No**	**No information**
Random assignment	2 (14.3%)	12 (85.7%)	—
Pre-Post design	6 (42.9%)	8 (57.1%)	—
Standardized writing sample	12 (85.7%)	2 (14.3%)	—
Keyboarding training included in study	6 (42.9%)	6 (42.9%)	2 (14.3%)
Peer-editing	3 (21.4%)	11 (78.6%)	—
Handwritten samples converted to WP format	3 (21.4%)	11 (78.6%)	—
Technical assistance provided to students	3 (21.4%)	2 (14.3%)	9 (64.3%)
Teacher's feedback on provided to students	3 (21.4%)	6 (42.9%)	5 (35.7%)

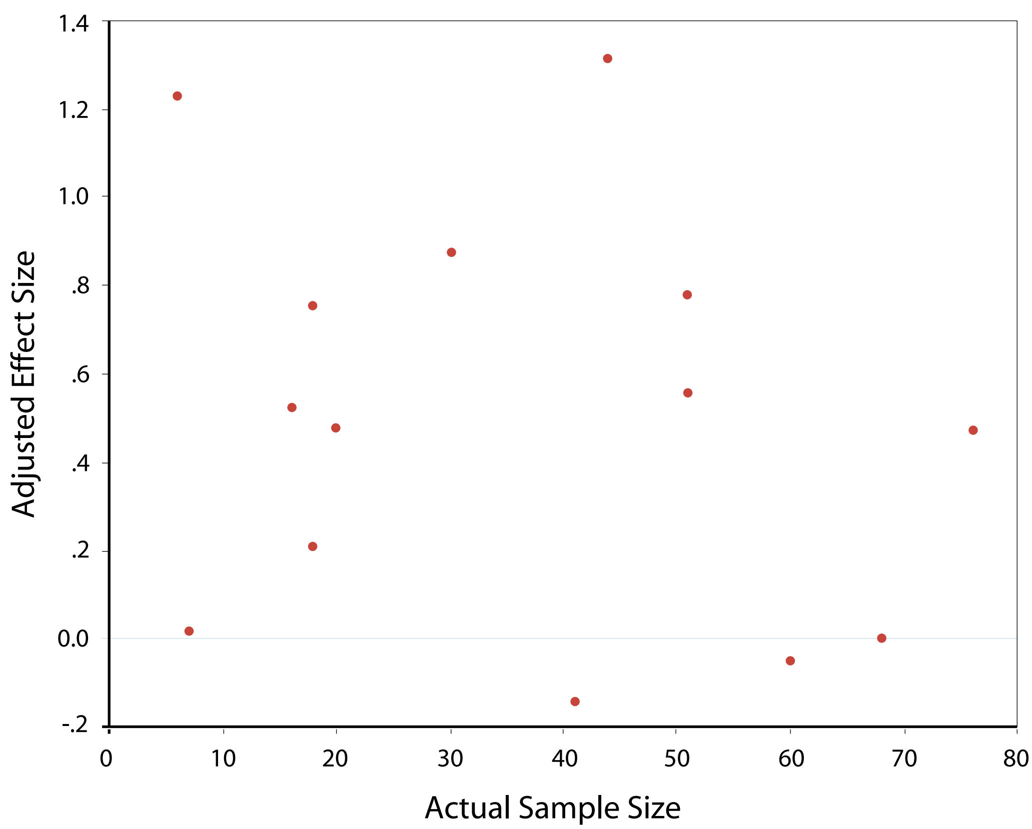
Sample Characteristics	***n* of studies (%)**		
	Yes	**No**	**No information**
Sample described demographically	6 (42.9%)	8 (57.1%)	—
Gender-diverse	4 (28.6%)	1 (7.1%)	9 (64.3%)
Racially/Ethnically diverse	3 (21.4%)	1 (7.1%)	10 (71.4%)
Prior keyboarding skill	7 (50%)	1 (7.1%)	6 (42.9%)
	Single	**Multiple**	**No information**
Sampling – school-level	11 (78.6%)	3 (21.4%)	—
Sampling – classroom-level	6 (42.9%)	8 (57.1%)	—
	Less than six weeks	**Between six weeks and one semester**	**One semester or longer**
Length of study	6 (42.9%)	6 (42.9%)	2 (14.3%)
	Elementary	**Middle**	**High**
Grade level	7 (50%)	3 (21.4%)	4 (28.6%)

	High	**Average**	**Low**	**Mixed**	**No Information**
Student sample ability level	3 (21.4%)	2 (14.3%)	1 (7.1%)	4 (28.6%)	4 (28.6%)
	Rural	**Urban**	**Sub-urban**	**Mixed**	**No Information**
School setting	2 (14.3%)	3 (21.4%)	4 (28.6%)	2 (14.3%)	3 (21.4%)

Publication Bias: Funnel Plot

The funnel plot depicted in Figure B1 shows that nearly two-thirds of effect size findings are approximately .50 or greater. Smaller-sized studies demonstrated a wide range of effect sizes, from virtually no effect at all through upwards of 1.2 units, as do the five largest studies (those with sample sizes greater than 50; ranging from -.05 to .87). Striking from the funnel plot, however, is the dearth of studies that employed a sample size greater than 50; exactly half of the studies had sample sizes that were 30 or less.

Figure B1: Funnel Plot for Quantitative Meta-analysis



Weighted Effect Sizes and Homogeneity Analysis

The overall effect of computers, as compared with paper-and-pencil, on quantity of student writing, based on 14 independent effect sizes, extracted from 14 studies, resulted in a mean effect size of .501. The weighted mean effect size, d_+=4.5226, with a 95 percent confidence interval ranging from .1.8187 through 7.2265. Individual weighted effect sizes ranged from –1.62 through 11.97. The homogeneity analysis resulted in Q_t=4120.6571, df=13, p < .0001. This significant Q_t statistic indicates that the 14 effect sizes comprising this analysis do not come from the same population, and that there may be moderating variables that impact the magnitude and/or direction of the effect sizes

In order to identify which, if any, of the coded study features have a significant moderating effect on the relationship between computers and quantity of writing, regression analyses were performed.

Weighted Effect Sizes and Regression Analysis

To examine the extent to which effect sizes were moderated by various study features, a mixed model approach was employed. This approach assumes that some of the variance in the effect sizes is systematic and thus can be modeled, while another portion of the variance in the effect sizes is random and, therefore, cannot be modeled (for a full discussion of mixed vs. fixed effects modeling in the context of meta-analyses, see Hedges & Olkin, 1985).

The first step in the analysis was to dummy code all of the categorical variables. Dichotomous variables were left as is, variables with three or more levels were transformed into a series of k–1 (where k is the number of levels in the original variable) dichotomous variables. In the process of creating these variables, categories within the "school level" and "student ability" variable were collapsed. The dummy variable for "school level" was created to compare studies conducted in elementary schools with those conducted in middle and high school combined. Student ability was transformed to contrast the "average" and "mixed" groups with the remaining groups (low, high, no information provided).

To identify those variables with sufficient variance between levels required by the matrix algebra used in regression analysis, frequencies of each dummy variable were examined. In general, if each level of a given variable had a frequency of three or more, then it could be successfully entered in the regression analysis.

Of the coded study features, eight variables met the criterion for sufficient variance. These eight variables were grouped into two themes:

- "student support," which included keyboard training, technical assistance, teacher feedback, and peer editing
- "student sample characteristics" which included keyboard experience prior to study, student ability, school setting, and school level.

Additionally, a regression analysis that focused on the "study's methodological quality" was conducted. For this analysis, methodological quality was calculated by summing assigned points across the 12 variables related to study quality, for a total possible score of 16. As presented below, the aggregate methodological quality rating was not a significant predictor. To explore whether individual aspects of study quality moderated the reported effects, the following study features were entered separately into a regression model: type of publication, presence of control group, presence of pre-post design, length of study, multiple vs. single classrooms, and multiple vs. single schools. Additionally, publication year was dummy coded and included along with these methodological variables. To dummy code publication year, studies were divided into two groups: those published between 1992–1995, inclusive, and those published after 1995.

Quantity of Writing: Features With Moderating Effects

Regression Model: Student Support in Writing

Table B2 shows the results of the "student support" multiple regression model. In total, the four predictors, entered in a single block, accounted for 6 percent of the variance. None of the individual predictors were significant. These results suggest that the various types of support provided to students during the course of each study did not systematically affect the amount of writing students produced.

Table B2: Regression Analysis of Student Support Variables on Weighted Effect Sizes of Quantity of Writing

	B	SE	-95% CI	+95% CI	Z	P	Beta
Constant	3.7541	2.4246	-.9980	8.5062	1.5484	.1215	.0000
Keyboard training	1.9465	3.5734	-5.0574	8.9503	.5447	.5860	.2133
Teacher feedback	-.6918	6.3335	-13.1053	11.7218	-.1092	.9130	-.0629
Peer editing	-.5389	5.2453	-10.8198	9.7419	-.1027	.9182	-.0490
Technical assistance	.9379	5.0348	-8.9302	10.8061	.1863	.8522	.0853

$Q_M = .4615$, $p = .9771$

Mean ES	R-Square	N
4.5250	.0598	14.0000

Regression Model: Student Sample Characteristics

Table B3 presents the results of the "student sample characteristics" multiple regression model. Although the five variables collectively accounted for over 52 percent of the variance, no variables were found to be significant predictors. One variable, school level, approached significance. As the variable was dummy coded, the large, positive Beta indicates that studies employing middle and high school student samples tended to demonstrate greater effect sizes than did those studies employing elementary school samples. These results suggest that the characteristics of students participating in each study was not systematically related to the amount of writing students produced.

Table B3: Regression Analysis of Student Sample Characteristics Variables on Weighted Effect Sizes of Quantity Of Writing

	B	SE	-95% CI	+95% CI	Z	P	Beta
Constant	1.0722	3.3559	-5.5055	7.6498	.3195	.7494	.0000
Prior keyboarding skills	-.1672	3.5419	-7.1094	6.7750	-.0472	.9623	-.0184
Geographic setting	-1.1249	3.7626	-8.4996	6.2499	-.2990	.7650	-.1235
School level	6.9368	3.7644	-.4414	14.3150	1.8427	.0654	.7616

$Q_M = 3.5892$, $p = .3094$

Mean ES	R-Square	N
4.3386	.5264	9.0000

Regression Model: Study Methodology

Table B4 presents the results of the "study methodology" multiple regression model. Although the five variables collectively accounted for 33 percent of the variance, none of the predictors were statistically significant. These results suggest that the various features of the studies were not systematically related to amount of writing students produced.

Table B4: Regression Analysis of Study Methodology Variables on Weighted Effect Sizes of Quantity of Writing

	B	SE	-95% CI	+95% CI	Z	P	Beta
Constant	2.2700	4.1183	-5.8018	10.3418	.5512	.5815	.0000
Publication year	.8193	3.7754	-6.5804	8.2190	.2170	.8282	.0898
Type of publication	-3.1169	4.3803	-11.7023	5.4686	-.7116	.4767	-.3307
Control group design	3.2659	4.7969	-6.1360	12.6678	.6808	.4960	.3617
Pre-post design	2.0379	5.2493	-8.2506	12.3265	.3882	.6978	.2234
Length of study	1.9022	3.9179	-5.7769	9.5813	.4855	.6273	.2086
School level	-.5315	5.3005	-10.9205	9.8574	-.1003	.9201	-.0483
Single or multiple classes	1.2208	4.2170	-7.0445	9.4861	.2895	.7722	.1338

$Q_M = 18.9594$, $p < .0003$

Mean ES	R-Square	N
4.5248	.3294	14.0000

Sensitivity Analysis

When heterogeneity among effect sizes are found in a meta-analysis, the "robustness" of the main findings can be examined through sensitivity analyses (Lipsey & Wilson, 2001). The sensitivity analysis explores ways in which the main findings are either consistent or inconsistent in response to varying the ways in which the data have been aggregated or included in the overall meta-analysis. For example, to provide a sense of how sensitive the main findings are across subgroups (say of school level), sensitivity analyses focus on a particular level of a variable.

A key variable of interest in this analysis is length of study. It can be reasonably argued that in studies of short duration (i.e., six weeks or less) measuring the impact of using computers on students' writing is different than measuring computers' impact on writing over a longer period of time. Studies conducted under longer time periods can result in students who are more adept at keyboarding, are more comfortable with features of word processing programs, and have sufficient time to adapt their writing strategies to exploit features of word processors.

Considering this, a sensitivity analysis was conducted which focused only on those studies for which the length of intervention was greater than six weeks. This selection procedure eliminated six of the fourteen studies from the analysis.

Sensitivity Analysis: Longer Study Duration and Student Support Multiple Regression Model

Due to insufficient variance on the other student support variables, the sensitivity analyses focused on peer editing and keyboard training, only. The resulting model (R^2 = .038) consisting of these two independent variables was statistically insignificant. These statistics indicate that there is no relationship between the weighted effect sizes of quantity of writing and these variables, regardless of length of study.

Sensitivity Analysis: Longer Study Duration and Student Sample Characteristics Multiple Regression Model

As shown in Table B5, the overall student sample characteristics multiple regression model, (excluding student academic ability) was significant (Q_M=18.9594, p=.0003). One variable, school level, was significantly related to the weighted effect sizes. For those studies that lasted for more than six weeks, the significant, positive beta weight for school level indicates that there were larger effect sizes for quantity of writing that favored computers over paper and pencil for studies that occurred in middle and high school as opposed to elementary school.

Table B5: Sensitivity Analysis: Regression Analysis of Student Sample Characteristics Variables on Weighted Effect Sizes of Quantity of Writing for Studies Lasting More Than Six Weeks

	B	SE	-95% CI	+95% CI	Z	P	Beta
Constant	.1617	2.2657	-4.2791	4.6025	.0714	.9431	.0000
Prior keyboarding Experience	.8231	2.9326	-4.9248	6.5710	.2807	.7790	.0796
Geographic setting	.5385	2.6193	-4.5954	5.6724	.2056	.8371	.0521
School level	9.3045	2.9334	3.5550	15.0540	3.1719	.0015	.9020

Q_M=18.9594, p<.0003

Mean ES	R-Square	N
4.0151	.9167	6.0000

Sensitivity Analysis: Longer Study Duration and Study Methodology Multiple Regression Model

The overall "study methodology" model was significant, Q_M =33.1016, $p < .0001$. This model revealed that five study features had significant relationships with the quantity of student writing weighted effect sizes. Curiously, the large negative beta associated with "year of publication" ($p < .0004$) indicates that the findings of those studies conducted between 1992 and 1995, inclusive, had effect sizes more strongly in favor of computers than did the later studies. Also, effect sizes were significantly larger in studies that were published in refereed journals ($p < .006$), incorporated a control group ($p < .0005$), sampled from more than one classroom ($p < .02$) and, in those that did not employ a pre- post-test design ($p <. 006$).

Table B6: Sensitivity Analysis: Regression Analysis of Study Methodology Variables on Weighted Effect Sizes of Quantity of Writing for Studies Lasting More Than Six Weeks

	B	SE	-95% CI	+95% CI	Z	P	Beta
Constant	1.5660	1.5189	-1.4110	4.5429	1.0310	.3025	.0000
Publication year	-10.6699	2.9550	-16.4618	-4.8781	-3.6108	.0003	-1.1902
Type of publication	10.9856	3.9274	3.2879	18.6833	2.7972	.0052	1.2170
Control group design	14.0606	3.9426	6.3330	21.7882	3.5663	.0004	1.5576
Pre-post test design	-24.2968	5.7386	-35.5444	-13.0492	-4.2339	.0000	-2.7913
School level	-2.4444	2.9519	-8.2301	3.3414	-.8281	.4076	-.1873
Multiple v. single classes	6.9256	2.9727	1.0991	12.7522	2.3297	.0198	.7956

Q_M=33.1016, p=.0001

Mean ES	R-Square	N
4.2706	.9707	8.0000

Computers and Writing: Quality

Fifteen independent effect sizes were extracted from 15 studies comparing quality of writing between computer and paper-and-pencil groups. Two additional studies focused specifically on the quality of writing produced on computer, but did not include paper-and-pencil comparison groups. As a result, these two studies were not included in the meta-analyses. Gallick (1997) reported a large positive, but statistically insignificant effect size (d=1.18, 95 percent CI range: –0.78 through 0.2, n=8) in her single-group, pre-post test designed study, and Hood (1994), in a study with the same design, also reported a large positive, yet statistically insignificant effect size (d=1.14, 95 percent CI range: -0.36 through 0.39, n=14).

Another study, conducted by Snyder (1993), included paper-and-pencil comparison groups but did not provide enough statistical data for inclusion in the data analyses. This study reported no mean differences between computerized and paper and pencil groups (n=51), but variance estimates were not provided and could not be calculated based on the reported statistics.

Below we present descriptive highlights of the 15 studies followed by an analyses of effect sizes and regression analyses that explore moderating variables.

Descriptive Highlights

As detailed in Table B7, 60 percent (n=9) of the included studies that focused on the quality of writing were published in refereed journals. Sixty percent of the studies also employed samples drawn from multiple classrooms, 20 percent (n=3) employed random assignment, and for 60 percent (n=9) the research duration lasted between six weeks and one semester. Thirteen of the fifteen studies (87 percent) utilized standardized writing tasks across groups, and in 40 percent (n=6) of the studies, students were provided with keyboarding training. Individual writing (as opposed to collaborative writing) was the focus in all 15 studies. Peer editing was a component in three (20 percent) of the studies, teacher feedback on writing was present in four of the studies (27 percent), and technical assistance was available to students in 27 percent (n=4) of the studies. It was unclear whether or not teacher feedback and/or technical assistance were study features in n=4 and n=9 studies, respectively.

Table B7: Characteristics of Studies Included in Quality of Writing Meta-analysis

Study Characteristics	*n* of studies (%)		
	Refereed journal article	Doctoral dissertation	Master's thesis
Publication type	9 (60.0%)	3 (20.0%)	3(20.0%)
	Yes	**No**	**No information**
Random assignment	3 (20.0%)	12 (80.0%)	—
Pre-Post design	9 (60.0%)	6 (40.0%)	—
Standardized writing sample	13 (86.7%)	2 (13.3%)	—
Keyboarding training included in study	6 (40.0%)	7 (46.7%)	2 (13.3%)
Peer-editing	3 (20.0%)	12 (80.0%)	—
Handwritten samples converted to WP format	3 (20.0%)	12 (80.0%)	—
Technical assistance provided to students	5 (33.3%)	1 (6.7%)	–
Teacher's feedback on provided to students	4 (26.7%)	7 (46.7%)	9 (60.0%)

Sample Characteristics	*n* of studies (%)		
	Yes	**No**	**No information**
Sample described demographically	6 (42.9%)	8 (57.1%)	—
Gender-diverse	5 (33.3%)	1 (6.7%)	9 (60.0%)
Racially/Ethnically diverse	3 (20.0%)	3 (20.0%)	9 (60.0%)
Prior keyboarding skill	7 (46.7%)	2 (13.3%)	6 (40.0%)
	Single	**Multiple**	**No information**
Sampling – school-level	14 (83.3%)	1 (6.7%)	—
Sampling – classroom-level	6 (40.0%)	8 (60.0%)	—
	Less than six weeks	**Between six weeks and one semester**	**One semester or longer**
Length of study	6 (40.0%)	8 (53.3%)	1 (6.7%)
	Elementary	**Middle**	**High**
Grade level	7 (46.7%)	5 (33.3%)	3 (20.0%)

	High	Average	Low	Mixed	No Infor-mation
Student sample ability level	4 (28.6%)	2 (13.3%)	1 (6.7%)	3 (20.0%)	5 (33.3%)
	Rural	**Urban**	**Sub-urban**	**Mixed**	**No Infor-mation**
School setting	2 (13.3%)	3 (20.0%)	6 (40.0%)	1 (6.7%)	3 (20.0%)

In terms of student demographics, only five studies (33 percent) had samples that were documented as gender-diverse, three studies (20 percent) reported racially/ethnically-diverse samples, while 60 percent (n=9) of the studies did not describe the gender or race/ethnic characteristics of the sample. All but two studies (87 percent) focused on mainstream education samples. Forty-seven percent (n=7) of the studies were conducted with elementary school students, 33 percent (n=5) were situated in middle schools, and the remaining 20 percent (n=3) were conducted in high schools.

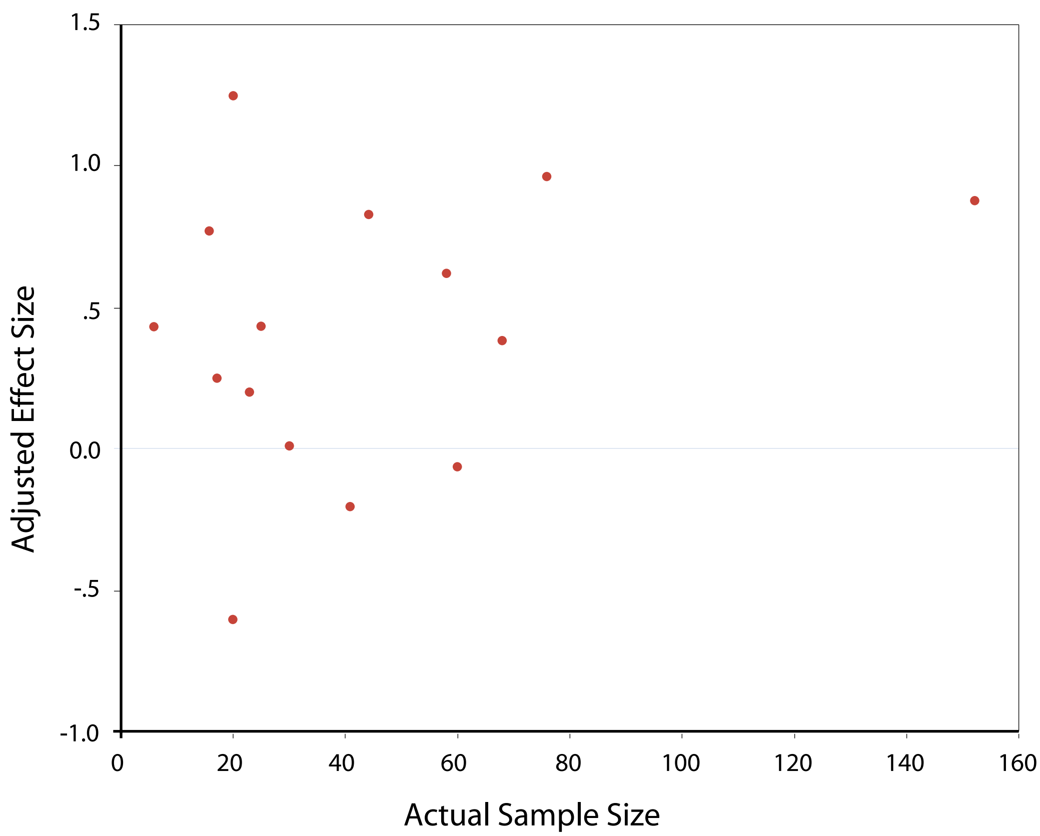
Geographically speaking, the studies were distributed across rural (n=2), urban (n=3), suburban (n=6), and mixed (n=1) settings; three studies lacked any geographic description.

In short, the demographic descriptions of the studies included in this meta-analysis did not appear to differ considerably from those studies included in the "quantity of writing" meta-analysis.

Publication Bias: Funnel Plot

The funnel plot depicted in Figure B2 shows that studies reporting positive effect sizes are distributed across small-to mid-range sample sizes. To a lesser extent, the same is observed for negative and near-zero effect sizes. The variability of effect size in relation to sample size appears more balanced as compared with that seen in the funnel plot for "writing quantity."

Figure B2: Funnel Plot of Quality of Writing Meta-analysis



Weighted Effect Sizes and Homogeneity Analysis

The overall effect of computers, as compared with paper-and-pencil, on quality of student writing, based on 15 independent effect sizes, extracted from 15 studies, resulted in a mean effect size of .501. Inverse variance weighting of each effect size resulted in a weighted mean effect size, d_+=6.030, with a 95 percent confidence interval that ranged from .1369 through .7024. The homogeneity analysis resulted in Q_t=24396.996, df=14, p<.0001. This significant Q_t statistic indicates that the 15 effect sizes included in this analysis do not come from the same population.

To investigate possible moderating variables, regression analyses on the weighted effect sizes and study features followed.

Weighted Effect Sizes and Regression Analysis

As with the meta-analysis for quantity of writing, a mixed effects model was used to explore the extent to which study features moderated the effect of computers on the quality of student writing. For these analyses, study features were dummy coded and examined to assure that sufficient variance existed.

The coded study features that were appropriate for regression analyses were grouped in the following way:

- "student support" which included keyboard training in the study, peer editing, teacher feedback provided, and technical assistance provided
- "student sample characteristics" which included prior keyboarding ability, academic ability, school level, and geographic location; and
- "study methodology" which included type of publication, random assignment, pre-post test design, multiple classes, time of intervention, conversion of handwritten writing samples to computer, and year of study publication.

The regression analysis employing the "study's methodological quality" variable was not a significant predictor of effect size and was again disaggregated.

Study Features with Moderating Effects on Quality of Writing

Regression Model: Student Support in Writing

Table B8 shows the results of the "student support" multiple regression model. In total, the four predictors entered as a single block accounted for nearly 16 percent of the variance. Neither the model as a whole or any of the variables were significant. This finding is consistent with the meta-analysis on "quantity of writing."

Table B8: Regression Analysis of Student Support Variables on Weighted Effect Sizes of Quality of Writing

	B	SE	-95% CI	+95% CI	Z	P	Beta
Constant	4.0030	4.6310	-5.0738	13.0797	.8644	.3874	.0000
Keyboard training	6.2855	7.1000	-7.6304	20.2014	.8853	.3760	.3680
Peer editing	14.4270	14.0833	-13.1762	42.0303	1.0244	.3056	.6896
Teacher feedback	4.7685	8.7855	-12.4512	21.9881	.5428	.5873	.2520
Technical assistance	-13.9250	12.8080	-39.0287	11.1786	-1.0872	.2769	-.7845

$Q_M = 1.4139, p = .8418$

Mean ES	R-Square	N
6.0322	.1559	15.0000

Regression Model: Student Sample Characteristics

Table B9 shows the results of the "student sample characteristics" multiple regression model. Together, the five variables account for 46 percent of the variance in the 'quality of writing' weighted effect sizes, but the model as a whole is statistically insignificant. However, the beta weight for school level was a statistically significant predictor of "quality of writing," ($p < .03$). Greater effect sizes in favor of computer vs. paper-and-pencil writing were found among the studies that took place in middle and high schools as compared with those studies conducted in elementary schools. This is consistent with the findings in the sensitivity analysis for "quantity of writing."

Table B9: Regression Analysis of Student Sample Characteristics Variables on Weighted Effect Sizes of Quality of Writing

	B	SE	-95% CI	+95% CI	Z	P	Beta
Constant	1.4858	5.1358	-8.5804	11.5520	.2893	.7723	.0000
Prior keyboarding	-10.0868	7.3984	-24.5877	4.4142	-1.3634	.1728	-.5959
School level	14.1769	6.5765	1.2869	27.0669	2.1557	.0311	.8375
Geographic setting	7.1541	6.5776	-5.7380	20.0461	1.0876	.2768	.4227

$Q_M = 4.7012, p = .1950$

Mean ES	R-Square	N
8.5397	.4635	11.0000

Regression Model: Study Methodology

Table B10 presents the result of the "study methodology" regression model. Although the model accounts for 43 percent of the variance, both the model and beta weights for each individual variable were not statistically significant. These results are consistent with the findings of the "quantity of writing" analysis.

Table B10: Regression Analysis of Study Methodology Variables on Weighted Effect Sizes of Quality of Writing

	B	SE	-95% CI	+95% CI	Z	P	Beta
Constant	.7500	13.5884	-25.8833	27.3833	.0552	.9560	.0000
Type of publication	-4.5507	9.2025	-22.5876	13.4862	-.4945	.6209	-.2664
Random assignment	9.4191	8.3572	-6.9610	25.7991	1.1271	.2597	.4502
Pre-Post design	3.7035	9.1364	-14.2040	21.6109	.4054	.6852	.2168
Single vs. multiple classroom	4.6590	6.5263	-8.1325	17.4505	.7139	.4753	.2727
Length of study	3.7963	7.5144	-10.9319	18.5244	.5052	.6134	.2222
Handwriting converted to WP format	2.4445	8.5858	-14.3837	19.2727	.2847	.7759	.1169
Publication year	-1.4965	7.1140	-15.4398	12.4469	-.2104	.8334	-.0876

$Q_M = 4.6671, p = .7005$

Mean ES	R-Square	N
6.0328	.4325	15.0000

Sensitivity Analysis

The sensitivity analysis focused on those studies for which the length of intervention was greater than six weeks. This selection procedure eliminated 4 of the 13 studies from the analysis.

Sensitivity Analyses: Longer Study Duration and Student Support, Student Sample Characteristics, and Study Methodology Multiple Regression Models

The multiple regression models were run on the nine studies that had interventions spanning more than six weeks. The peer editing and handwriting conversion variables were excluded due to insufficient variance. The student support multiple regression yielded an insignificant model, Q_M=1.342, df=3, p=.72. The student sample characteristics and study methodology multiple regression models were also found to be statistically insignificant (Q_M=1.963, df=3, p=.58, and (Q_M=4.471, df= 5, p=.484, respectively). This lack of predictive power indicates that the effect sizes included in this study are not significantly moderated by these variables, regardless of study duration time.

Appendix C: Determination Regarding Inclusion

Article Collected	Determination Regarding Inclusion
Albertson, L. R., & Billingsley, F. F. (1997)	Focus on reviewing skills
Allen, G., & Thompson, A. (1994)	Focus on effect of audience on quality
Allison, B. (1999)	WP small part larger intervention, insufficient quantitative data reported
Baker E. & Kinzer, C.K. (1998)	Qualitative
Barrera, M. T., et al. (2001)	Included in meta-analysis
Biesenbach-Lucas, S. & Weasenforth, D. (2001)	ESL focus
Bogard, E. A. (1998)	Design and outcomes not aligned
Borthwick, A. G. (1993)	Review of research
Bowman, M. (1999)	Verbal/collaborative/Vygotsky focus
Bracey, G. (1992)	Not an empirical study
Breese, C., et al. (1996)	Included in meta-analysis
Brigman, D. J. P. (1995)	Included in meta-analysis
Bruce, B. & Peyton, J. K. (1992)	WP small part of larger intervention, case study
Bucci, S. M. (1996)	Not paper vs. computer design: outcome measure was revision of paper written draft on WP after conference
Burley, H. (1994)	WP small part of larger intervention, outcomes not aligned
Butler, S. & Cox, B. (1992)	Qualitative
Casey, J. M. (1992)	WP part of larger intervention, insufficient quantitative data reported
Creskey, M. N. (1992)	Quantitative data not reported
DeFoe, M. C. (2000)	WP part of larger intervention, insufficient quantitative data reported
D'Odorico, L., & Zammuner, V. L. (1993)	Included in meta-analysis
Dodson, L. E. (2000)	WP part of larger intervention, outcomes not aligned
Dybdahl, C. S., et al. (1997)	Included in meta-analysis
Ediger, M. (1996)	Lack of quantitative data
Escobedo, T. H. & Allen, M. (1996)	Emergent writing focus
Fan, H.L. & Orey, M. (2001)	Multimedia focus
Fletcher, D. C. (2001)	Case study on editing process
Freitas, C. V. & Ramos, A. (1998)	Qualitative/Insufficient Quantitative data reported
Gaddis, B., et al. (2000)	Focus on effect of collaboration and audience needs
Gallick-Jackson, S. A. (1997)	WP small part of larger intervention, outcomes not same focus
Godsey, S. B. (2000)	Included in meta-analysis
Greenleaf, C. (1994)	No paper/pencil group
Grejda, G. F. & Hannafin, M. J. (1992)	Included in meta-analysis
Hagler, W. J. (1993)	Included in meta-analysis
Hartley, J. (1993)	Not empirical study

Head, B. B. (2000)	Included in meta-analysis
Hood, L. M. (1994)	Insufficient quantitative data, computer group only
Hydrick, C. J. (1993)	Case study, no quantitative data on outcome measures
Jackiewicz, G. (1995)	Included in meta-analysis
Jackowski-Bartol, T. R. (2001)	Qualitative
Jankowski, L. (1998)	Not empirical study
Jones, I. (1994a)	Same data already included in meta-analysis
Jones, I. (1994b)	Included in meta-analysis
Jones, I & Pellegrini, A.D. (1996)	Included in meta-analysis
Joram, E., & et al. (1992)	Included in meta-analysis
Keetley, E. D. (1995)	Included in meta-analysis
Kehagia, O. & Cox, M. (1997)	Design and outcomes not aligned
Kumpulainen, K. (1994)	Social focus of collaborative writing
Kumpulainen, K. (1996)	Social focus of collaborative writing
Lam, F. S. & Pennington, M. C. (1995)	Included in meta-analysis
Langone, J., et al. (1996)	Included in meta-analysis
Lerew, E. L. (1997)	Included in meta-analysis
Lewis, P. (1997)	Software feature focus
Lewis, R. B. (1998)	Software feature focus
Lewis, R. B., et al. (1999)	Software feature focus
Lichtenstein, N. (1996)	Included in meta analysis
Lohr, L., et al. (1996)	Multimedia focus
Lomangino, A. G., et al. (1999)	Social focus of collaborative writing
Lowther, D. L., et al. (2001)	No data collected on writing quality/quantity
Lund, D. M. & Hildreth, D. (1997)	Case study/Multimedia
MacArthur, C., et al. (1994)	Not an empirical study
MacArthur, C. A. (1996)	Not an empirical study
McBee, D. (1994)	Emergent writing focus
McMillan, K. & Honey, M. (1993)	Insufficient quantitative data reported
Mehdi, S. N. (1994)	Design and outcomes not aligned
Moeller, B., et al. (1993)	Email focus
Mott, M.S. & Halpin, R. (1999)	Multimedia and writing focus
Mott, M. S., et al. (1997)	Not an empirical study
Mott, M. S. & Klomes, J. M. (2001)	Multimedia writing focus
Moxley, R. A., et al. (1994)	Emergent writing focus
Moxley, R. A., et al. (1997)	Emergent writing focus
Nichols, L. M. (1996)	Included in meta-analysis
Olson, K. A. (1994)	Included in meta-analysis
Osborne, P. (1999)	Impact of WP measured by coursework/exams
Owston, R. D., et al. (1992)	Included in meta-analysis
Owston, R. D. & Wideman, H. H. (1997)	No paper/pencil group, focus low vs. high computer access settings

Padgett, A. L. (2000)	Included in meta-analysis
Peacock, M. & Beard, R. (1997)	Described subgroup of 1980–1992 studies
Pennington, M. C. (1993)	Included in meta-analysis
Peterson, S. E. (1993)	Included in meta-analysis
Philips, D. (1995)	Data collected were prior to decade of interest
Pisapia, J. R., et al. (1999)	Outcome measures: test scores
Pohl, V. & Groome, D. (1994)	Not empirical study
Priest, N. B. (1995)	Outcome measures: WP small part of larger intervention; goal attainment
Reed, W. M. (1996)	Review of research
Robertson, S. I., et al. (1996)	Outcome measures: technology knowledge and use
Roussey, J. Y., et al. (1992)	Individual vs. dyad/Vygotsky focus
Roblyer, M. D. (1997)	Not an empirical study
Seawel, L., et al. (1994)	Included in meta-analysis
Shaw, E. L., et al. (1994)	Insufficient Quantitative data reported
Snyder, I. (1993a)	Included in meta-analysis
Snyder, I. (1993b)	Not empirical study
Snyder, I. (1994)	Same data collection as that included in meta-analysis, qualitative view
Waldman, H. (1995)	Multimedia focus
Walker, C. L. (1997)	Revision focus
Wolfe, E. W., et al. (1996)	Included in meta-analysis
Yackanicz, L. (2000)	Qualitative
Zammuner, V. L. (1995)	Research focus: individual vs. collaborative writing
Zhang, Y., et al. (1995)	Hypercard focus
Zoni, S. J. (1992)	WP small part of larger intervention, insufficient quantitative data reported

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