Developmental Analysis of the Effects of CAI on Mathematics Achievement

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Abstract

This meta-analysis examined the research question "What differences exist among the academic achievement levels of mathematics students who were exposed to computer-assisted instruction, and those who were not exposed to this instruction?" Hence, a comparison of the mathematics achievement between students who received either traditional instruction or traditional instruction supplemented with computer-assisted instruction (CAI) was conducted. From the twenty-seven conclusions, an overall mean effect size of 0.236 was calculated, indicating that, on average, students receiving traditional instruction supplemented with CAI attained higher academic achievement than did 59.48 percent of those receiving traditional instruction alone. Moreover, a .094 correlation between effect size years indicates that the effect of CAI on mathematics achievement has slightly increased during this period.

1. Introduction

As more students plan on entering higher education, it is even more imperative that they are prepared for both the national and the international competition of the 21st century [1]. Consequently, an area of emphasis in this endeavor is mathematics achievement, which was made very clear by the Carnegie Task Force [2]. Regretfully, however, there is a shortage of recent inquiry investigating the effectiveness of computer-assisted instruction of (CAI) on the achievement of mathematics students. Subsequently, as students prepare for entry into higher education, it seems that an exploration of CAI on the academic achievement of mathematics students is important [3]. Moreover, it has been established that computers provide students with enjoyable tools for learning and understanding information, thereby improving their academic performance; and CAI positively affects academic achievement, thus this study intends to build on the prior research and earlier meta-analytic conclusions of earlier researchers [4]. There is a kaleidoscope of research showing that students who use technology in the schools benefit from their use [3] However, the research is mixed on which subjects benefit from the use of CAI in the content areas and mathematics is a subject-area of interest in determining the effectiveness of CAI [3] [4].

2. Rationale

Although collected works of literature overflows with research exploring the effectiveness of CAI in education, providing evidence that CAI is a valuable tool in the enhancement of mathematics achievement is needed [5]. To the contrary, however, Clark has criticized research findings that show the effectiveness of CAI in stimulating academic achievement, contending that such findings do not reflect the influence of extraneous variables such as instructional methods, curriculum content, or innovation [6]. In response, Kozma proposed further study on CAI and recommended the meta-analytic investigation of research findings in an effort to minimize the influence of external factors [7]. In compliance with this proposal, the present study is a meta-analysis that will focus on previously conducted research on mathematics achievement comparing CAI to traditional instruction. As a result, this meta-analysis has possibly revealed those areas where contemporary CAI is more, as well as less effective than traditional instruction among mathematics students.

3. Statement of the Problem

The necessity for improving mathematics academic achievement has created an impetus for conducting this meta-analysis of available research pertaining to computer-assisted instruction. This study has focused on the following research questions:

RQ1: What differences exist among the academic achievement levels of mathematics students who were exposed to computer-assisted instruction, and those who were not exposed to this instruction?

RQ2: Is there a significant relationship between the mathematics achievement of students who received only traditional instruction and those who received

 | DOI: 10.20533/ijcdse.2042.6364.2023.0595

traditional instruction supplemented with CAI during consecutive years?

The research evaluated the effectiveness of CAI on student academic achievement across various grade-levels and mathematics content-areas. Moreover, it focused on research that specifically examined the effectiveness of CAI on mathematics achievement. As a result, a determination has been made on where CAI is most and least effective in enhancing academic achievement.

4. Methodology

The compiled data from the studies were analyzed through a meta-analysis, which is a secondary statistical analysis or re-analysis of previous research, used as a vehicle for answering new questions through existing data [8] [9]. In essence, it is a quantitative application of deduction. More specifically, such analysis would have been impossible through any other previously known methodology [10].

The meta-analytic approach used in this study is similar to the method used by Glass et al. back in 1981. Their approach to meta-analysis required the following: (a) locating studies through unbiased and replicable data searches, (b) coding the studies for prominent features, (c) describing each study's outcomes and creating a common scale, and (d) using statistical methods for combining a mixed set of results into a quantified conclusion.

The studies included in this research met the following predetermined criteria:

- they were conducted in mathematics;
- they included quantitative results in which academic achievement was the dependent variable and CAI was the treatment;
- they were of an experimental, quasi-experimental, or correlational research design;
- 4the sample sizes had a combined minimum of 20 students in the experimental and control groups.

Although more than a thousand studies were reviewed, twenty-two publications resulting in twenty-seven calculated effect sizes met the predetermined criteria for inclusion in this meta-analysis. Rejected studies did not meet each of the four selection criteria for inclusion. The majority of those CAI publications that did not meet the criteria for integration into the study did not statistically analyze the reported data.

5. Limitations

Cheung and Slavin criticized previous meta-analyses because of their assignment of equal weights to both methodologically strong and weak, and relevant and less relevant studies, proposing that all future meta-analyses include narrative reviews of those studies that were contained in the results. Hence, in efforts to avoid the contamination of methodologically weak and irrelevant studies while simultaneously finessing the inherent qualitative flaw of subjective selection, this meta-analysis relied on the accuracy of both published and unpublished research results, using CAI as the independent variable, with the dependent variable being mathematics achievement as determined by teacher-assigned grades, commercially-designed standardized tests, locally developed tests, teacher evaluations, or percentile rankings on standardized tests. Again, this meta-analysis included only studies that: (1) used CAI as the independent variable and mathematics achievement as the dependent variable; and (2) met the four predetermined criteria for inclusion.

6. Analysis

As previously mentioned, the data were analyzed through the meta-analysis procedure, a technique that relies heavily on the calculation of effect sizes to establish statistical meaning [11]. According to Glass et al. and Rosenthal, effect size is the degree to which a phenomenon is present in the population of the study [8] [9]. In meta-analysis, effect size is calculated to determine the presence of a statistical difference in mean standard deviation units ($\underline{SD}_x$) [11]. However, such calculation is dependent on the type of statistical method used in the original research design. For example, a multivariate analysis yields an $\underline{F}$ ratio in determining whether the ratio between two or more groups is significant [12]. When only two means are compared, a $\underline{t}$-value is used to determine significance [13]. However, effect sizes can be calculated by incorporating the $\underline{t}$-values, the $\underline{F}$ ratios, or the correlation coefficients ($\underline{r}$) into the effect size equations.

Once the mean effect size was calculated, the relative statistical significance was determined through an effect size classification. The approach used in this study is similar to that used by Cohen (1977), who provided the following ranges for mean effect size interpretations: $\underline{ES}$ = 0.200 to 0.499 = small effect; $\underline{ES}$ = 0.500 to 0.799 = medium effect; and $\underline{ES}$ = 0.800 and above = large effect.

Each study included in this research was reviewed with a design that necessitates the inclusion of each study's sample, location and setting, method, variables, findings, and effect size. All studies meeting these criteria yielded sufficient information for calculating effect sizes.

6.1. Meta-Analysis

Twenty-two publications resulting in twenty-seven effect sizes from over 1,000 studies met the predetermined criteria for this meta-analysis. Table 1 presents the location, sample size, and mean effect size for each study. A total of 2032 students participated in twenty-two studies, which resulted in 27 conclusions. The sample size ranged from 28 to 425, and the mean sample size was 156 students.

Table 1. Subject, Sample Size and Effect Size of Each Study

Author(s)	Subject	n	ES
Bailey, T.E.	Mathematics	46	0.775
Bass, et al.	Mathematics	121	0.414
Bass, et al.	Mathematics	121	0.066
Battista, et al.	Mathematics	48	0.189
Bochniak, J.S.	Mathematics	40	0.510
Brown, F.	Mathematics	101	0.566
Christie, et al.	Mathematics	265	0.108
Davidson, R. L.	Mathematics	54	0.175
Dunn, S. M.	Mathematics	96	0.413
Elliot, E. L.	Mathematics	191	0.114
Ferrell, B. G.	Mathematics	91	0.488
Foster, et. al.	Mathematics	243	0.360
Foster, et. al.	Mathematics	243	0.480
Foster, et. al.	Mathematics	243	0.570
Foster, et. al.	Mathematics	243	0.01
Gambari, et. al.	Mathematics	120	0.623
Klein, et al.	Mathematics	96	-0.061
Manuel, S. Q.	Mathematics	28	-0.073
Marty, J. E.	Mathematics	425	0.293
Ravenel, et. al.	Mathematics	31	-0.327
Salarno, C.A.	Mathematics	80	1.242
Soliman, et. al.	Mathematics	63	0.079
Spradlin, et. al.	Mathematics	99	0.315
Tienken, et. al.	Mathematics	267	-0.751
Wohlegahagen, K. S.	Mathematics	242	-0.378
Wood, J. B.	Mathematics	104	0.081
Wood, J. B.	Mathematics	104	0.077

6.2. Mean Effect Size

The mean effect size calculation across the 27 conclusions of the 22 studies generated by the original authors was 0.236. Although Cohen interprets this effect size as small, the difference in academic achievement resulting from CAI was an improvement of 9.48 percentile ranks from the central region of the distribution. Using this measure, it can be concluded that CAI is probably more effective than traditional methods of instruction in raising overall mathematics achievement.

Again, the current study has provided 27 effect sizes in mathematics, showing that CAI is effective in bolstering the mathematics achievement of students. Cohen classifies this effect as small. Wolf's interpretation of the average effect in SD_x units for the comparison between the traditional instruction group and the CAI group indicates that the average student exposed to CAI showed academic achievement that was greater than that of 59.48% of those students who were exposed to traditional instruction [11]. Moreover, this finding indicates that the typical student moved from the 50th percentile to the 59.48th percentile when exposed to CAI.

6.3. Relationship Between Effect Sizes and Time

A correlation for the data did not reveal that the mean effect sizes and progressive time span (in years), were significantly related, r_s (25) = 0.094, $p = 0.320$. Furthermore, Figure 1 displays a scatterplot showing a low positive correlation between consecutive years and the effectiveness of CAI.

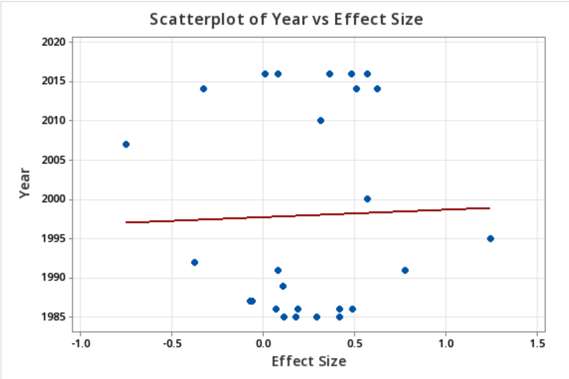

Figure 1. Relationship between mean effect size and years

6.4. Comparing Mean Effect Sizes by Differing Years

Studies included in this meta-analysis were conducted between 1985 and 2016. The 27 effect sizes examined ranged from a low of -0.751 to a high of 1.242. During the thirty-one-year span, the overall mean effect size by year progressively increased, supporting Mason's (1984) belief in the relationship between technological advancement and academic improvement. It is possible that this increase in effect size is attributed to improvements in technological capabilities. It is also possible that the software implementation between 1985 and 2016 in conjunction with more affordable and higher-performance hardware. From 1985 to 2016, microcomputers were rapidly improved through the development of more advanced microprocessors. Interestingly, the calculated effect sizes reflect a upward trend in mathematics achievement during the 1985 to 2016 period.

7. Discussion

Effect sizes. Cohen provides the following ranges for effect size interpretations: ES of 0.200 to 0.499 = small effect; ES of 0.500 to 0.799 = medium effect); and ES of 0.800 and above = large effect. However, Tallmadge reports that an effect size difference of 0.250 or more is considered to be educationally significant. Effect sizes (ES_x) in standard deviation units (SD_x) show the degree of overlap between the control and experimental groups

[14]. Therefore, the percentage of the experimental group exceeds the upper half of the control group, showing the impact of the CAI treatment on academic achievement [11].

Mean effect size. The mean effect size calculation across the 27 conclusions of the 22 studies generated by the original authors was 0.236. Although Cohen interprets this effect size as small, the difference in academic achievement resulting from CAI was an improvement of 9.48 percentile ranks from the central region of the distribution. Using this measure, it can be concluded that CAI is probably more effective than traditional methods of instruction in raising overall mathematics achievement.

Again, the current study has provided 27 effect sizes in mathematics, showing that CAI is effective in bolstering the mathematics achievement of students. Undoubtedly, there are many other instructional factors that positively affect student learning outcomes of mathematics students. More specifically, Gall, Borg, and Gall show the relative effectiveness of eight instructional factors on student performance [10] (see Table 2).

Table 2. Instructional Factors that Influence Learning

Instructional Factor	Effect Size
Cooperative learning	0.760
Instructional time	0.380
Home environment	0.370
Higher-order questions	0.340
Individualized instruction	0.320
Socioeconomic status	0.250
Sequenced lessons	0.240
Class size	0.090

7.1. Reliability and Literature Searches

It is generally accepted that many research journals select and publish studies that report only the positive effects of CAI. Hence, such publication biases may have increased the effect sizes found in this meta-analysis. Furthermore, certain methods of statistical analysis compute results that do not reflect actual effect sizes [11]. Nevertheless, this meta-analysis has attempted to describe the research results found; however, determining the true effect size of a treatment is very difficult, especially when the inadequacy of reported data prevents utilization of the definitional formula for every effect size calculation in the meta-analysis. Also, means and standard deviations are essential for the most accurate estimates of effect sizes. Cohen recommends that effect sizes appear in every report; regretfully, however, this is not always the case [15].

8. Conclusion

The study focused on a comparison between the academic achievement effects of CAI and traditional methods of instruction. Although this meta-analysis indicates that CAI is an effective intervention for improving mathematics students' academic achievement, further research is needed to predict and explain how CAI can become a more effective instructional tool.

8.1. Questions of External Validity

The findings reported in this article include studies that have been conducted to date and that were possible to retrieve. Obviously, this study does not include research that was not published or presented; according to Glass et al. (1981), using only published research in a meta-analysis can inflate the mean effect size. Yet, Glass et al. observed that this potential bias can be eliminated by including unpublished research in a meta-analysis. Therefore, eight dissertations (ESx = 0.248) were included in this meta-analysis in an effort to reduce potential publication bias.

8.2. Suggestions for Future Research

Obviously, some educational researchers feel responsible for developing ways to bolster academic achievement and determine how students best learn using CAl. However, such research has previously been restricted to controlled environments, which may not adequately explain the total dynamics of what occurs in natural settings. Qualitative research methods, such as ethnography, could help researchers construct meanings and better determine when students grasp information or become confused during CAl activities.

For example, when comparing the effectiveness of computer use to that of more traditional instructional methods, this research shows a favorable basis for integrating CAI into course instruction. Perhaps the novelty of newer technologies continues to motivate teachers and students in classrooms globally. Whatever the case, researchers need to continue to determine which instructional methodologies best influence learning.

Hence, future researchers should generate research pertaining to why CAI helps some students learn in some areas better than in others. Therefore, such research could explain how CAI might enhance specific types of learning, singularly or in collaboration with other educational interventions. For example, such research could possibly disclose how CAI in conjunction with higher-order questions could affect better comprehension of mathematics' content. Again, however, it is essential that the effects of CAI on areas beyond mathematics academic achievement be explored.

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