Educational Sciences: Theory & Practice • 14(5) • 2026-2035

www.edam.com.tr/estp
DOI: 10.12738/estp.2014.5.2311

Effectiveness of Computer-Assisted Mathematics Education (CAME) over Academic Achievement: A Meta-Analysis Study*

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Abstract

The aim of the current study is to determine the overall effects of Computer-Assisted Mathematics Education (CAME) on academic achievement. After an extensive review of the literature, studies using Turkish samples and observing the effects of Computer-Assisted Education (CAE) on mathematics achievement were examined. As a result of this examination, statistical data was combined from 40 studies which met the inclusion criteria and they were coded using a coding form. An inadequate number of studies held on the topic of meta-analysis of educational research proves the importance of this study, for it makes it possible for one to see the overall effects of the methods carried out in studies as well as their application. In the current study, the Random Effect Model was used since the included studies ranged in terms of both study design and variables. After calculating the common units of measurement, effect size, and variance, Q statistics were used to test the homogeneity of studies both overall and within the design levels for each selected variable. I^2 statistics were calculated to determine the degree of heterogeneity when effect sizes were statistically and significantly heterogeneous ($Q_B > X^2.95$; $p < .05$). MetaWin 2.0 and SPSS 15.0 package software were used in analysis of the data. As a result of the current study, it was observed that the effect of CAME on academic achievement is positive in general, and on a large scale ($Q_T = 30.1670$; $p = .8439$). Moreover, it was concluded that the effect sizes of the studies included in this research are homogeneous. Fail-Safe N was calculated using the Rosenthal method and revealed a value of 902.2, showing the reliability of the study, a combination of 40 studies, to be quite high.

Keywords

Academic Achievement, Computer Assisted Education (CAE), Computer Assisted Mathematics Education (CAME), Mathematics Achievement, Meta-analysis.

In recent years there have been significant changes in both mathematics and mathematics education. Education now aims to teach not only pure knowledge but also continuous learning, critical thinking, questioning, innovation and keeping up with innovations. Similarly, mathematics education aims to raise people who know not only pure mathematics but also how to study mathematics, solve problems, communicate, make realistic plans and get pleasure from doing these things.

* This research is a part of first author's master thesis.

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Therefore, the requirements of mathematics have been gradually increasing since it forms a basis for science and improves the ability to think (Akgül, 2008).

The topic of the research is a meta-analysis of the studies in Turkey about the effects of computer-assisted education on mathematics achievement. The number of scientific studies held in Turkey on the effects of computer-assisted education on mathematics achievement has been rapidly increasing, and each of these studies has a different effect size. Since effect size has positive and negative ranges, research methodologies, and population and sample variations among studies, it is difficult to get an overall result. This makes it necessary to run a meta-analysis research on this topic. Considering all of these points, the main aim of the current study is to learn the effects of "Computer-Assisted Education" (CAE) on academic achievement. There are many studies in the literature that compare CAE with other teaching techniques. Kulik, Kulik, and Bangert-Drowns (1985), analyzed about 200 studies comparing CAE to traditional teaching and concluded that CAE increases student achievement by 20%. However, Clark (2005) disagrees with the results of Kulik et al. by claiming that most of the differences with student achievement result from different teaching design and application methods. In the literature, there are many studies on the effect of "Computer-Assisted Mathematics Education (CAME)" on academic achievement in different education levels, especially in the primary, secondary, and high school levels. The studies of Mevarech and Rich (1985), Öztürel (1987), Sezer (1989), Xin (1999), Efendioğlu (2006), Pilli (2008), and Uygun (2008) are on students in primary school. The studies of Kirnik (1998), Brown (2000), Sulak (2002), Aktümen and Kaçar (2003), Özdemir and Tabuk (2004), Üstün and Ubuz (2004), Kurt (2005), Tienken and Wilson (2007), Egelioğlu (2008), Çamlı and Bintaş (2009), Budak (2010), Helvacı (2010), Li and Ma (2010), Şataf (2010), İçel (2011), and Selçik and Bilgici (2011) are on students in secondary school. The following studies are also on students in primary school: Bayraktar (1988), Genel (1998), Kutluca, (2009), and Bayturan (2011). Additionally, the studies by Hartley (1977), Kulik (1983), Kulik and Kulik (1987), Kulik and Kulik (1991), and Camnalbur and Erdoğan (2008) are meta-analysis studies about the effects of CAE on academic achievement. Moreover, books by Baki (2002), Arı and Bayhan (2003), and Olkun and Toluk-Uçar (2006) are a few of the reference books on the effects of CAME on academic achievement.

As a result of an extensive literature survey, to the best of our knowledge there are no meta-analysis studies conducted in Turkey which question the effects of CAME on academic achievement. In the current study, several studies analyzing the effects of CAME on academic achievement were combined via the meta-analysis method and it was intended to produce a measure of effect size to indicate the overall effect of CAME on academic achievement. Meta-analysis studies enable researchers to conclude some scientific generalizations by synthesizing the results of different studies (Akgöz, Ercan, & Kan, 2004; Şafak, 2008). Meta-analysis is a method that systematically summarizes a bunch of studies on a certain topic with the help of statistical methods (Başol-Göçmen, 2004a). With the help of the techniques developed by Glass, McGraw, and Smith (1981), Hedges and Olkin (1985), Hunter, Schmidt, and Jackson (1982), and Rosenthal (1984), in the 1980's many meta-analysis studies were conducted on different fields. In meta-analysis, information obtained from previous studies is used and a sample is generated from the samples of the previous studies (Tarım, 2003). According to Kavale (2001), one can make rational decisions by using the results of meta-analysis studies.

In this meta-analysis study, the following question will be answered: "What is the overall effect of computer assisted mathematics education on academic achievement?" Moreover, whether the effect of CAME on academic achievement differs according to the characteristics of the study will be investigated.

Computer Assisted Education (CAE)

The method of making good use of computers in the education process is called "Computer Assisted Education (CAE)." Students learn their deficiencies and performance through mutual interaction, control their learning by getting feedback, and become more interested in classes with the help of graphics, sounds and animations (Rushby, 1989; Uşun, 2000). Aşkar (1991) stated that computers have an undeniable role in realizing the top level targets. Similarly, according to Keser (1988) one of the most distinctive features of computers in the education-treatment process is that it focuses on the students.

Computer Assisted Mathematics Education (CAME)

Mathematics education using cognitive devices dependent on computers is called "Computer-

Assisted Mathematics Education (CAME)." Displaying abstract mathematical concepts and the ability to make them concrete is the most remarkable use of CAME (Baki, 1996; Özdemir & Tabuk, 2004). One can say that the most efficient way is to make the best use of computers while raising individuals with top level cognitive talents (Altun, Uysal, & Ünal, 1999). Dis-proportionality between teachers-student ratios and an increased importance on individual diversity direct people to make use of educational computers (Uşun, 2000). Computers and software are the biggest supporters of education and must be used to increase the curiosity of students as well as help them understand mathematics easily (Heddens & Speer, 1997; İçel, 2011). The two main important forms included in the software are "Computer Algebra Systems (CAS)" and "Dynamic Geometry Software (DGS)" (Şataf, 2010).

Academic Achievement

According to Wolman (1973), achievement means "to go further towards an intended destination." Academic achievement is the interpretation of knowledge gained in school in terms of grades and test scores (Carter & Good, 1973). Intended achievement in mathematics is possible by learning the subjects deeply (Baykul, 1999). Papanastasiou (2002) found out that the physical condition of a school is a crucial factor on the mathematics achievement of students. The first meta-analysis study on the effects of CAE on students was conducted by Hartley (1977) in which it was stated that CAE increases student achievement from 50% to 66%. Kulik (1983) carried out a meta-analysis study in which he identified that CAE is more effective on the variables of achievement and attitude compared to traditional education. Frequently used variables in both national and international studies on CAME are achievement, attitude, retention level, motivation, as well as student and teachers' views. According to the results of the studies on CAME, one can observe that it has a positive effect on these variables (Aktümen & Kaçar, 2003; Bayraktar, 1988; Brown, 2000; Ersoy, 2009; Güven, 2002; Helvacı, 2010; İçel, 2011; Kutluca, 2009; Lesh, Guffey, & Rampp, 1999; Li & Ma, 2010; Mevarech & Rich, 1985; Nan, 1994; Özdemir & Tabuk, 2004; Öztürel, 1987; Palmer, 2009; Pilli, 2008; Selçik & Bilgici, 2011; Sezer, 1989; Sulak, 2002; Üstün & Ubuz, 2004). On the other hand, there exist studies in the literature that state CAME has no significant effect on academic achievement (Bağçıvan, 2005; Katz & Yablon, 2003; Kirnik, 1998; Kula & Erdem, 2005; Steele, Batista, & Krockover, 1983; Tanaçan, 1994; Zhang, 2005). Moreover, in studies by Kulik and Kulik (1987), Funkhouser (2002), Uygun (2008), Budak (2010), Şataf (2010), and Bayturan (2011) it is declared that CAME significantly increases academic achievement but has no significant effect on a student's attitude towards mathematics.

Method

In this research, the literature review method of meta-analysis was used. Glass (1976) was the first to name such research as "meta-analysis". The main reason for preferring the meta-analysis method is to obtain a comprehensive result by combining existing studies in the literature rather than conducting an individual study on the topic. When the number of studies on a topic increases, so does the range of study methodologies (Başol-Göçmen, 2004b). Thus, reasons for using the meta-analysis method are as follows:

- Studies result in differentiating effect sizes
- Study designs having methodological differences

To this end, the quantitative data of the available studies that satisfy the inclusion criteria were conjoined with a statistical process, and their meta analytical effect sizes were calculated.

Meta-Analysis

As Glass (1976) suggested, meta-analysis is used to summarize different research results on a topic by using the quantitative research synthesis method (Başol-Göçmen, 2004a, p. 3). According to another definition, meta-analysis is a technique which combines the results from several studies with the help of one or more statistical methods and produces more information (Hedges & Olkin, 1985). Moreover, meta-analysis can be considered as gathering the results of many scientific studies in order to make a generalization (Lipsey & Wilson, 2001). Meta-analysis makes it possible to compare the results of different studies according to a common unit of measurement and calculate the effect sizes with the help of statistical techniques (Rudy, 2001). The *implementation steps* of meta-analysis are (Durlak, 1995): *(i)* defining the research problem, *(ii)* aims and goals, *(iii)* literature survey, *(iv)* coding the studies (via coding form), *(v)* calculating the effect sizes, *(vi)* statistical analysis, *(vii)* results, comments and reporting.

Effect Size

Meta-analysis requires a representation of scientific studies in terms of effect sizes. According to Cohen's *d*, "effect size" can be expressed as the frequency of existence of a phenomenon in a population and it is first considered in the literature in 1978. Cohen (1988) defined effect sizes as small (d = .2), medium (d = .5), and large (d = .8). Glass (1976) defined his own effect size measurements as *g*. When calculating Cohen's *d*, the difference between the means of the experimental and control groups is divided by the standard deviation of one of the groups ($d = \frac{\overline{X_E} - \overline{X_C}}{S_E \,/\, S_C}$), for Glass's *g*, the difference is divided by the standard deviation of the control group ($g = \frac{\overline{X_E} - \overline{X_C}}{S_C}$). In addition to these effect size measurements, in the books on meta-analysis by Cooper (1984), Hunter and Schmidt (1990), and Rosenthal (1991) different formulas for calculating the effect sizes for given values of *t* and *F*, or *r* are proposed (Başol-Göçmen, 2004a).

Choice of Statistical Model

As studies included in this research show diversity in terms of study design and variables, thus being heterogeneous, the random effect model was chosen as the most appropriate model (Borenstein, Hedges, Higgins, & Rothstein, 2010; Cooper, 2010; Lipsey & Wilson, 2001).

Data Collection Method

In this meta-analysis study, only experimental and quasi-experimental studies existing in the literature that analyzed the effect of CAE on mathematics achievement were considered. Out of these studies, 40 of them (4 PhD theses, 16 master's theses, 17 articles, and 3 technical/congressional/symposium reports) were selected as the research sample, as they satisfied the inclusion criteria. They were then combined using the meta-analysis method.

Inclusion and Exclusion Criteria

According to Wolf (1986) and Lipsey and Wilson (2001), studies that will be included in a meta-analysis study should be related to the research subject and should contain statistical data necessary for analysis. Inclusion criteria for this meta-analysis study are as follows:

- The experimental or quasi-experimental study should be related to the CAME subject.
- Sample of the study should consist of students with education levels in preschool, primary school, secondary school, high-school, or college.
- The study should analyze the effect of CAME on academic achievement.
- The study should be conducted in Turkey.
- The study should contain sufficient data (mean, standard deviation, population sizes of experimental and control groups) for calculation of the effect size.
- If the study does not report any effect size, it should reveal some parametric statistics such as "*t*" and "*F*" test results, "Mann Whitney *U*" or "*r*" values, and mean and standard deviations.

The studies with only qualitative findings were excluded from the current study due to insufficient data to calculate the effect size.

Coding Form

A self-evident and detailed coding form was developed for the studies included in the meta-analysis. This coding form is composed of six main headings: *identification of the study*, *content of the study*, *inputs of the study*, *outcomes of the study, outcome statistics of the study* and *all the variables given in the study*.

Dependent Variables

The dependent variables of this meta-analysis study are the calculated effect sizes based on the mathematics achievement scores in each study.

Independent Variables

In a meta-analysis study, independent variables are called study characteristics. Independent variables obtained from the studies that are considered in the meta-analysis are included in the coding forms as they will be used in the evaluation of the effect sizes. The independent variables of the current meta-analysis are: *(i)* year, *(ii)* publication type (master's thesis, PhD thesis, article, technical/congressional/symposium report), *(iii)* school type(public / private school), *(iv)* grade level, *(v)* region/province where the study was conducted, *(vi)* subject lesson (mathematics/geometry), *(vii)* usage of specialized software, *(viii)* usage of worksheet, *(ix)* usage of educational computer games, *(x)* usage of distance learning, *(xi)* weekly teaching periods, *(xii)* total teaching periods (in weeks), *(xiii)* assignment of homework/projects, *(xiv)* sample size, *(xv)* gender distribution in the sample, *(xvi)* study design, *(xvii)* method used in the study, and *(xviii)* employed measures in the study.

Data Analysis

The statistical data, presented in the studies included in the current meta-analysis study were converted into Hedges' *d* effect size, which is a common unit of measure. The formulas to be used with mean, standard deviation, *t*, *F* or *r* values, the formulas used for calculating variance and standard error (Field, 2005; Rosenberg, Adams, & Gurevitch, 2000), and the formulas to be employed when the Mann Whitney "U" was given (Corder & Foreman, 2009) were determined and used in the analysis. In the meta-analysis of the data obtained from the included studies, MetaWin Version 2.0 (Statistical Software for Meta-Analysis) was used. Effect sizes, ranging from -∞ to +∞, that were obtained from the calculations were interpreted as the follows (Cohen, 1988):

- Zero (0) value means that there is no difference between the experimental and control group.
- A negative (-) result means the control group had higher scores, thus the method used has a negative effect.
- A positive (+) result means the experimental group had higher scores, thus the method used works well.

"In order to apply the tests that were used in the statistical studies, the distribution should be normal or approximately normal" (Kalaycı, 2010, p. 53). In order to see the resemblance between a normal distribution and the distribution of the effect sizes realized by the current study, the descriptive statistics and *z* values obtained by SPSS 15.0 software according to Hedges' *d* effect sizes and weighted histograms as well as the Q-Q plots of the normal distribution produced by MetaWin 2.0 software were analyzed.

Homogeneity Test: *Q* Statistic – The Degree of Heterogeneity: I^2 Statistic

In current study, a homogeneity test was implemented using MetaWin 2.0 software through the *Q* statistic method. As a result of the calculations, when the effect sizes were statistically heterogeneous ($Q_B > \chi^2_{.95}$; $p < .05$), the hypothesis on homogeneity of the effect sizes is rejected (Gavakhan, Moore, & McQay, 2000). I^2 statistic, which is the complementary of the *Q* statistic, is useful as it determines the degree of heterogeneity (Huedo-Medina, Sanchez-Meca, Marin-Martinez, & Botella, 2006). The I^2 statistic represents the percentage ratio of heterogeneity of the study variables in relation to the total variability in effect sizes (Carter, 2012).

$$I^2 = \begin{cases} \frac{Q-(k-1)}{Q} \, . \, 100\% & Q > (k-1) \text{ ise} \\ 0 & Q \leq (k-1) \text{ ise} \end{cases}$$

Results

Descriptive Data

In the current study, the statistical confidence interval of the included researches was assumed to be $p = .05$. The total sample size of the current study was 5623; sample sizes of the experimental and control groups were 3002 (53.34%) and 2621 (46.66%), respectively. If all 40 studies included in the current study are examined, the following majority statistics are obtained: performed in 2011 (20%), article (42.5%), master's thesis publication (40%), public school (82.5%), secondary school education level (50%), in the Central Anatolia Region (25.0%) and the Black Sea Region (25.0%), in the subjects of mathematics (% 52.5) and geometry (42.5%), specialized software used (55.0%) and not used (45.0%), worksheet used (27.5%) and not used (72.5%), educational computer games were used (15.0%) and not used (85,0%), distance learning is used (5.0%) and not used (95.0%), weekly four-hour lectures (27.5%) were dedicated to CAE, total CAE application time was two weeks (22.5%), and homework/projects were assigned (5.0%) and not assigned (95.0%).

Disjoint Findings of Included Studies' Effect Sizes Analyses

For each study, Hedges' *d* effect size, standard error and variance values were calculated according to the data obtained from the included studies. These values form a basis for further calculations. When the calculated effect sizes were inspected, it was observed that 37 of the studies (92.5%) had positive effect sizes. If the effect size is positive or negative, this means that the inspected performance affects the effect size (Wolf, 1986). Thus, it can be concluded for the corresponding study that CAME has a positive effect on increasing the academic achievement. According to the calculated effect sizes, 32 of the studies (80%) had extensive effect sizes (Cohen, 1988). As a result of the descriptive statistics of effect sizes, the minimum and maximum effect sizes were -.3345 and 2.5885, respectively. Moreover, it can be concluded that the effect sizes of the studies included in the meta-analysis have approximately normal distribution since skewness and kurtosis coefficients were calculated to be .435 and .410 respectively, and the z values obtained ranged from -1.94 to +2.54. Furthermore, as the points in the effect sizes' normal Q-Q plot lie approximately on the confidence interval along the line X = Y, one can conclude that the effect sizes of the included studies had negligible deviations and approximately normal distribution (Rosenberg et al., 2000). According to these results, it is convenient to combine the studies included in this meta-analysis.

Effectiveness of CAME of the Random Effect Model

According to the results of the random effect models based on the data obtained from the 40 studies included in this research, with a .1032 standard deviation and a 95% confidence interval, .6687 as the lower bound and 1.1311 as the upper bound, the average effect size was calculated as ES = .8999. This means that CAME raises academic achievement in mathematics by .90 standard deviations. As a result of the homogeneity test conducted to see the homogeneity of the effect sizes of the included studies, the Q statistic was calculated as Q_T = 30.1670. As this value is insignificant (p = .8439), the null hypothesis of homogeneous effect sizes was obtained. Thus, effect sizes of the included studies have homogeneity. Accordingly, one can conclude that variability in the Hedges' d effect sizes can only be caused by sampling errors.

Effectiveness of CAME of the Studies on Applied by Region

If the included studies are grouped in accordance with the region they were conducted, it can be observed that the maximum and minimum effect sizes were obtained in the groups from the Aegean and Mediterranean region, respectively. Besides, the Q_B statistic, observed as a result of the homogeneity test of chi-square distribution calculated with a 0.05 confidence interval and five degrees of freedom(Q_B = 13.2191; p = .0162), reveals that the current study is statistically heterogeneous. Consequently, the effect of CAME on academic mathematics achievement has significant variability with respect to the regions of implementation. Moreover, as a result of I^2 statistics, it was observed that heterogeneity of the regions where the studies were implemented represents 62.1759% of the total variability in the effect sizes.

Discussion

According to the results of the current study, an average scoring student in a population with a normal distribution of academic achievement scores is more successful than 82% of the students where CAME is not applied. In other words, an average scoring student (in the 50th percentile) rises to the 82nd percentile after the application of CAME. Thirty-seven of the included studies have positive effect sizes. Common effect size is also large according to Cohen's classification scheme (1988). Thus, CAME has a positive and extensive effect on academic achievement. Moreover, as the confidence interval of the effect size does not contain zero, we can conclude that the positive effect of CAME on academic achievements is statistically significant. This result is consistent with the results of many national and international studies (Aktümen & Kaçar, 2003; Anderson, 2000; Bayraktar, 1988; Bayturan, 2011; Brown, 2000; Budak, 2010; Çamlı & Bintaş, 2009; Efendioğlu, 2006; Egelioğlu, 2008; Genel, 1998; Helvacı, 2010; İçel, 2011; Kirnik, 1998; Kutluca, 2009; Lesh et al., 1999; Li & Ma, 2010; Mevarech & Rich, 1985; Özdemir & Tabuk, 2004; Öztürel, 1987; Pilli, 2008; Poole, 1995; Selçik & Bilgici, 2011; Sezer, 1989; Sulak, 2002; Şataf, 2010; Tienken & Wilson, 2007; Uygun, 2008; Üstün & Ubuz, 2004; Xin, 1999). In spite of the studies that support the results of this meta-analysis study, in the studies of Steele et al. (1983), Tanaçan (1994), Bağçıvan (2005), Kula and Erdem (2005), Zhang (2005), and Palmer (2009), it was stated that CAME does not have a significant effect on academic achievement. CAME has a positive effect on academic achievements with respect to all study characteristics. As a result of homogeneity tests being performed separately according to the random effect model, it can be observed that the studies have statistically significant heterogeneity only with respect to their regions and when the I^2 statistic is calculated. In the meta-analysis of Camnalbur and Erdoğan (2008) on CAE, it was concluded that effect sizes are insignificant to education, and Kablan, Topan, and

Erkan (2013) observed in their meta-analysis study on the usage of materials in class that effect sizes are the same for different subjects. These results are also analogous to the results of the current study.

The fail safe number for the meta-analysis was calculated to be 902.2 according to the Rosenthal method and 140.0 according to the Orwin method. This means that, in order to invalidate the results of the current study, according to Rosenthal, there should be at least 902.2 (or for Orwin, 140) studies that conflict with the findings of the current study. These results strengthen the reliability of the outcomes of this meta-analysis study.

The usage of specialized software increased the positive effect of CAE on mathematics achievements. Due to this result, it is possible to propose the usage of CAE in every level of the education system. When studies on the effects of CAE on mathematics achievement are considered, it is observed that the samples are mostly selected from large cities. Existence of new studies with different samples may increase the reliability of the results of further meta-analyses. It can be proposed to researchers on this subject that they study the effects of CAME on consistency in learning, or some factors like attitude, anxiety, and motivation. Moreover, it is possible to perform meta-analyses on the effects of CAE on academic achievement in different subjects.

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