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THE DIFFERENTIAL LEARNING ACHIEVEMENTS OF CONSTRUCTIVIST TECHNOLOGY-INTENSIVE LEARNING ENVIRONMENTS AS COMPARED WITH TRADITIONAL ONES: A META-ANALYSIS*

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ABSTRACT

Different learning environments provide different learning experiences and ought to serve different achievement goals. We hypothesized that constructivist learning environments lead to the attainment of achievements that are consistent with the experiences that such settings provide and that more traditional settings lead to the attainments of other kinds of achievement in accordance with the experiences they provide. A meta-analytic study was carried out on 32 methodologically-appropriate experiments in which these 2 settings were compared. Results supported 1 of our hypotheses showing that overall constructivist learning environments are more effective than traditional ones (ES = .460) and that their superiority increases when tested against constructivist-appropriate measures (ES = .902). However, contrary to expectations, traditional settings did not differ from constructivist ones when traditionally-appropriate measures were used. A number of possible interpretations are offered among them the possibility that traditional settings have come to incorporate some constructivist elements. This possibility is supported by other findings of ours such as smaller effect sizes for more recent studies and for longer lasting periods of instruction.

For the last three decades numerous kinds of technology-intensive learning environments have been developed and their effectiveness repeatedly compared

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with that of more traditional settings (Bayraktar, 2001/2002; Hong, 1973; Kulik & Kulik, 1991; Kulik, Kulik, & Bangert-Drowns, 1985; Liao, 1998). Most of these comparisons employed standard criteria by means of which learning achievements of both kinds of learning environment were studied. The evaluation criteria and the achievement measures were usually common to both kinds of learning environment, thus overlooking the possibility that due to their inherent differences, these qualitatively different kinds of learning environment are likely to serve qualitatively different learning goals and outcomes. The use of the same achievement measures is therefore a search for the lowest common denominator which may possibly mask important differences in the kinds of learning outcomes attained. The much too frequent finding of "no significant differences" (e.g., Russell, 1999) may well be the result of the employment of undifferentiated measures. Indeed, when differential measures were used, measures that tap the unique elements of each learning environment, also differential findings of achievement emerged. In a comparison between the more exploratory, team- and problem-solving based *Jasper* learning environment and a more traditional one (Biswas, Schwartz, Bransford, & Teachable Agents Group at Vanderbilt University, 2001) the researchers found that the former served best problem solving achievements whereas the latter served best the goal of computational skill.

More specifically, it can be argued that qualitatively different kinds of learning environment are based on different assumptions concerning the nature of learning, are guided by different rationales and offer dissimilar learning-related activities and experiences. To the extent that these are indeed different from each other, to that extent will the learning outcomes be qualitatively different (Salomon, 2002). In light of this logic, the idea of comparing different learning environments by using common rather than differential criteria, would seem to be conceptually unsatisfying and empirically misleading.

The purpose of the present study was to test the above assertion through a meta-analysis of comparative studies. Toward that end, the learning attainments of constructivist technology-intensive learning environments (CTILEs) were compared with those of more traditional, didactic ones. The differential effects of the learning environments were computed on the basis of a meta-analysis of studies that carried out such comparisons and employed differential outcome measures that corresponded to the rationales, activities and experiences of the learning environments under study.

THE DIFFERENTIAL NATURE OF LEARNING ENVIRONMENTS

Two classes of learning environment were compared in the present meta-analytic study: Technology-intensive, constructivist-oriented mathematics learning environments, and traditional ones. According to the constructivist approach, which is the basis of typical technology-intensive learning environments, learning is a process by which knowledge is actively constructed by the learners, who are often actively engaged in problem-solving teams (Prawat & Folden, 1994), guided, rather than didactically taught by their teachers and equipped with a variety of computerized tools. This practice differs from the traditional approach the essence of which is the transmission of mathematical knowledge from teacher to student (Perkins, 1992).

More specifically, CTILEs are designed to cultivate self-guided and team-based problem solving abilities (e.g., Hickey, Moore, & Pellegrino, 2001), higher order thinking skills (e.g., Hopson, Simms, & Knezek, 2001-2002), and participatory teamwork (e.g., Shyu, 1999), through active exploration, problem solving, and critical thinking (e.g., Ryser, Beeler, & McKenzie, 1995). All these constructivist learning objectives share the assumption that real understanding of mathematics can be achieved when learners socially appropriate and actively constructs knowledge.

On the other hand, more traditional learning environments are designed to allow for the transmission of knowledge from teachers to students, to cultivate skills of disciplined math learning and computing skill (e.g., Buzin, 2001). Thus traditional learning objectives in math education which are typical of a traditional learning environment, appear to cultivate the following: Mathematics computation and accuracy (Buzin, 2001; Dalton & Hannafin, 1988); ability to solve problems as understood in a traditional manner such as the development of problem-solving skills (Ball, 1988); word math problems and effective use of equations (Blume & Schoen, 1988); and achievement on a basic standard math skills test (e.g., Borton, 1988). The common denominator of all these traditional learning objectives is to provide basic math knowledge and skills under conditions of traditional drill and practice learning (e.g., Gellert, 2004).

A number of comparative studies in the field of math education used different measures in accordance with these differences of rationale and purpose. These studies served as the basis for the current meta-analysis. The main objective of the present meta-analytical study was to examine the extent to which different learning environments contribute differentially to the achievement of different goals in mathematical education. More specifically, this research undertook a comparative analysis on the basis of constructivist and traditional criteria in two learning environments: CTIL and traditional.

The statistical analysis was conducted according to the meta-analytic approach (Glass, McGaw, & Smith, 1981; Hedges & Olkin, 1985) of comparative studies existing in the field of mathematics education. This system of analysis enables the reevaluation of the findings in existing research through an inclusive quantitative approach. The "subjects" are 32 studies that meet the criteria set in this study.

The following hypotheses were tested in the current meta-analysis:

1. Math students in CTILEs show higher learning achievements when tested against constructivist-appropriate criteria, as compared to students in more traditional learning environments.

2. Math students in traditional learning environments show higher learning achievements when tested against traditionally-appropriate criteria, as compared to students in more constructivist learning environments.

In addition, the present study also examined the effects of certain methodological characteristics: a) grade level; b) duration of treatment; and c) year of publication. Grade level and duration of treatment included in the present study as potential variables affecting the effectiveness of both learning environments. The examination of the publication year may be of interest as the sophistication of measuring devices and methodological rigor change over time.

METHOD

Procedure

The present meta-analysis followed the steps set out by Glass, McGaw and Smith (1981) as follows:

1. *Identifying the research problem*: Investigating the learning achievements of CTILEs vs. those of traditional learning environments as they serve different educational objectives that are unique to each of the environments.
2. *The screening stage*: Locating relevant studies that meet the following conditions:
   - The studies are experimentally designed, entailing experimental and control groups;
   - The experimental group is engaged in learning math in a CTILEs setting whereas the control group studied math in a traditional way. We classified each study by its characteristics (constructivist-appropriate or traditionally-appropriate measures, grade level, duration of treatment, year of publication). In cases of combined constructivist and traditional outcomes in the same study, the main outcome measured was selected. Inter-rater reliability of the classification of mathematical goals was assessed on the basis of the judgments of 10 independent expert judges. Inter-rater agreement reached 87%;
   - Math in both groups studied for at least 5 hours;
   - The two groups are comparable with no obvious methodological bias or flaw;
   - Data collected are quantitative;
   - Learning took place in an elementary or high school classroom or laboratory;
   - The students in the selected studies do not come from special populations, such as special education or particularly low or high socio-economic status;

- The studies were published in refereed journals between 1986 and 2002 and are available in various academic libraries.

3. *The encoding stage:* extracting the relevant data and encoding the research results on a common scale.
4. *Data processing and testing of the research hypotheses*: An omnibus analysis of the studies' effect sizes was carried out to test the research hypotheses, using between-classes comparisons, according to the various types of learning objectives: Constructivist or traditional. That is, since in each study either a constructivist- or traditionally- appropriate achievement measure was used the two experimental conditions (constructivist and traditional) could then be compared on that measure. A positive result suggests that the achievements of the constructivist learning environment exceed those of the traditional one, regardless of the measure used. A negative result indicates higher achievements by the traditional learning environment, regardless of the measure used. In addition, comparisons were carried out on the methodological characteristics of grade level, length of treatment, and year of publication. This procedure provides a between-classes effect that estimates by *Qb* (a between-group analysis analogous to the *F*-value in an analysis of variance). Statistical tests were carried out by means of the *Software for the Meta-Analytic Review of Research* (DSTAT), (Johnson, 1993), in accordance with the formulae developed by Hedges and Olkin (1985).

Data Sources

We used only studies that were professionally published in refereed journals between 1986 and 2002, but not over the Internet, in books, at meetings, or as unpublished reports. One of the reasons for this strict selection was that in recent years, a growing number of researchers have become doubtful about the quality of research not published in refereed scientific journals (National Research Council, 2002). In all, from 156 studies initially considered, 32 studies met our selection criteria.

The following were the journals from which the studies were selected: *Journal of Research on Computing in Education*, *Journal of Computers in Mathematics and Science Teaching*, *Journal for Research in Mathematics Education*, *Computers in Human Behavior*, *Journal of Educational Computing Research*, *American Educational Research Journal*, and *School Science and Mathematics.*

RESULTS

The studies included in the meta-analysis with their effect sizes (ESs) of educational effectiveness (CTILE compared to traditional learning environment) are presented in Table 1. Of the 32 studies included in the present meta-analysis,

Table 1. The Primary Studies Included in the Meta-analysis with Effect Sizes

Authors	Year	Educational outcome measured	Type of educational outcome	ES
Anand & Ross	1987	TK & Word PS skills	Constructivist	1.38
Ball	1988	Fraction PS skills	Traditional	.78
Bass, Ries, & Sharpe	1986	Math basic skills	Traditional	.41
Battista & Clements	1986	Various PS abilities	Constructivist	.84
Blume & Schoen	1988	PS performance	Traditional	–.04
Borton	1988	Math basic skills	Traditional	.72
Buzin	2001	Computation & Application	Traditional	.25
Campbell, Fein, & Schwartz	1991	Ability of estimation	Constructivist	.70
Clements	1986	Creativity	Constructivist	.74
Clements	1991	Creativity	Constructivist	1.26
Dalton & Hannafin	1988	Computation accuracy	Traditional	.72
Estep, McInerney, Vockell, & Kosmoski	1999	Computation & PS	Traditional	.08
Ferrell	1986	Computation & PS	Traditional	.48
Funkhouser & Dennis	1992	Various PS abilities	Constructivist	.76
Hickey, Moore, & Pellegrino	2001	Data interpretion & conceptual math knowledge	Constructivisit	.22
Hopson, Simms, & Knezek	2001	Analysis, Synthesis & Evaluation skills	Constructivist	.40

Johnson-Gentile, Clements, & Battista	1994	Geometric thinking	Constructivist	2.00
Lehrer, Guckenberg, & Lee	1988	Metacognitive & PS abilities	Constructivist	.49
Lehrer & Randle	1987	PS skills	Traditional	–1.15
Lehrer, Randle, & Sancilio	1989	Knowledge organization	Constructivist	.74
McClurg & Chaille	1987	Spatial cognition	Constructivist	.56
Meijer & Riemersma	2002	TK ability	Constructivist	.62
Ortiz, & MacGregor	1991	Deep understanding of the concept of variables	Constructivist	.76
Rieber	1987	Various PS abilities	Constructivst	.86
Ryser, Beeler, & McKenzie	1995	Criticial thinking ability	Constructivist	1.91
Schumacher, Young, & Bembry	1995	Algebra knowledge	Traditional	–.58
Shyu	1999	Complex PS skills	Constructivist	.82
Thompson & Wang	1988	TK ability	Constructivist	1.00
Turner & Land	1988	Math concepts	Traditional	–.35
Watkins	1986	Cognitive abilities	Constructivist	.63
Zehavi (a)	1988	Intuitive understanding	Constructivist	1.52
Zehavi	1988	Intuitive understanding	Constructivist	.28
Mean Effect Size				**.46**

Note: Total *N* of studies = 32. (a) Two separate studies reported in one article. Abbreviations: TK — transfer of knowledge; PS — problem solving.

Table 2. Summary of Analysis Results

Variables and classes	*N*	Between classes effect (*Qb*)	Mean effect (*d+*)
Educational outcomes		142.61**	
Constructivist	21		0.902
Traditional	11		0107
Grade Level		5.29*	
K-6	23		0.413
7-9	9		0.583
Duration of treatment		10.76**	
1-6 weeks	9		0.686
Longer than 7 weeks	23		0.408
Year of publication		6.16*	
1986-1991	22		0.554
1992-2002	10		0.388

*$p < .05$; $p < .01$.

27 (85%) of the ESs were positive, favoring CTILEs, 3 studies (9%) were negative and favored traditional learning environments, and 2 (6%) showed no difference between CTILEs and traditional learning environments.

The range of the ESs was from –1.152 (higher achievements of the traditional learning environment) to 2.003 (higher achievements of CTILE). An effect is considered to be small when ES = 0.2 standard deviations, of medium magnitude when ES = 0.5 standard deviations, and large when ES = 0.8 or more standard deviations (Cohen, 1977). Mean effect size for all 32 studies was 0.460, suggesting that overall, the learning attainments of CTILEs are of medium magnitude when compared with traditional learning environments. A summary of the analysis results is presented in Table 2.

Table 2 presents the large weighted average effect size ($d+ = .902$, $Qb = 142.61$, $p < .01$), which was found in that group of experiments that evaluated learning according to constructivist criteria in CTILEs, as compared with those who studied in a traditional learning environment. That is, in accordance with our first hypothesis, learning attainments are profoundly better in constructivist learning environments when constructivist-appropriate measures are used. However, our second hypothesis could not be supported: Even when traditional measures are used, achievements are not any higher in traditional learning environments than in less traditional ones ($d+ = .107$, $Qb = 142.61$, $p < .01$). It thus appears that regardless of the measures used, traditional learning environments yield either poorer or similar outcomes when compared with CTILE. However, it needs to be noted that the variation of effect sizes between studies using traditional achievement measures is larger than that within the group of constructivist-using studies (*SD* = .615 and .482, respectively). This is an unexpected observation. One would have expected didactic instruction to be more uniform than instruction in CTILE. But this, apparently, was not the case.

Grade level was found to moderately affect the results—although the effect sizes favored CTILE regardless of grade level, still the effect size for grades 1-6 were significantly smaller than those for grades 7-9 ($d+ = .413$, $d+ = 0.583$ respectively, $Qb = 5.29$, $p < .05$). A similar relationship between CTILE and grade level has been reported in previous meta-analyses (Kulik & Kulik, 1991; Liao, 1998). However, this finding is not consistent with the majority of the meta-analyses (Bayraktar, 2001/2002; Flinn & Gravat, 1995) that report no significant effect size differences for different grade levels.

Constructivist learning environments yielded significantly higher achievements than traditional ones when math instruction lasted for up to six weeks as compared with instruction that lasted for seven weeks or more ($d+ = .686$, $d+ = .408$ respectively, $Qb = 10.76$, $p < .01$). Also year of publication made a difference—CTILE yielded larger effect sizes when the studies were published between 1986 and 1991 than between 1992 and 2002 ($d+ = .554$, $d+ = .388$ respectively, $Qb = 6.16$, $p < .05$).

DISCUSSION

We entertained the possibility that qualitatively different learning environments offer different kinds of learning experiences and thus serve different learning goals. Comparing different learning environments using the same measuring devices can thus overlook profoundly different kinds of learning outcomes, erroneously leading to the all-too-frequent finding of "no significant difference." We hypothesized that since constructivist technologically-intensive math learning environments are designed to provide self-guided and team-based problem solving, participatory meaning appropriation, and active knowledge construction, that they serve entirely different learning goals than more traditional, didactic learning environments. Using constructivist-appropriate measures, such learning environments should lead to higher achievements than more traditional learning environments. We also hypothesized that since the latter provide their own kind of learning experiences they serve other goals such as well organized and disciplined mastery of basic math knowledge, computation, and word problems. Using more traditional measures these learning environments should lead to higher achievements than constructivist learning environments.

The main purpose of the present meta-analysis was to compare the relative effectiveness of these two kinds of learning environment in differentially achieving learning objectives that are appropriate for each. Toward this end, we chose experiments that compared the two kinds of learning environment using either constructivist- or traditionally-appropriate achievement measures. We ended up with 32 experiments published in refereed journals since 1986 that met a set of rigorous methodological and quality criteria.

The results of our meta-analytic study supported the first hypothesis. As predicted, math students in CTILEs, compared to students in more traditional learning environments, show higher learning achievements (ES = .902) when tested against constructivist-appropriate criteria. On the other hand, findings did not support our second hypothesis: Math students in traditional learning environments showed learning achievements similar to those studying in CTILEs when tested against traditionally-appropriate criteria (ES = .107).

The overall average effect size presented in Table 1, (ES = .460), agrees with results of former meta-analytic studies (Bayraktar, 2001/2002; Christmann & Badgett, 1999; Kulik & Kulik, 1991; Liao, 1998; Ryan, 1991), where a moderate positive effect size was found for the learning achieved in computer-assisted learning environments compared to traditional ones. However, this effect size of .460 conceals a much more important finding: When constructivist-appropriate measures are employed, the effect size in favor of constructivist learning environments rises to .902. Such a differentiation between the goals, and hence the measures of learning outcomes, of different kinds of learning environments has not been done in previous meta-analyses in the present field.

The fact that when learning in constructivist learning environments leads to higher constructivist-related achievements than traditional settings should not surprise us. If a learning environment is characterized by the unique kinds of experiences it offers, and the kinds of learning processes it evokes, it must, by necessity, serve different learning goals than another setting that operates in a qualitatively different way. Indeed, studies of the *Jasper series* (e.g., Hickey et al., 2001) show how a constructivist learning environment cultivates problem solving but not computational skills when compared with a more traditional setting. On the other hand, the latter cultivates calculation but not problem solving. Thus, it is less clear why we find in the present meta-analysis that learning in a traditional setting does not yield higher achievements when measures appropriate for that setting are used.

A number of possible explanations become possible. One possible explanation may well be that as the traditional learning environments in the 32 studies under consideration here served as control groups, the quality of instruction there may not have been as high as it should have been. The larger variance in effect sizes within the group of studies using traditional measures may support such a possibility. A second explanation may be that novelty of the constructivist approach plays a role here. This could be overall novelty—moving away from the traditional year-long math curriculum, or temporary novelty—the very participation in an experiment in which a new approach to math instruction is promoted. One way or another, this possibility can not be easily ruled out in light of the observation that the effect size in favor of longer lasting constructivist instruction is smaller than that of shorter periods of such instruction (similar findings are reported by Kulik and Kulik, 1991 and by Bayraktar, 2001/2002, and dissimilar ones by Liao, 1998). The uniqueness of this approach may decay as instruction continues.

Although our findings lend some support to the novelty interpretation, a more reasonable interpretation may well be that with the increased integration of computers into education (National Center for Education Statistics, 2000; Reiser, 2002) and with the increased acceptance of constructivist-like instructional goals (Gagnon & Collay, 2001; Karagiorgi & Symeou, 2005), traditional instruction gradually moves away from the strict didactic approach. It becomes less uniform as it comes to incorporate constructivist-like elements such as team work and teambased problem solving, which are then reflected in achievement measures. Such a possibility is supported by our finding that older studies yielded larger effect sizes than more recent ones, suggesting that so-called traditional learning environments become less dissimilar from constructivist ones. This interpretation does not refute *in principle* the differential hypothesis tested here. Thus, the observed overall superiority of achievements attained in constructivist learning environments may suggest that such environments are indeed more effective. They are more effective when constructivist-related measures are used and of equal effectiveness to traditional environments when traditional measures are used.

The statistical analysis carried out in this study pertained to research done in the field of math education. Would the same findings emerge when other disciplines are examined? It is essential to carry out similar meta-analyses to examine the differential effectiveness of different learning environments in other disciplines, and compare those to traditional learning environments.

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