An Investigation of the Effects of Multimedia Research on Learning and Long-Term Retention in Elementary Math: A Research Agenda

Yuliang Liu, Ph.D.
Southern Illinois University Edwardsville, Illinois

Abstract

This paper first identifies that there is an underachievement in math nationwide as well as an underutilization of research principles from cognitive science in math curriculum and instruction. Then the paper provides a compelling rationale addressing the theoretical foundation and relevant prior empirical evidence supporting the proposed project. Finally, the paper provides the significance of the proposed project.

1. Identify the Education Problem That Will Be Addressed by the Project

(1) Underachievement in math

Current levels of math achievement at the elementary and secondary levels within the U. S. suggest that we are neither preparing the general population with levels of math knowledge necessary for the twenty-first century workplace, nor producing well prepared students to meet national needs for domestic scientists and mathematicians (Research & Policy Committee of the Committee for Economic Development, 2003; U.S. Department of Education, 2003a, 2003b, 2003c). Despite the fact that levels of math achievement have improved over the past decade, achievement gaps continue to exist. Further, low levels of achievement are more likely to be present among minority groups and students from low-income backgrounds (U.S. Department of Education, 2003a). This underachievement in math may be related to math anxiety that is formulated in the later elementary grades (grades 3-6) with increasing exposure to events or significant others such as teachers and friends who solidify the anxiety (Hackworth, 1985). Additionally, there has been much debate regarding what constitutes math proficiency and which teaching methods support student achievement of this proficiency. Limited empirical research has been conducted to compare these instructional approaches to determine what leads to improved math achievement across ethnic and socioeconomic groups in the U.S.

(2) Underutilization of research principles from cognitive science in math

According to Carver and Klahr (2001), cognitive scientists have identified numerous basic principles of learning that are supported by empirical research in traditional, well-controlled laboratory settings. In math, over the past 20 years, cognitive and developmental researchers have described the growth of young children's scientific knowledge and numeracy (e.g., Kalchman, Moss, & Case, 2001; Lehrer, Schauble, Strom, & Pligge, 2001; Palincsar & Magnusson, 2001). However, for the most part, curriculum in math has not widely or systematically incorporated findings from this accumulation of research either through the creation of materials that support teaching and learning or at the level of instruction. Furthermore, little work has been conducted to evaluate the effectiveness of math curricula and instructional practices for improving student learning and achievement (Glaser, 2001).

The three components of cognition (attention, memory, and reason) are the basis for achievement in math and other academic areas. Many scholars have called for research to bridge the gap between detailed, rigorous models of attention and successful academic performance (Baddeley, 1990; Carver & Klahr, 2001; Glaser, 2001; Hitch & Logie, 1996). Recent discoveries about multiple memory systems and their underlying neurological processes hold particular promise for developing instructional methods that tap into implicit learning (Baddeley, 1990, 1999; Carver & Klahr, 2001; Hitch & Logie, 1996). Thus research is needed regarding how to improve the encoding of information and retrieval of implicit memories for learned material, how memory representations can better reflect what has been taught, and how the flexible use of memory systems can facilitate accurate reasoning and problem solving.

2. Provide a Compelling Rationale Addressing the Theoretical Foundation and Relevant Prior Empirical Evidence Supporting the Proposed Project

(1) Provide a compelling rationale addressing the theoretical foundation

According to Bork (1992), a multimedia learning environment is a new paradigm for learning in current education. This is especially true for math learning. According to Tooke (2001), “The computer affected mathematics education. It changed the mathematics curriculum, the teaching of mathematics, and even the way mathematics was learned,”(p. 1). But investigating the effects of computer-based multimedia on learning and performance requires a solid foundation in cognitive psychology and learning theory (Astleitner & Wiesner, 2004; Dijkstra, Jonassen, & Sembill, 2001; Mayer, 2001; Rouet, Levonen, & Biardeau, 2001; Sweller, 1999). Multimedia scholars have recently built their research on cognitive learning theory (e.g., Bishop & Cates, 2001; Schnottz, 2001; Wright, 2001). In addition, Mayer’s recent work of multimedia investigations are heavily grounded in cognitive

Mayer (2001) based the majority of his recent multimedia work on an integration of Sweller's cognitive load theory (1988, 1999), Paivio's dual coding theory (Clark & Paivio, 1991; Paivio, 1986), and Baddeley's working memory (WM) model (Clark & Paivio, 1991; Paivio, 1986). Mayer focuses on the auditory/verbal channel and visual/pictorial channel. Mayer establishes his cognitive theory of multimedia learning through the following model (p. 44).

Figure 1. Mayer's (2001) Cognitive Theory of Multimedia Learning

This model is based upon three primary assumptions: (a) Visual and auditory information is processed through different information processing channels. (b) Each channel is limited in its ability to process information. (c) Processing information in different channels is an active cognitive process designed to construct coherent mental representations. Furthermore, this model is activated through five steps: "(a) selecting relevant words for processing in verbal working memory, (b) selecting relevant images for processing in visual working memory, (c) organization of selected words into a verbal mental model, (d) organizing selected images into a visual mental model, and (e) integrating verbal and visual representations as well as prior knowledge," (Mayer, 2001, p. 54).

According to Mayer (2001), multimedia design is a potentially powerful system for enhancing human learning. The two approaches to multimedia design are: technology-centered approach and learner-centered approach. The technology-centered approach typically starts with the functional capabilities of multimedia and focuses on the incorporation of multimedia into emerging communication technologies. According to recent research (e. g., Cuban, 1986; Cognition and Technology Group at Vanderbilt, 1996a), the technology-centered approach does not usually lead to durable improvements in education. Thus scholars in multimedia research have focused on another important theoretical alternative--the learner-centered approach. The learner-centered approach typically starts with how the human mind processes information and focuses on how to use multimedia technology as an aid to enhance human cognition and learning. The learner-centered approach supports the idea that humans process information more effectively if the multimedia design is consistent with the way the human mind works.

Based on Mayer and colleagues’ recent studies, Mayer (2001, p. 184) proposed seven multimedia design principles: (a) Multimedia: Students learn better from two or more types of media such as words and pictures rather than from words alone. (b) Spatial Contiguity: Students learn better when corresponding words and pictures are presented close to each other rather than far apart on the page or screen. (c) Temporal Contiguity: Students learn better when corresponding words and pictures are presented simultaneously rather than successively. (d) Coherence: Students learn better when extraneous words, pictures, and sounds are excluded rather than included. (e) Modality: Students learn better from animation and narration rather than from animation and on-screen text. Thus multimedia presentations involving both words and pictures should be created using auditory or spoken words, rather than written text to accompany the pictures. (f) Redundancy: Students learn better from animation and narration rather than animation, narration, and on-screen text. Thus multimedia presentations involving both words and pictures for the same content should present text either in written form or in auditory form, but not in both. (g) Individual Differences: Design effects are stronger for low-knowledge learners than for high-knowledge learners, as well as for high spatial learners rather than for low spatial learners. In all, this model provides instructional designers with a summary of main factors that have to be considered when developing multimedia-based learning environments (Astleitner & Wiesner, 2004). Many other cognitive researchers (e. g, Kumpulainen, Salovaara, & Mutanen, 2001; Leahy, Chandler, & Sweller, 2003) also suggest focusing on the design of instructional situations and pedagogical supports for multimedia-based learning.
Recently many multimedia scholars have suggested that all courses be redesigned on a national or international scale based on the characteristics of the multimedia environment (Bork, 1992; Confrey, 1996; Cuoco & Goldenberg, 1996). However, systematic multimedia integration into the current math instruction has yet to be integrated in the schools (e. g., Neuwirth, 2002; Robertson, 1998). The creation and development of a multimedia version of current elementary math curricula will follow Mayer’s (2001) multimedia design principles described previously. All content areas in the elementary math curriculum will be examined for adding appropriate multimedia components. The design and development of such multimedia curriculum will be based on the principles and standards for school mathematics from the National Council for Teachers of Mathematics (NCTM, 2000). The project will also be based on the Analysis, Design, Development, Implementation, and Evaluation (ADDIE) model (Dick, Carey, & Carey, 2001). The ADDIE model includes five components: (a) Analysis: Including analyzing the elementary students’ characteristics, learning tasks, and environments. (b) Design: Including writing course objectives, developing course outlines, and determining effective multimedia delivery methods for each content chapter. (c) Development: Including writing course content by integrating multimedia (e. g., video clips, animation) and sound into math instruction, such as content presentations, readings, activities, and assessments. (d) Implementation: Including delivering the multimedia instruction to the experimental student. (e) Evaluation: Including formative weekly or unit evaluation that is used to improve instruction during the multimedia instruction every week and yearly summative evaluation that measures the overall effectiveness of the course at the end of each semester and/or academic year.

(2) Provide relevant prior empirical evidence supporting the proposed project

The study of technology improving learning in the classroom is a debatable one, due to the relative novelty of using technology in an educational setting. In evaluating the effectiveness of technology on students’ cognition and learning, several factors must be considered. These factors include things such as the goal of the instruction and the information presented, the type of technology used, the implementation and use of the technology by the educator, and the students’ personalities. Most studies have found that these factors must be considered in order to determine if technology improves learning (e. g., Arnone, 2003; Baker, 2000; Barton, 1998, 2002; Schwartz & Beichner, 1999).

Mayer’s (2001) seven multimedia design principles (described previously) are consistent with the proposition described in the above paragraph. Based on Mayer’s seven multimedia design principles, Mayer and colleagues have conducted a series of studies investigating the nature and effects of multimedia presentations on human learning for the past decade. According to Mayer, there are two basic goals of multimedia learning. The first goal is to remember information. This refers to the ability to recall, recognize, or reproduce information presented. This goal focuses on retention of acquired information. The second goal is to understand information. This refers to the ability to apply acquired information to novel situations. This goal focuses on transfer of the acquired information.

Based on Mayer and colleagues’ recent multimedia research, Mayer (2001) proposed three possible types of multimedia learning outcomes: (a) no learning at all, (b) rote learning, and (c) meaningful learning. In meaningful learning, students will learn integrated knowledge and exhibit good performances in both retention and transfer. Mayer and colleagues focused on investigating the effects of multimedia presentations on college students’ cognition and learning. Mayer further summarized the empirical evidence based on retention and transfer tests that he and his colleagues administered in their research. With the exception that no differences were found regarding the temporal contiguity effect for retention between both experimental and control groups, the effects of all principles were better for both retention and transfer in the experimental group than in the control group (p. 185-186).

Recent limited studies have found that multimedia has a positive impact on learning across K-12 educational settings (e. g., Felix, 1998; Gouzouasis, 1994; Khalili & Shashaani, 1994; Maddux, Johnson, & Willis, 2001; Najjar, 1996; Scarlato, 2002; Wenglinsky, 1998). These effects have been found in a variety of school subjects such as math (Mikk & Luik, 2003), reading (Heimann, Nelson, Tjus, & Gillberg, 1995; Passig & Levin, 2000), geoscience (Chang, 2004), biology (Koroghlianian & Klein, 2004), educational technology (Orman, 1998), as well as for special education students such as autistic students (Heimann, Nelson, Tjus, & Gillberg, 1995; Higgins & Boone, 1996; Tjus, Heimann, & Nelson, 2001), learning disabled students (Langone, Shade, Clees, & Day, 1999; Okolo & Ferretti, 1996), and dyslexic learners (Dimitriadi, 2001). In addition, Maki and Maki (2002) directly attributed improved learning to multimedia comprehension in online courses.

Multimedia instruction has been specifically noted to be effective especially for learning abstract subjects such as math (Apostol, 1991; Apostol & Blinn, 1993; Blanchard & Stock, 1999; Clark & Paivio, 1991; Paivio, 1971, 1986, 1991; Szabo & Poohkay, 1996; Tooke, 2001; Wiest, 2001) since teaching with multiple representations facilitates and strengthens the learning process by providing several sources of information (Grouws, 1992; Kozma, Russell, Jones, Marx, & Davis, 1996; NCTM, 1989). Multimedia technologies also have great potential as learning...
activities in the primary school context (Baxter & Preece, 1999; Eskicioglu & Kopec, 2003; Jones, 1994; Nulden & Ward, 2002; Smith, 1999). According to Jones (1994), commercial multimedia software titles for children usually lack directed learning objectives. Research examining the impact of computer-controlled multimedia on student learning in school subjects is relatively recent, beginning around 1994. Jones encouraged researchers to focus on exploration of multiple simultaneous representations in school math. Now, 10 years later, there has been progress in this field. Based on recent literature, there are three basic types of projects investigating the impacts of multimedia in K-12 math instruction and learning.

The first type of project includes projects involving the use of multimedia resources to train preservice math teachers at the university level (e.g., Bitter, 1994; Bitter & Hatfield, 1994; Bitter & Pryor, 1996; Daniel, 1996; Dugdale, 2001; Garcia, 1999; Herrington, Herrington, Sparrow, & Oliver, 1998; Herrington & Oliver, 1999; Kim, Sharp, & Thompson, 1998; Lampert & Ball, 1998; Townsend & Townsend, 1992). Lampert and Ball (1998) used hypermedia to enable students to access teacher education materials in two classrooms videotaped over a one-year period. That is, the preservice teachers were video-taped while they were being trained on math instruction. Barron and Goldman (1996) focused on a major strand of math curriculum and used cases for preservice teachers to investigate and discuss. Herrington, Herrington, Sparrow, and Oliver (1998) designed an interactive multimedia resource to develop preservice teachers’ knowledge and practices for teaching and assessing mathematics in K-12 classrooms. Herrington and Oliver (1999) described a qualitative study on students’ use of higher-order thinking as they use an interactive multimedia program based on a situated learning framework. Sharp and Kim (2000) studied six hours of multimedia-enhanced instruction over a two-week period for preservice elementary teachers in a methods course that emphasized constructivism and involved problem-solving multimedia. Their study found that multimedia-enhanced instruction facilitates students’ teaching abilities and confidence in their future teaching.

Bowers and Doerr (2003) designed and investigated a multimedia case study for preservice mathematics teachers in methods classrooms. They found that the multimedia case approach received the highest ratings from students enrolled in courses where the case exploration activities were integrally woven into the course goals. Overall, most of these projects promoted students’ learning of math teaching methods and their teaching in other fields by integrating multimedia to situate the materials in real contexts.

The second type of study includes students’ authoring and/or creation of specific multimedia projects. In the multimedia project conducted by Penuel, Golan, Means, and Korbak (2000), teams of K-12 teachers were trained to develop curriculum-based multimedia projects with students. Results indicated that students in the multimedia project classrooms consistently outscored their peers in the non-project classrooms in various areas such as understanding content, applying principles of designs, and adapting to meet students’ needs. Maor (2001) studied 10th grade students to conduct a formative evaluation of an authentic data-based multimedia program. The students’ formative evaluation resulted in helpful information for modifying and improving the existing multimedia program, as well as raising further questions regarding how to promote students’ development of desired high-level thinking skills in the program. McFarlane, Williams, and Bonnett (2000) involved elementary students in a multimedia authoring project related to drug education using HyperStudio software. Neither the teachers nor the students had previous multimedia experiences, although they were provided with training. At the end of the study, various measures were used to assess students’ understanding of the content. The study indicates that student-produced multimedia projects can reveal important aspects of learning that traditional tests may not recognize, such as higher order thinking skills and processes. However, most of these studies were conducted either with middle school students (e.g., Liu & Hsiao, 2002; Macnab & Fitzsimmons, 1999; Wilder & Schoech, 2002) or high school students (e.g., Koroghlanian & Klein, 2004; Looi & Ang, 2000).

The third type of project includes designing and delivering some kind of multimedia instructional materials and then assessing their impact on students’ learning. The Cognition and Technology Group at Vanderbilt (1996a, 1996b) developed a well-known series of films called the Jasper Series. The series utilizes hypertext terminology in order to describe their theory that their films offer semantically rich anchors which construct a macrocontext. These macrocontexts present meaningful authentic problems that must be solved. Smith and Westhoff (1992) describe the Taliesin Project that extends far beyond a simple program and speaks to the institutional context as well, including (1) curriculum revision with the aim of overcoming the segmentation of subjects and introducing interdisciplinary block teaching that covers math, science, and technology, (2) development of a hypermedia system with protocolling, communication, network connection, and application, and (3) development of tools for designing lessons. Johnson and O’Neill-Jones’ (1999) collaborative team designed a multimedia title called “Wyz’t’s Playground” to emulate and simulate the real life scenario of building a playground for 4th grade students to practice as a part of math curriculum. Results from this study indicate that the playground project supports the instruction of math and proficiency measures in five NCTM (1989) standards: spatial, patterns, computation, statistics, and communication.
Macaulay (2003) conducted an experiment to study the impact of multimedia on math learning performance of non-English-speaking third world children. In the study, 36 elementary students were randomly assigned into two groups: multimedia (experimental) and non-multimedia (control). All 36 students completed a pretest before the experiment and no statistically significant differences were found between experimental and control groups. Two types of computer-based learning applications on the same type of computers were used to present addition and subtraction concepts in elementary math. The control group was presented the materials using text only while the experimental group used a combination of text, images, animation, and sound. The presentation of math materials in both groups was similar in terms of structure and interactivity. The only difference between the two groups was the inclusion of multimedia components in the experimental group. Results from the posttest indicated that the multimedia group significantly outperformed the non-multimedia group in terms of the mean math test scores.

Moreno (2002) conducted a study on who learns best in elementary math with multiple representations based on an interactive multimedia game in emigrant, low-income, Spanish-speaking children. According to this study, presenting symbolically and visually how an arithmetic procedure works in math does not ensure that all students will understand the explanations unless cognitive theory of multimedia learning is applied to the design. Thus this project suggests focusing on integrating multimedia into the math curriculum design by applying the seven principles from cognitive theory of multimedia learning described previously.

Currently, computer-based instruction containing multimedia appears to be increasingly used as a supplement to traditional classroom instruction. However, systematic research investigating the impacts of multimedia-based learning in math is still largely lacking (Christian, 2003; Fan & Orey, 2001; Herrington, Herrington, & Sparrow, 2000; Koroghlanian & Klein, 2004; Royce, 2002). In order to stimulate more research in this field, an international cooperative workshop entitled “Multimedia Tools for Communicating Mathematics (MTCM)” was held in Portugal in 2000. The meeting aimed at providing, “fruitful and stimulating ground for the further development of multimedia tools for mathematical education, communication, and research.” (Borwein, Morales, Polthier, & Rodrigues, 2002, p. vi) Thus this project is designed to meet the aim of the international meeting as well as to meet other multimedia design challenges in math proposed by other researchers in the field (e.g., Astleitner & Wiesner, 2004; Cognition and Technology Group at Vanderbilt, 1996b).

Based on the above review, it is found that the multimedia curriculum and instruction are neither a cure-all for problems facing the schools nor are they fads without impact on student learning. When designed and used properly, multimedia curriculum and instruction may serve as important tools for improving student proficiency in math and the overall learning environment of the school. This is consistent with Wenglinsky’s (1998) conclusion regarding the impact of computers on student learning. In addition, a careful review indicates that those limited studies in the literature are not systematic or rigorous for various reasons: (a) most multimedia designs did not systematically follow the principles based on cognitive science and proposed by Mayer (2001); (b) most research designs in elementary math were not well controlled; (c) most studies did not examine the variable of attention; (d) some studies that were highly controlled have problems generalizing to real educational classrooms; (e) none of those studies assessed the long-term effects of multimedia instruction on students’ standardized tests; and (f) no studies covered one or more years of elementary math curriculum. Thus this study is necessary to address all of the described previously challenges.

3. Provide the Significance Of the Project

Although many math teachers also use overheads in their teaching, the effects on student learning are still very limited. The most significant change in the classroom today is not just the addition of computers, but direct Internet access (Cattagni & Farris, 2001; Education Week, 2001; Williams, 2000). However, education has not progressed beyond the machines. For most students in K-12, the lecture/textbook/workbook approach is the primary medium for the delivery of math instruction. Unfortunately, textbooks are often presumptuous about the breadth and depth of students’ background knowledge, are written at readability levels that exceed those of average students and fail to structure information to facilitate comprehension of important concepts and relationships. As a result, students from low-income backgrounds are often excluded from receiving the benefits of effective math instruction (Chambel & Guimaraes, 2002).

This project is designed to investigate the effects of multimedia research on learning and long-term retention in elementary math. Based on (a) the NCTM directives, (b) Mayer’s (2001) cognitive theory of multimedia learning, and (c) multimedia literature presented in the previous section, it is hypothesized that the multimedia math curriculum will have significant positive impacts on students’ cognitive processes and learning in math. That is, there will be significant mean differences between the experimental group (that will receive the multimedia math curriculum and instruction) and the control group (that will receive regular math curriculum and instruction) for low-income third graders in terms of these dependent variables: (a) attention to math instruction, (b)
immediate recall of the newly acquired math information, (c) long-term retention of the newly acquired math information, and (d) academic standardized test scores in third grade as measured by the math portions of the standardized achievement tests.

The focus of this project is not on a replacement for math teachers, but using the computer-based multimedia curriculum and instruction to assist teachers and students in the math learning process. The actual intervention in this project is multimedia curriculum and instruction in elementary math. Multimedia-based curriculum and instruction can be an effective alternative to the exclusive dependence on textbook-based math instruction. In this project, multimedia refers to the integration of different media such as text, graphics, animation, sound, video (digital or analog), imaging, and spatial modeling into a computer system where appropriate (Jonasses, 2000). Multimedia representations including animation typically provide a rich set of communication vehicles and have been essential for communicating and transmitting mathematical concepts to learners (Chambel & Guimaraes, 2002).

This project aims to foster meaningful learning by integrating multimedia design principles into the elementary math curriculum in grades 3-5. This project will examine how to design, develop, and deliver the effective multimedia curriculum and instruction by integrating multimedia design principles in elementary math curriculum materials for grades 3-5 in local elementary schools for three years. The planned curriculum materials, when fully designed and developed, will form an instructional sequence that covers the math curricula for grades 3-5. This project has three major tasks: (a) to design and develop effective multimedia curriculum and instruction for math based on recent cognitive research in multimedia and cognition as described previously, (b) to deliver the effectively designed multimedia curriculum and instruction for math, and (c) to empirically examine the effects of the above multimedia curriculum and instruction on students’ learning, cognitive processes, and academic achievement for low-income and low-achieving children.

This project will advance solutions to underachievement in elementary math that teachers confirm to be a critical problem from their point of view. According to Eskicioglu and Kopec (2003), computer-based multimedia should be employed as the centerpiece for an emerging pattern of instruction. We agree with this perspective based on our recent teaching and research experiences. We have found that computer-based multimedia can promote independent and cooperative learning, and improve performance of low achievers and special student populations. The overarching purpose of this project is to bridge the gap among the laboratory research in cognitive science, multimedia learning, and the practices of in-service teachers. This knowledge could then be used to improve elementary math instruction.

This project is significant in both practice and theory for many reasons. In practice, different from previous multimedia research projects, this project focuses on (a) one fundamental school subject--math, (b) the design and development of computer-based multimedia curriculum and instruction by integrating Mayer’s seven multimedia design principles mentioned previously, (c) numerous variables of students’ cognitive functioning such as attention, recall, and long-term retention, and (d) students’ academic achievement as measured by standardized tests. This project will also theoretically contribute greatly to the multimedia literature in K-12 math curricula and education.
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