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THE EFFECTS OF THE USE OF DYNAMIC GEOMETRY SOFTWARE ON STUDENT ACHIEVEMENT AND INTEREST

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THE EFFECTS OF THE USE OF DYNAMIC GEOMETRY SOFTWARE ON STUDENT ACHIEVEMENT AND INTEREST

Heidi B. Hansen

This study examines the current research that exists on the effects that the use of dynamic geometry software has on student achievement and interest level in mathematics. Additional questions examined are whether using dynamic geometry software has a greater impact on high or low achievers, and what current methods of implementation are suggested by the research. A review of the relevant literature indicates that the use of dynamic geometry software does have a positive effect on student achievement, particularly achievement in areas of high-level thinking. Insufficient research has been done on the effect that the use of dynamic geometry software has on student interest and the impact of dynamic geometry software on high or low achievers. Current methods of implementation suggested by the literature stress the need for a student-centered environment, for appropriate teacher training, and the need for curricular reform.

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Chapter 1: Introduction

Setting

Teachers of mathematics are continually challenged to find the most effective methods of reaching students. Middle school and high school students today are part of a generation bombarded by media. They watch DVDs, play video games, listen to music constantly, and watch more television than students ever have. While these types of technology may seem more entertainment than tool, teachers today are finding ways to work with various forms of visual media to help gain and keep students' attention. The mathematics community nationwide is also seeing potential value in the variety of forms of technology now available. In 2000, the National Council of Teachers of Mathematics found technology to be of such import they included a Technology Principle in their Principles and Standards for School Mathematics. Specifically, they state that "Technology is essential in teaching and learning mathematics; it influences the mathematics that is taught and enhances students' learning." (National Council of Teachers of Mathematics [NCTM], 2000, p.24).

To better reach the current generation of teenagers, instructors have implemented new technologies in the classroom, including various forms of dynamic computer software for mathematics. Some of these types of programs allow students to manipulate geometric figures or data they create and to analyze those figures and data. They can interact with the software rather than simply viewing static pictures. The premise is that this interaction will help students gain a deeper understanding of the topics they are studying by helping them become participants in their learning, rather than observers. In an attempt to reach more students through this constructivist style of teaching, many teachers have eagerly implemented the use of these programs as a new way of teaching mathematics.

One type of dynamic software that has been commonly accepted is dynamic geometry software, often referred to as DGS. The predominant programs today are Geometer's Sketchpad, Cabri Geometry (originally named Cabri-géomètre and often referred to as simply Cabri) and a relative newcomer, Cinderella. These types of software allow the user to construct geometric figures and manipulate them in an exploratory setting. None of these products have a structured "follow the steps" setting. The software is designed for students to create a variety of examples and reach conclusions. On their website, the producers of Sketchpad at Key Curriculum Press claim:

> With *Sketchpad,* students can construct an object and then explore its mathematical properties by dragging the object with the mouse. All mathematical relationships are preserved, allowing students to examine an entire set of similar cases in a matter of seconds, leading them by natural course to generalizations. *Sketchpad* encourages a process of discovery in which students first visualize and analyze a problem and then make conjectures before attempting a proof.
>
> (Key Curriculum Press website, 2004, ¶ 2)

Likewise, Texas Instruments (2004), which markets Cabri Geometry II, makes the claim on their site that: "Cutting-edge technology lets students alter figures on the screen, allowing them to see patterns, make conjectures and draw their own conclusions." (¶ 2) Since the software is designed to be used in an exploratory manner, the individual mathematics teacher determines how the software is used in the classroom.

Statement of the Problem

While dynamic geometry software has been widely accepted as a tool for teaching mathematics to students, studies are just beginning to appear examining the effectiveness of these systems. The problem of "effectiveness" of the use of dynamic software is multifaceted in nature.

This research paper proposes to examine current research in order to answer the following questions:

- Are students achieving greater success and understanding through the use of dynamic geometry software, that is; do studies show a difference in achievement levels in students who use these types of software?
- Does research show that the use of this dynamic software makes a difference in the interest level of the students in the topic?
- Is the use of dynamic software, according to the research, effective in meeting the learning needs of all students in a classroom, or some more than others, in particular; does it cater to academically higher-level learners or lower-level learners?
- What have studies shown to be the best methods of implementing this technology in the classroom?

Significance of the Problem

The question of the effectiveness of dynamic software is one that concerns mathematics teachers across the country, indeed, throughout the world. Teachers often jump on the bandwagon of new educational tools or ideas before they are fully researched. It is imperative that teachers learn how to most effectively put into practice these new ideas. It is also important for teachers and administrators to have thoroughly researched the benefits (or drawbacks) of using a tool, particularly a costly tool, prior to purchase and implementation. A goal of teaching is to reach the greatest number of students using the best methods available, and this is not effective if the methods have not been tested. To quote the NCTM Standards (2000) Teaching Principle: “Effective mathematics teaching requires understanding what students know and need to learn and then challenging and supporting them to learn it well.” (p.16) Knowing the results of research will help teachers make informed decisions about why and how to implement this type of technology.

Definitions

In order to help the reader better understand the discussion of this research, I will define some terms that will be encountered, and some acronyms that will be used.

CAI- Computer-assisted instruction. This can imply anything from using a computer tutorial to using an open-ended dynamic program.

DGS- Dynamic geometry software (see below).

Dynamic geometry - Finzer and Jackiw (1998) defined “dynamic geometry” software programs as having three defining features: First, the program *allows direct manipulation*. When users “drag” a point on the screen, they perceive they are moving the point, not just the mouse. Second, the program implements *continuous motion*. There is no lag time between the movement of the mouse and the movement of the point. Third, the program is an *immersive environment*. Items on the screen are realistic and behave like their counterparts in the real world, giving the user the feeling of involvement in the program. (p. 1)

GSP- a shortened form of Geometer's Sketchpad.

Interactive programs- Computer programs that allow input from the user. Some methods of interaction include typed or voice commands, or use of the mouse or other input devices.

OELE- Open-ended learning environment. A learning environment where students are provided varying amounts of help and support on an individual basis to help them reach their learning goals.

Delimitations

This research paper will be limited to studying interactive software in the area of mathematics. It will specifically examine the use of geometry software, primarily by secondary and middle school students. These results cannot be generalized to other curricular areas. While the research paper may include some overall concepts of implementing technology and learning styles, the purpose is not to cover all areas of technology, nor to cover every curricular area.

Format of the Paper

In discussing the subjects of achievement and interest in students using dynamic geometry software, the format of this paper will be as follows: I will discuss first a brief history of dynamic software, followed by general research on the impact technology has had on student achievement and interest. After the general research, I will narrow in on specific research on the effects of dynamic geometry software, followed by a discussion of the research on implementing and teaching with DGS. Once I have completed the review of the literature, I will summarize the results, and end the paper with a discussion of the implications of this research.

Chapter 2: Review of the Literature

History of Dynamic Geometry Software

As a number of Geometry software programs have emerged over the years, it is important for the reader to have somewhat of a timeline from which to consider the development of dynamic geometry software. Not all geometry software has been dynamic. In fact, dynamic geometry software is relatively new to the market, originating in the late 1980's.

Cabri and Geometer's Sketchpad.

In the mid 1980's, two software developers on opposite sides of the world separately began a process of creating software tools which would allow students to explore geometric figures. In France, Jean-Marie Laborde introduced a proposal for Cabri-géomètre in 1985. Meanwhile, Nicholas Jackiw began the design of Geometer's Sketchpad as part of the Visual Geometry Project at Swarthmore College, an NSF funded project. The Swarthmore project's original intent was to produce a three-dimensional software program, in fact, several of them, but the extant technology would not allow them to make the progress desired, so Jackiw and his colleagues decided to concentrate on a single program for plane geometry. In 1990, the two design groups first met at a NATO workshop in Grenoble, France. Cabri was already in use in schools in France, but Sketchpad was yet in its early stages. After meeting in Grenoble, Jackiw and one of Cabri's designers each spent time beta testing the other's products, and Sketchpad was released as a commercial package in 1991 (Jackiw, 1999). Each program has since progressed through various versions, each gaining powerful but sometimes differing features. Current versions are Geometer's Sketchpad 4 and Cabri Geometry II Plus.

Cinderella and other programs.

Cinderella (Richter-Gebert & Kortencamp, 1999) is a dynamic geometry program which originated in Germany. Two of its designers were Jürgen Richter-Gebert and Ulrich H. Kortenkamp. It first became available in the late 1990's. Cinderella differs slightly from Cabri and Sketchpad in that it was designed for research, rather than educational use. One of the most outstanding features of Cinderella is that it was the first to the have ability to depict hyperbolic and spherical geometries onscreen (Burgiel, 1999).

Other software programs have been used for some of the research reviewed in this paper, including the Geometric Supposer (Schwartz & Yerushalmy, 1993). This program was created by Michal Yerushlamy, a renowned college professor in Haifa, who has written a great deal of research on technology in education, and Judah Schwartz, a professor at MIT and professor emeritus at Harvard. Supposer allows users to create a variety of geometric figures in different positions that students examine in order to deduce properties of those figures. In its earliest versions, Supposer did not have dynamic capabilities. However, the latest version of this software, Geometric Supposer-3, now is dynamic (Talmon, 1999).

An add-on feature to Geometer's Sketchpad is Shape Makers (Battista, 1998), which is geared for younger students, grades five through eight. This software is more structured than the others, including explorations for the students to work through, unlike the wide-open exploratory software forms of Cabri, Sketchpad and Cinderella. Other software programs have emerged as well, but little research has been done regarding those programs, so they will not be discussed in this paper.

General Research on Technology's Impact on Students

A great deal of research has been written on the impact of technology on education, running the gamut of research on student and teacher attitudes and beliefs about technology to the use of graphing calculators, and covering a wide range of curricular areas. I will outline some of the research here on the areas of student achievement and interest as it relates to technology.

Impact on achievement.

Since the early days when technology meant overheads and filmstrips, researchers have investigated the impact forms of media can have on student achievement. With the advent of computer technology and software programs, this research has increased in volume and specificity, but with often contradicting results. One landmark study on the impact of technology on achievement was Harold Wenglinsky's extensive report "Does it Compute? The Relationship between Educational Technology and Student Achievement," which appeared in 1998. Wenglinsky analyzed data from the National Assessment of Educational Progress (NAEP) study of 1996, to determine if technology played a role in student achievement. The subjects of the NAEP study were fourth, eighth and twelfth grade students, but Wenglinsky only examined the data for the two younger grades. Some of the topics that the NAEP data included were: how often computers were used in school, what type of access and frequency of use of computers at home, professional development of math teachers in computer use, and kinds of instructional use. In terms of achievement, Wenglinsky, in his analysis of the data, found that how often computers were used had little impact on the achievement levels of students, in either fourth or eighth grade, but that when computers were used to teach concepts that required higher level thinking, and teachers were appropriately trained, significant gains in student achievement could be seen (Wenglinsky, 1998). He also noted that when computers were used for lower order thinking skills, there was even a detrimental effect on student achievement, perhaps related to students not being on task.

Another study by Leah P. McCoy in 1996 researched computer based mathematics learning from a constructivist point of view (McCoy, 1996). The belief behind constructivism is that students use prior knowledge to construct new knowledge on their own, or through guidance; that is, "students learn mathematics by active involvement with mathematical models that allow them to internally construct their own understandings and concepts." (p. 438). In her study, she examined research on three major categories of computer use for education, programming, computer-assisted instruction, and use of tools. She found that use of computers overall could have a significant impact on achievement in conceptual areas, while studies showed little difference in computation and manipulative skills. McCoy commented that this supported the value of using computer tools in a constructivist classroom. However, she also emphasized the importance of the role of the teachers in guiding students in constructivist learning.

Christmann, Badgett, and Lucking in 1997 completed a meta-analysis on the achievement of students using traditional methods, supplementary computer-aided instruction (CAI), and computer-aided instruction alone. This re-analysis of data from 26 studies on high school students had some interesting results. While one of their major findings was that students who had supplemental computer-aided instruction did indeed score higher on average after the treatment period, they also found that over the 12 years of studies, the mean effect of computers on achievement diminished. That is, in the later years, use of computers had less of a positive effect than in the earlier years. They felt that this might have been a result of the novelty of computers wearing off.

A more recent study by Hede (2002) created a model to identify the major variables, which impacted how multimedia affects learning. With learning designated as the dependent variable, he studied factors such as visual input, auditory input, learner control, attention, working memory, long-term storage, motivation, cognitive engagement, intelligence and reflection. Using data from his study, he created a model that related these factors. His research agreed with previous studies in that it was not how much or what type technology is used, but how it is used:

> The reality is that the new and emerging instructional technologies used by multimedia are only tools—unless they are applied with careful regard to the complex nature of human information processing, they can have a detrimental effect on learning. The integrated model has the potential to prove useful in fostering good instructional design that properly accounts for the complex nature of multimedia effects on learning." (p. 187)

Hede (2002) also noted that there is a great deal of disagreement in the research on whether media has a positive or negative effect on learning. Some of this disagreement lies in what types of learning are studied. For example, Cradler, McNabb, Freeman and Burchett (2002) took part in study by the Center for Applied Research in Educational Technology (CARET). They examined the impact of technology on three aspects of learning: achievement in content areas, higher order and problem solving skill development, and work force preparation. Their results showed that content area learning could be affected when use of technology supported specific curricular goals or standards. They stated that: "…making standards and learning explicit to the students is part of effective technology implementation." (p.47). They agreed with Wenglinsky on higher order skills development: well-trained teachers are needed to guide students carefully in their learning activities. They agreed, as well, that lower order skills might not be improved using technology. In addition, the CARET study also found that use of technology in school is important in preparing students for work in a technological world.

Impact on interest.

While many studies offhandedly remark that computers increase interest in mathematics, little empirical research has been done in this area. Interest seems often to be a secondary object of study in reports on achievement. For example, Wenglinsky determined that use of technology among eighth grade students had a positive effect on social environment, which he defined as including such factors as student tardiness and absenteeism, teacher morale, teacher absenteeism, and how students treated school property (Wenglinsky, 1998). It appears that students wanted to attend in order to use the technology. In a 1999 study, Roberts and Stephens studied the effects of time spent in the computer lab on achievement. While their study found no difference in student achievement as a result of technology use, they did find that it added to students' enjoyment and interest. One caveat they note is that some students also said they felt time spent in the regular classroom would have been more beneficial to them.

The commonly held observation that students seem to enjoy using technology points to the possibility that interest and motivation may impact achievement indirectly. In another research overview, Middleton and Spanias (1999) examined motivation for achievement in the math classroom. They came to several conclusions. First, they found that if students perceive they will have success, they are more motivated to learn the subject. The researchers felt that it was important for the students to attribute success to their own hard work and innate ability, while being able to place blame for failure outside of themselves. Second, they found that motivations are highly affected by teacher attitudes and actions, and indeed, expectations. Third, they found that intrinsic motivation is more powerful than extrinsic, and that teachers should emphasize skills students perceive as meaningful in order to motivate students. Certainly technology can be used to motivate students by providing real world situations to practice skills. As a fourth point, Middleton and Spanias noted that there are gender inequities in motivation, and that it is important for teachers to combat learned helplessness in girls. Finally, they determined that while student motivation level is generally stable, it may be improved through careful planning of instruction. That is, teachers can adjust their instruction to meet the motivational needs of students (Middleton & Spanias, 1999). Using technology may be a way teachers can change to meet those needs.

Singh, Granville, and Dika in a 2002 study attempted to link motivation, interest and academic achievement. Their research project examined 3,227 eighth grade students in an analysis of three constructs to performance in math and science. These three factors were motivation, attitude and interest in mathematics and science, and time spent at the academic subject. Their findings indicated that motivation, positive attitudes and engagement in academic work have a strong positive effect on success in math and science. They noted that this result was consistent with prior research. Singh and Granville stated: “Educators have an opportunity to alter the negative attitudes and strengthen more positive attitudes toward mathematics and science by promoting better classroom practices and by providing positive experiences in these subjects" (p.331). While this study did not specifically discuss technology, it is not a great leap to presume that use of technology can help students have positive learning experiences.

In general, it is clear from the research that there is some disagreement on the effects of the general technology use on student achievement and interest. We now move away from the general to a more specific examination of the impact of the use of dynamic geometry software.

Specific Research on Dynamic Geometry Software

Dynamic geometry software is relatively new to the mathematical scene, but already there have been a number of studies done on the effects of using the software on students, how to implement it, and how it fits into the current curriculum. Here we explore some of the studies that have been undertaken in an attempt to understand its effects on achievement and interest.

Impact on achievement.

Studies on the effect of the use of dynamic geometry software on achievement began to appear soon after the software was released. One early study by M.L. Lester took place in 1996. That study, used for her dissertation, involved research on 47 female high school students. Lester's control group used traditional geometry tools, while her experimental group utilized Geometer's Sketchpad. The study examined three variables: geometric knowledge, geometric construction, and geometric conjectures. After treatment, which consisted of completing a number of geometry lessons, Lester results showed no difference between the control and experimental groups in terms of Geometric knowledge and construction, but did find the variable geometric conjectures was significantly higher for the experimental group. She stated that this implied students learn higher-level skills as a result of creating and manipulating geometric objects using the computer in a process she called dynamic visualization (Lester, 1996).

Prolific writer R.D. Hannafin joined B.N. Scott to study the effects of dynamic software on learning. However, their study was more focused on how students learn. Much of Hannafin and Scott's earlier work revolved around open ended learning environments, or OELEs, where students are guided by teachers who act as facilitators to help support students in deciding what resources are needed to reach their learning goals. The authors stated that while dynamic geometry programs are not OELEs themselves, they could be used in these situations to support learning (Hannafin & Scott, 1998). In this particular study the researchers proposed to examine possible learner traits of eighth grade students in the less structured environment of Geometer's Sketchpad. Three traits to be examined in the study were working memory capacity, student preference for amount of instruction, and ability to solve problems in a spatial context. Hannafin and Scott proposed four hypotheses: (a) high working memory will result in greater factual and conceptual understanding, (b) higher needs for instruction will correlate with better factual understanding, (c) students who are better spatial problems solvers will have greater conceptual understanding, and (d) students with high math grades will have better factual skills than those with lower grades and students with lower grades will have greater conceptual gains than factual gains. The experimental treatment involved use of Geometer's Sketchpad, and the results of the study surprised the authors. Of the four hypotheses, only the last one was supported. That is, students with high math grades appeared to advance in factual achievement, and students with low grades made gains in conceptual areas. One other result was noted that was unexpected. Students who preferred low instruction levels outperformed those who prefer more instruction in the conceptual areas. One reason for this that Hannafin and Scott suggested was that those students might be better at reasoning things out on their own. Regarding working memory and achievement, the authors noted that while previous research shows working memory has an influence on achievement in text situations, using the more visual, text-free environment of Sketchpad might make a difference. Hannafin and Scott found the most encouraging result of the study to be that the low ability students made gains comparable to the high ability students in the conceptual areas.

Studies on mathematics learning are not limited to the United States. Studies on Cabri Geometry have taken place in France as well (Laborde, 2003). Laborde's study notes that technology alone is not enough to increase learning. Teachers play a critical role in guiding student learning in the use of dynamic geometry software. One interesting study encountered in this examination of the literature was an unpublished manuscript by a student at the Flinders University of South Australia, Katherine Dix. Dix had several research questions. She studied the effect of technology versus pencil and paper instruction on achievement, motivation, and attitude. In addition, she also examined whether there were differences in attitude based on gender, and whether time requirements varied with the technology versus the traditional geometry teaching methods. Dix's study group was a group of eighth grade students. The experimental group used Geometer's Sketchpad while the control group learned in a traditional classroom. Dix put forth five hypotheses. She postulated that there would be no difference in achievement, that use of computers does not influence motivation, that attitudes towards computers don't differ between male and female students, that students attitudes towards computers don't change after using technology, and, finally, that time to complete assignments does not differ in technology rich learning environments.

In Dix's study, the students completed two assignments using Geometer's Sketchpad in their respective groups, took an end of unit test, completed a computer attitude survey before and after the treatment period, and answered questions posed by the researcher (Dix, 1998). Her results were as follows: Achievement was actually slightly higher for the traditional group on both assignments and test (but not significantly), while motivation increased with the use of technology. She also found that males more likely to explore using the software, but didn't always finish their work, while females explored less, but got their assignments done. She did find differences between male and female attitudes toward computers, as will be discussed in the next section. Her last hypothesis, that there was no difference in time for lessons was accepted, since both the traditional and computer students requested more time to complete assignments. One note that Dix added to her conclusions was that students on the computers tended to do more work, for example creating several versions of the assignment before turning it in, while pen and paper students created only one version.

An article by Glass and Deckert outlined some of the directions they felt research was pointing on how technology, including Geometer's Sketchpad, can help students learn geometry. They made four points. First, using technology can help students focus on relevant aspects of a problem rather than seeing just a single example. Second, technology can help students function at a higher level of geometric understanding.

Third, technology can help them differentiate between drawings and constructions, by allowing them to adjust figures and see what changes and what doesn't. Finally, the authors stated that the research shows students can better learn to generate conjectures based on seeing patterns by using technology (Glass & Deckert, 2001).

A number of studies have also been done attempting to link the van Hiele levels of geometric learning with use of dynamic geometry software. A husband and wife, Pierre van Hiele and Dina Van Hiele-Geldof who were Dutch educators, created the Van Hiele levels. The van Hieles determined that there are 5 levels of geometric understanding, which must be progressed through sequentially. The first level is visualization, when students recognize figures and relate them to objects they know. For example, students might state that a rectangle is like a door. The second level is analysis, where students know what the properties of figures are but do not know which properties are enough to define the figure. The third level is abstraction, in which students can classify figures and use basic logic to justify reasoning. The fourth level is deduction. Students at this level can write simple proofs, like those needed in high school. The final level is rigor, at which point students are capable to understand non-Euclidean geometry and can construct more difficult proofs. Prolific writers Clements and Battista suggested a sixth level, level 0 (Clements and Battista, 1992). This level they called precognition, where students can see some of the properties of a shape, but can't always distinguish figures (Mason, 1998).

A number of the studies relating the van Hiele levels to use of dynamic geometry software were written as dissertations. Some of these studies indicated that students can progress through the van Hiele levels faster when they can use dynamic geometry software (July, 2001), while others found no difference in either achievement advances or progression in the van Hiele levels following the use of Geometer's Sketchpad (Johnson, 2002; Moyer, 2003). July specifically noted that data indicated that GSP used appropriately could help improve spatial skills, improve students' understanding of 3 dimensional objects and help students progress in the van Hiele levels. Johnson commented that no advancement was seen and that use of dynamic geometry software even seemed to hinder students in proof writing.

Another study mentioning the van Hiele levels was a case study by Choi-Koh (1999). The author observed a single seventh grade student for 21 hours while the student completed nine units of geometry using Geometer's Sketchpad. She also utilized video and audio taping of the student at work and interviews to gather information. In her study, she found that the student did make progress in the van Hiele levels. She stated: "The interactive environment provided by geometry software has the potential to foster students' movement from concrete experience with mathematics to more formal levels of abstraction, to nurture students' conjecturing spirit, and to improve their mathematical thinking." (p. 309).

Michael Battista conducted a study in 2002 on younger students, to examine the effects of use of dynamic software on fifth grade student learning. Battista utilized Shape Makers (Battista, 1998) an add-on program for Geometer's Sketchpad that he had created. The program is dynamic, but is used to create shapes that can be manipulated in a slightly more structured environment. The program includes lessons that students work through in a progressive discovery process. Battista utilized the case study method for his research. A result he observed was that students who were at different levels helped each other progress in the van Hiele levels. He also found that student thinking processes moved from concrete to abstract, and that students made gains in classification knowledge by exploring shapes. He commented that the program helped students develop mental models that progressively became more complex as they worked with the program. His findings indicated that he felt students were more able to construct their own meanings, and thus make strides in learning through the use of dynamic geometry software.

Other dissertations (Hodanbosi, 2001; Baharvand, 2001) indicated increases in achievement level following use of DGS. A lengthy (18 week) study by Funkhouser of older students (tenth and eleventh grade) also found that students using the Geometric Supposer had significant increases in test performance over a control group not using the software. (Funkhouser, 2002-2003)

Not all studies of the impact of software showed a positive impact on student achievement. Thomas Gawlick (2002) used a pretest-posttest method of study on 214 students in grade 7. He chose a control group who were taught using traditional teaching methods, a computer group which used DGS and a pen and paper group who used the same problem solving worksheets the DGS group did, but without the computer. He found that for the majority of the study, pen and paper groups did about the same as the computer group. One exception was that for girls in private school, the pen and paper group was significantly higher. Gawlick also found that the high ability students in the pen and paper group did better than those in the computer group, except that high achieving girls from coed schools did better in the computer group. The author felt that one of the reasons for this result was the factor that time was needed to learn the computer and adjust to the presentation method. He also noted that low achieving boys wasted time playing on the software program. In a later post-test follow-up, he did find that the computer group scored slightly higher than the pen and paper group.

Finally, a couple of studies by Hannafin and others produced some interesting results. Hannafin, Burruss, and Little produced an article (part of a larger study) on perspectives of teachers and learners who were using DGS. Comments by seventh grade students indicated that they felt they were learning using the materials of the study, which consisted of an activity book, Geometer's Sketchpad and a software program created for the study called Intro to Geometry. Students utilized Sketchpad to complete activities in the booklet, but the differences in the control and experimental group consisted in how the students used the tutorial. One group progressed through the entire tutorial prior to beginning the activities, while the other group utilized the tutorial only when they felt they needed it. The authors noted that students appeared to make greater use of the tutorials as time progressed (Hannafin, Burruss, & Little, 2001). Students also appeared to appreciate having control over their learning.

This research on teacher and learner perspectives was a sub-study of a larger analysis published by Hannafin in 2004. The larger study involved looking at achievement differences in structured versus unstructured learning environments, with use of dynamic software being one such possible unstructured environment. Hannafin states "identifying the factors that influence success under such unstructured environments could have critical development and implementation implications." (p.20) Hannafin chose student mathematics ability and type of instructional program as independent variables with student achievement as his dependent variable. He stated three hypotheses. In the first, he hypothesized that students in the structured environment would score higher on factual information questions on the end of study test than those in the unstructured program, but that students in both programs would score comparably on difficult conceptual test items. Second, he theorized that higher ability students would outscore lower ability students by a greater margin on the factual items than on the difficult items. Third, he hypothesized that high ability students in the structured program would outscore high ability students in the unstructured program, but the scores of the low ability students would not differ by program.

Hannafin's findings contradicted his previous research with Scott. Regarding his first hypothesis, although differences were not significant, he found the opposite of what he expected. Students in the unstructured program outscored the other group on the factual items and students in the structured program also performed slightly better on the difficult conceptual items than those in the unstructured program. Also, for his second hypothesis the outcome was the opposite of that expected. High ability students surpassed low and medium ability students on the difficult items by a larger margin than on the easy items. Although Hannafin had had different results in a previous study, he noted that this was what commonly occurs in a classroom (Hannafin, 2004). The third hypothesis was partially supported. High ability students in the structured environment outscored high ability students in the unstructured, as expected, but Hannafin found that low ability students in the unstructured program did better than those in the structured, although neither group of low ability students did particularly well. The author did find this somewhat encouraging because it indicated that low ability students may be able to function in unstructured environments given appropriate support.

While the focus and subjects of the studies varied slightly, the majority of these studies found that use of dynamic geometry software does appear to have a positive impact on student achievement. This appears to be true particularly for achievement of higher-order thinking skills, and less applicable for factual information.

Impact on interest.

For the purposes of this research paper, studies on motivation and attitude will be examined as being linked to interest, although the concepts are not identical. Students may be motivated to do things they may not like to do, but do anyway for a variety of reasons. While there are considerably fewer studies on interest and motivation than on achievement, the research is still worth reviewing.

Some of the previously mentioned studies on achievement also measured interest or motivation of students. For example, in Hannafin, Burruss and Little's 2001 study, students reported after the study that they now enjoyed geometry. Likewise Baharvand (2001) not only reported an increase in achievement, but also significant positive differences in attitude. Hodanbosi (2001) found that males had improved attitudes toward mathematics after her study, although they did not show better achievement than the females in the study. Funkhouser (2002-2003), on the other hand, noted that that following his study using the Geometric Supposer, there was no significant difference in attitude, although some students in the experimental group had a more positive attitude to begin with, so differences may not have been noticeable. Some implications he notes are that use of the computer alone doesn't result in a more positive attitude, but that initial attitudes toward math may be critical for student performance in the classroom. Dix (1998) found there was a slight but not significant positive change in attitude among females following technology-rich lessons, but that males showed a significant positive shift in attitude. Another encouraging observation Dix made was that many students requested to keep working on assignments during lunch or recess although this was not allowed.

In addition to the previous research, A.E. Yousef, in a 1997 dissertation, found in his research that the effect of use of GSP on attitudes was significant. He found an increase in positive attitudes in the experimental group using both quantitative data from a questionnaire and qualitative data from interviews and observations.

Studies on Teaching and Implementing DGS

Many challenges lie ahead for teachers who want to implement dynamic geometry software into the curriculum. Current research indicates some of the difficulty lies in reluctance of teachers to change. Other problems exist in the very structure of the educational system.

Teacher attitudes and beliefs about technology.

Teachers often are reluctant to move from a teacher-centered learning environment to a student-centered classroom because they feel they have less control over their students. A study by D.E. McDougall (1997) reported on four teachers implementing a computer-based exploratory environment. He found that the teachers felt an initial loss of control in three areas: management control or discipline, personal control or the ability to determine expectations, and professional control in that they felt they no longer had all the answers to the students' questions. The study took place in a Canadian city with eighth grade students in one all boy school, one all girl school and two coed schools. Teachers were observed and interviewed about their feelings as the study progressed. Despite the early feelings of loss of control, the teachers gained confidence as they realized students were learning geometry and enjoying it. McDougall noted that the control of the classroom that teachers desire is one important area that must change in the implementation of a computer based geometry program. He stated the students get mixed messages from teachers as directors of the classroom, since they are expected to follow directions to the letter, yet also think creatively and be responsible for their own learning. McDougall commented that teachers need to move from the role of controller of the classroom to facilitator or guide, and that dynamic computer environments provide an ideal place for teachers and students to work together.

A study by Norton, McRobbie and Cooper (2000) examined teachers' reasons for not using computers in their classrooms. They observed that at the particular school being studied, technology was readily available, but underutilized. They used the case study method to determine why teachers were choosing not to use the available computers. They found five major themes: (a) teachers perceptions that the classroom should be teacher centered, (b) belief that computer time could be better spent in the classroom on other activities, (c) belief that the need for basic skills work is more important than computer use, (d) preferences for particular texts or other materials, and finally, (e) perceptions about appropriate assessment methods (not computer based). The authors concluded that teachers had philosophical and educational reasons for not using computers and that in order for change to occur, staff dynamics and culture will need to be changed.

In the previously mentioned study by Hannafin, Burruss and Little (2001), perspectives of teachers were examined. The authors examined teacher attitudes and potential resistance in the shift in roles from leader to facilitator in the dynamic geometry environment, as well as the difference between theoretical views and what actually occurred in the classroom. Data was gathered via interviews and observations and the teacher kept a journal with her feelings and comments. During the study, despite the fact the students said they felt that they were learning, the teacher questioned deep learning and retention of concepts. The teacher also expressed her feeling that directed practice and use of Sketchpad as a tool was more appropriate than exploring. The teacher also felt that students didn't get enough assessment or feedback during the study; and expressed a conflict that she felt that the students were moving too slow, but also not being careful enough and checking work. Overall, the teacher had difficulty giving up control of the classroom despite the fact that she had agreed to do so at the beginning of the study. The authors felt that some reasons for this might be that she felt accountable to supervisors and parents and that she felt the need to be preparing students for standardized tests. The authors also note that the teacher did not have training in facilitating in the classroom. (Hannafin et al, 2001).

Based on this research, teachers appear to be somewhat resistant to changing to a more computer-centered mathematics learning environment. Some of the authors attribute this to the age of the teachers (McDougall, 1997). Fortunately, teachers are more often using computer technology in their pre-service education and some are seeing the benefits of it. A comment by a student in an undergraduate teacher program where Geometer's Sketchpad was used makes it clear that some doubts remain, but also clearly reflects enthusiasm for use of software:

> I don't know if this software will help students learn more or not, but what I do know is that I was a lot more motivated to think about the theorem than I would have been in the past. If I can use Sketchpad when I start teaching to get kids excited, that seems like a good enough reason to do it. (Pandiscio, 2002, p. 221)

Suggestions for implementing DGS.

Many studies on education topics conclude with recommendations or implications for the classroom. Several studies giving comments on how or why to implement DGS will be outlined here. Choi-Koh (1999) notes that "…critical attributes of a well designed computer environment are that it be useful enough to help students build bridges between intuitive and analytical aspects…and be flexible enough to allow…open-ended investigations…and promote the ability for conjecture…" (p.309) Jones (2002) explains what he terms "key messages" from a review of the literature: (a) dynamic software used inappropriately does not help and may even be detrimental, (b) dynamic geometry integrated within an appropriate curriculum and teaching method can result in achievement gains, (c) what matters is how the software is used, (d) if DGS is used to explore higher concepts it can lead to higher level learning; and (e) dynamic software can assist some types of learning, and add to others.

A study by Rochelle, Pea and Hoadley (2000) suggested that use of technology should be implemented to support the following learning areas: active engagement, group work, interaction and feedback, and connections to real world problems. In order to learn how to most effectively meet those needs, the authors suggested that more research is required in four areas. They stated that these areas are cognitive learning;

curricular reform; coordinated work to improve assessment, the curriculum and professional development; and capacity for technological change in schools.

It appears that all research examined here on implementing DGS agrees that change is needed. In fact, curricular reform is a repeated theme. An article by Heid (1997) explains the cyclic relationship of mathematics reform and the technological revolution. The author states: "Research in the area of technology and mathematics education has corroborated many of the assumptions of the mathematics reform movement…and the mathematics reform movement has, in turn, guided the direction of research on technology-intensive approaches to mathematics reform. " (p. 41)

Gawlick (2002) outlined three processes prior to beginning his research which he felt would make his study workable. These can be projected to generalized implementation of DGS. The three processes were: (a) selection and processing of appropriate materials for students to work with while using DGS, (b) training of teachers to make use of this material, and (c) making the teaching methods work with regular teaching conditions. Gawlick concluded his study by noting that teachers shouldn't expect too much from implementing DGS in the current curriculum, but that curricular reform is necessary.

Several other sources comment that teacher training and change in teacher attitudes is crucial to implementing dynamic geometry software (Dix, 1998; Hannafin, Burruss & Little, 2001; McDougall, 1997; Norton, McRobbie, & Cooper, 2000). Norton emphasizes that not only do teachers need to make a change, but that structural change is also required to accommodate computerized learning. For example, types of texts and other resources need to be adjusted, as does assessment criteria. Gawlick (2002) also stated that schools need to have equipment available to allow DGS homework and appropriate DGS assessment. Without such changes, effective implementation of DGS will not be possible.

Chapter 3: Results

Question 1: What is the Impact of DGS on Achievement?

Do studies show a difference in achievement levels in students who use dynamic geometry software? The research, in general, indicates yes, with some caveats. Use of dynamic software appears to be more effective when used to teach conceptual rather than factual knowledge. In other words, dynamic software seems to support gains in higher level thinking skills more strongly than factual gains.

From the research we can also conclude that how software is used is important to achievement gains, that is, whether the software is used as a tool or as a part of an exploratory student-centered classroom also has an effect on how much students learn. When used simply as a tool, gains in achievement are less likely to occur.

Question 2: What is the Impact of DGS on Interest/Attitude?

Does research show that the use of this dynamic software makes a difference in the interest level of the students in the topic? Research on this topic was not conclusive. Some researchers found that attitude was impacted by DGS use while others disagreed. More research is necessary in studying the impact specifically of dynamic geometry software, and generally the effect of technology on students' interest and attitude toward learning mathematics.

Question 3: Does DGS Meet the Needs of Both High and Low Ability Students?

Is the use of dynamic software effective in meeting the learning needs of all students in a classroom, or some more than others; in particular, does it cater to academically higher-level learners or lower-level learners? Again, little research has been done on this question. Hannafin's work in this area seems to be encouraging regarding low level students' ability to work better in an unstructured DGS environment. Gawlick's study found that some high level students performed better using DGS and some did not. However, more specific research on the impact of the use of DGS by both high- and low- level students is needed.

Question 4: What are the Suggestions for Implementing DGS?

What have studies shown to be the best methods of applying this technology in the classroom? Discussion in this area seems to encompass three main ideas: the necessity of creating a student-centered classroom, providing appropriate teacher training and ongoing professional development, and reforming the curriculum to make it appropriate to the student centered classroom. Current classrooms are traditionally teacher centered, whereas use of DGS for more than a tool requires a student-centered, computer-based classroom. Teachers require training to make this happen, as most were educated themselves in a traditional classroom, and experienced traditional style training in college as well. In order to change this traditional education pattern, college teacher training programs must implement change as well. Classroom teachers are not always taught how to run a student-centered environment. They need to be trained in techniques of facilitating and guiding self-learning, as these methods are probably unfamiliar to them. Finally, few texts support student-centered learning, but rather provide materials to support the teacher. Changes in the curriculum and resources available to teachers are necessary for appropriate teaching using DGS to take place.

Chapter 4: Discussion

Problems with the Research

Some of the findings in the research examined for this paper were less than conclusive or even contradictory. During my examination of the literature I discovered that I had some difficulty in agreeing with some aspects of the research that I encountered. I found several problems with areas of study, which included problems with subjects, size, and expectations of the researchers.

One concern I had involved age of the subjects. It appears that there has been less research done on the use of DGS with older students than with younger. For instance, many of the studies that I read investigated seventh or eighth grade students. I would suggest that to use students this age for research in the area of geometry rather than older students is not as productive. If it is commonly high school students who take a geometry class, where is the benefit in studying junior high or middle school students? In fact, if we are to study higher-order thinking skills and their relationship to the use of dynamic geometry software, perhaps these students are not yet at a cognitive level where some of those skills can be gained. While not saying that we should stop studying younger students, I would suggest that more research should be done using older students, possibly even college undergraduate students.

A further worry I have about many of these studies is that they were often quite short, only 5-10 days. I do not feel this is an appropriate amount of time for judging cognitive gains. Students need time to reflect on concepts and a week is certainly not enough time to determine whether high-order thinking skills have progressed. Likewise, the research on progression in the van Hiele levels as it related to DGS seemed inappropriate. Some researchers expected students to make gains in van Hiele levels during the brief study period, when students often spend up to three years at the same level. This does not mean progress is not being made during that time period, and some of the researchers seemed to fail to take that into account when they concluded that no advances had been made. The research community needs to consider long-term studies of students, even studies that encompass several years of learning. However, if we want to study geometry learning over a period of several years, we may need to change the way that geometry is being taught. While that change may not be feasible at this time, a long term of study would be more effective than the short-term studies that are currently taking place.

Size of some of the studies was an additional factor that concerned me. For example, although the author had some valid points, I questioned the validity of the results of the Choi-Koh study, as only one student was involved in the research. It is too difficult to tell in this study whether student progress was a result of use of GSP or of the one-on-one tutoring the author provided. The larger studies were more appropriate to the topic being examined, although there were differences in student ability grouping among the studies, which is a topic that must be examined as well, if we are to replicate studies in the future.

Suggestions for Further Research

One conclusion is certain, however, from an examination of the literature; there is a great need for further research on dynamic geometry software. Much more research needs to be done in two of the areas this research paper covered: the effect of using DGS on student attitude and interest in math, and studies on high and low ability students and their experiences with DGS.

The need for further research on attitude and interest is a formidable challenge. Attitude measurement studies do not always seem accurate. Much of the data is qualitative and depends on student responses, which are notoriously unstable. Also, personalities of teachers can certainly affect student attitudes in class. This fact was noted in only some of the studies I examined. Perhaps future research can develop a more objective tool for the measurement of interest and attitude.

It is imperative that we make further studies of the effects of the use of dynamic geometry software on both high and low level students. Knowing if DGS is appropriate for a classroom that includes special education or gifted students is necessary if we are to implement these programs. Again, long-term studies in this area as well would be more appropriate in order to determine if significant gains are being made by these students through use of DGS.

A new area of interest in the literature is dynamic geometry and proof. Recent research has been done on the role DGS may play in student creation of geometric proofs. This early research seems to indicate that students can create proofs or at least make sense of prewritten proofs by using dynamic software (Vincent, 2003; Marrades & Gutierrez, 2000; Scher, 2002). Because of the importance of proofs in geometry, this is an area in which more study will be necessary if teachers are to move to a completely computer-centered geometry class. Perhaps future research will find increased achievement levels in the area of proof using DGS.

Finally, research studies should be planned which utilize teachers who are experienced DGS users, rather than first time users of the software, in order to isolate some of the variables that may be affected by lack of teacher knowledge about the software program, unless the research is specifically examining the role of first year teachers of DGS. This research should also require further examination of the training of preservice teachers in the use of DGS.

Usefulness of This Study

Fort new users of DGS, the following four points are essential to effectively implementing DGS in a classroom:

- Training of teachers prior to use of these software programs is absolutely necessary. Not only is training needed in the use of the software, but training is also necessary in changing the role of the teacher to classroom facilitator in a student-centered classroom rather than lecturer in an instructor-centered classroom. This training needs to begin with our teacher education system.
- Students using this software can make significant achievement gains if the software is implemented correctly, in a guided exploration setting. Students are more likely to make conceptual gains through the use of this software rather than factual gains, so teachers must use that knowledge in guiding the students.
- Curricular change is necessary for effective use of this software. The move from teacher-centered to student-centered classroom will require changes not only in teacher attitudes and training, but also in textbooks, other teacher resources and computer equipment.

- Further research is needed in the use of dynamic geometry software. Studies need to examine specifically who benefits most from this software and in what areas of the geometry curriculum. Researchers need to further explore effects of the use of dynamic geometry software on interest as well. Finally, our research needs to be greatly improved in order to answer the questions we want answered. Well-planned research needs to be done with trained, experienced teachers in a setting appropriate to the study.

In conclusion, I hope that this study will be valuable to other teachers who are looking to determine whether DGS can improve student learning in their classrooms. While significant changes must be made in the curriculum in order to use dynamic geometry software, the results and student benefits are worth it.

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