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Analysis of Cognitive Tutor Geometry Curriculum

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Analysis of Cognitive Tutor Geometry Curriculum

By

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A dissertation submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Major: Education

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Abstract

The Carnegie Learning Cognitive Tutor curricula are based on cognitive models, which include a representation of the learner’s thinking, strategies, and misconceptions. The Cognitive Tutor curricula typically speed up learning and yield greater learning as compared to traditional math curricula (Morgan & Ritter, 2002; Sarkis, 2004; Koedinger, Anderson, Hadley & Mark, 1997). In 2003 – 2004, sixteen school districts in Iowa started implementing Cognitive Tutor Algebra I, which proved to be very successful. Due to the success of the program, its implementation was expanded to Geometry and Algebra II. This research focused on the implementation of Cognitive Tutor Geometry Curriculum in eight schools in Iowa. The purpose of this study was to develop a case study evaluation of eight schools. Significant gains in student growth were observed in all the participating schools. Geometry teachers from all participating schools were interviewed for the study to gain teachers’ perspectives about the curriculum. The Cognitive Tutor Geometry textbook was reviewed for coherence, focus and alignment of topics with Iowa Core Curriculum. This study presents both quantitative and qualitative analyses of the Cognitive Tutor Geometry curriculum.
Chapter 1. Introduction

This chapter informs about the problems in the mathematics education, followed by the objectives of the study, which lead to the research questions.

Statement of Problem

Success in High School Mathematics can launch students into more advanced math and science classes, and can boost their confidence throughout their secondary school careers. Unfortunately, many students struggle with mathematics and are left behind. This problem was evident in the 2006 Programme for International Student Assessment studies (PISA). According to this study, U.S. students scored lower than the Organization for Economic Cooperation and Development (OECD) average on the mathematics literacy scale. In addition, the Mississippi Bend Area Education Agency 9 showed a significant drop in state of Iowa math scores for eighth grade students, especially in the area of problem solving, and particularly among students from low socioeconomic backgrounds. The Cognitive Tutor Curriculum, a high school curriculum that combines text and teacher-led classroom instruction with software tutoring for individual students, is one way to address this issue.

The assumption is that the students will use the software in Algebra I, Geometry and Algebra II. 2,600 schools across United States have adopted Cognitive Tutor curricula (www.carnegielearning.com). More than 500 schools in Pennsylvania currently use the program. In Iowa, sixteen school districts started implementing Cognitive Tutor Algebra I at middle school/junior high or high school level in 2003-2004. Classroom time is structured to provide students with 60% direct instruction with their teacher, cooperative work with classmates and peers, and time to complete mathematics tasks. During the remaining 40% of the time, students work at their own pace on the Algebra I curriculum with the Computer Tutor. The software
allows students to work at an individual pace. It also offers teachers a way to closely monitor student progress. When students solve difficult math problems with the computer tutor (without the human tutor), it empowers them to realize that they really did it by themselves. In 2004-2005, the Mississippi Bend Area Education Agency evaluated Cognitive Tutor Algebra program and reported positive results (http://www.aea9.k12.ia.us/index.cfm?nodeID=11564&action=display&newsID=1737).

Due to the success of this program in Algebra I, its implementation was extended to the geometry curriculum. So far, the Cognitive Tutor Curricula software and instructional material is supported by the No Child Left Behind (NCLB) and Enhancing Education Through Technology (E2T2) grants. Challenges can arise for school districts that cannot afford the equipment and software and/or if students have to travel to a dedicated computer lab to access this program. Schools where the funds and grants were available have provided laptops to students in math classrooms. There is a need to examine and evaluate the implementation of this curriculum to see if these resources contribute significantly to student achievement. It is also important to determine if the Cognitive Tutor Geometry curriculum is aligned with Iowa State Standards.

**Objectives of the Study**

This study focused on three areas: First, it examined the implementation of Cognitive Tutor Geometry curriculum in seven schools and a traditional Geometry curriculum in the eighth school. Each school offered different number of geometry classes with 1-4 teachers in each school. Six schools used the Cognitive Tutor Geometry software along with its accompanying textbook. One school was using a different textbook with Cognitive Tutor Geometry software. The last school used a different geometry curriculum and served as a control school.
Second, this study examined students’ pre-test and post-test scores in geometry classes in all eight schools. The scores for each topic were analyzed separately to find out which topics are covered well, and which topics need improvement in Cognitive Tutor Geometry curriculum. After that, students’ scores were analyzed for the low-ability and high-ability students to see if student progress is uniform for all ability levels.

Since teachers’ knowledge, beliefs, and perceptions play a fundamental role in implementation of a curriculum, it was important to bring their perspectives into the study. Their interviews were conducted to understand the level of implementation, issues and suggestions for this curriculum. If the curriculum is implemented according to developers’ intention, it is expected to be more coherent, connected and comprehensive. On the other hand, if there is a gap between curriculum goals, and practices, it might end up in waste of resources and demoralizing experiences (Bantwini, 2009).

Finally, this study aimed to explore how teachers comprehend the Cognitive Tutor Geometry curriculum, and its impact on student progress. After examining student progress and teachers’ perspective, this research presents a few recommendations and improvement strategies, which would help schools to improve mathematics instruction. This research would also help curriculum developers and administrators in successful implementation and future planning of Cognitive Tutor Geometry curriculum.

**Research Questions**

The central aim of this study is focused on distinguishing between implementing the entire Cognitive Tutor Geometry Curriculum and implementing the Cognitive Tutor Geometry software with a different textbook. The following research questions guided the inquiry:
1) Does the Cognitive Tutor Geometry curriculum increase student academic achievement as measured by post-test scores?

2) To what extent was the Cognitive Tutor Geometry curriculum implemented within adopting schools? How did the scope of implementation differ across schools?

3) What are the teacher’s views on the effectiveness, efficiency, and convenience of the curriculum?

4) If improvements are necessary, then how can the Cognitive Tutor Geometry curriculum be improved?

Before attempting to answer these questions, it was important to review the existing research on the Cognitive Tutor curricula. The next chapter illustrates how the Cognitive Tutor curricula were built and evaluated in past.
Chapter 2. Literature Review

The review of literature begins with a brief history of Anderson’s ACT-R Theory, on which Cognitive Tutor curricula were developed. It is followed by a detailed look into the development of Cognitive Tutor curricula, which includes the theoretical basis, the application of theoretical principles, careful evaluations and a methodology for improvement based on the knowledge and studies of Ritter, Anderson, Koedinger, Corbett, McGuire, Brown, Collins, Duguid, and several others. The methodology for improvement is divided into two areas: 1) improved software prediction and 2) efficient help models as discussed by Aleven, Sarkis, Morgan and Ritter. Afterwards the implementation of Cognitive Tutor curriculum is discussed.

History of ACT-R Theory and Cognitive Tutor

The development of Cognitive Tutor Curriculum was started at Carnegie Mellon University, when John Anderson developed the ACT-R theory of cognition (Ritter, Anderson, Koedinger, & Corbett, 2007). ACT-R, which stands for Adaptive Character of Thought and Rational, is a unified theory of cognition that aims to explain the full range of human cognition. ACT-R theory tries to represent human knowledge, and understand how that knowledge results in particular behaviors (Anderson, 1990). Applied to education, this representation of knowledge results in predictions about what students are able or unable to do as well as predictions about what activities and experiences will help students learn to achieve curriculum goals. The representation of knowledge inherent in this kind of model is called cognitive modeling, and the approach of using a cognitive model in a tutoring system is called a Cognitive Tutor (Anderson, Boyle, Corbett, & Lewis, 1990). The first cognitive tutor, ANGEL, was developed at Indiana University-Purdue University Indianapolis (IUPUI). ANGEL was to address computer programming and mathematics. It was successful in a school setting, but its success was highly
dependent on the teacher’s ability to integrate the tutoring software into broader classroom goals (Ritter, et al., 2007). Looking at broader goals helped the researchers focus on the importance of working with teachers and administrators in better understanding school’s curricular needs. The research for Carnegie Learning Cognitive Tutors included experienced mathematics teachers. This team set out to build curricula that were based in cognitive research, focused on emerging national and state standards and addressed practical needs of students, teachers and administrators.

According to Ritter et al. (2007), it was decided to include textbooks in addition to the software. The purpose of including textbooks in the curricula allowed for some aspects (such as collaboration, diagramming, and writing about mathematics) that were easier to do on paper than on a computer. The combination of the textbook and software also supported the software as a routine part of mathematics instruction.

**Development of Cognitive Tutor Curriculum**

Development of the Cognitive Tutor Curriculum is based on cognitive models that explain the basic facts about learning and performance, such as why we remember some things and forget others, how we solve problems, and how we use language. The models explain the way that memories are stored in our brain and the way that perceptual information from our senses brings memories to our consciousness. The process of building this curriculum involved four parts: 1) having a solid theoretical basis, 2) applying the basic theory to the particular domain and objectives of interest, 3) evaluating results, and 4) developing and implementing a methodology for improving the curriculum. Following is an explanation of each.
Theoretical basis.

ACT-R shapes the primary theoretical basis of the Cognitive Tutors (Koedinger and Corbett, 2006). It is a theory and a cognitive model that allows the researchers to predict important characteristics of human behavior, including error patterns and response times. Most of this work has been conducted in the laboratory, but ACT-R has also been applied outside of the laboratory in areas related to human-computer interaction, training and education (Anderson et al., 1990; Koedinger & Anderson, 1993). This model assumes that problem solving skills can be modeled as a set of independent rules. The cognitive model enables the tutor to trace the students’ solution path through a complex problem solving space, providing feedback and advice on each problem-solving action as needed. This model tracing process ensures that students reach a successful conclusion to each problem. Here are some of the important tenets of ACT-R theory.

There are two basic types of knowledge: procedural and declarative (McGuire & Ritter, 2006). Declarative knowledge includes facts, images and sounds. Procedural knowledge is an understanding of how to do things. All tasks involve a combination of these two types of knowledge. Procedural knowledge tends to be more fluent and automatic. As we learn, we usually start with declarative knowledge, which becomes more fluent and automatic through practice. Declarative knowledge tends to be more flexible and also more broadly applicable. Because of the distinct characteristics of declarative and procedural knowledge, robust understanding of a domain involves both types of knowledge (Seigler, 2002, as cited in McGuire & Ritter, 2006). McGuire & Ritter (2006) present the interaction between declarative and procedural knowledge in learning to type on a keyboard. Initially this task is largely driven by procedural knowledge. If the learner wants to type without looking at the keyboard, he/she must
actively think about, for example where the ‘e’ key is located. As the learner repeats this activity many times, his/her ability to strike the ‘e’ key becomes more automatic. A beginner may rely on a mix of procedural and declarative knowledge, sometimes hitting the key without thinking, and sometimes struggling to visualize the keyboard. For such people, the procedural knowledge has been strengthened, but the declarative knowledge of the location of keys is relatively weak. Procedural knowledge cannot replace the declarative knowledge. More likely, the procedural skills continue to be strengthened through practice, but the declarative knowledge of visualizing particular keys becomes weak through disuse. Both declarative and procedural knowledge become more strengthened with use and weakened with disuse (McGuire & Ritter 2006). Strong knowledge can be remembered and called to attention rapidly and with some certainty. Weak knowledge may be slow, take more effort, or may be impossible to retrieve. Thus, if something is learned and repeated over intervals of time, the information is more likely retained. For example, if a student studies intensely for a short period of time before the test, he/she may retain the information for a short period, but not long term. This “outcome is likely because some of the context in which learning takes place is encoded within the knowledge itself, so spacing practice over a period of time helps the fact or procedure to gain multiple contexts in encoding” (Glenberg, Smith & Green, 1977, as cited in McGuire & Ritter 2006).

Declarative knowledge can be reasoned in a way that is not possible with procedural knowledge. Thus, declarative knowledge is more flexible and more easily applied in a new context. McGuire and Ritter (2006) offer the following example: a student who has learned basic algebraic transformations may use declarative knowledge to reason whether or not taking the square root of both sides of an equation is an action that preserves the equality. Knowledge is strengthened through practice and strong knowledge is easier to retrieve when needed. It is
important to note that it is possible to strengthen both correct and incorrect knowledge. The human mind cannot distinguish correct from incorrect knowledge. In the absence of feedback from the world or internal reflection, there is nothing to prevent incorrect knowledge from being strengthened. “Two plus two equals five” is a perfectly fine piece of declarative knowledge, and someone who practices that knowledge will strengthen it” (McGuire & Ritter, 2006).

Declarative knowledge may also be described as a collection of interconnected facts; rather than being stored independently as a list. Along with the facts themselves, the mind stores relationships between the facts (Mayer and Schvaneveldt, 1971 as cited in McGuire & Ritter, 2006). Facts can be brought into active consideration, which allows us to focus on related topics. Retrieving memories involves starting with a focus of attention and spreading that focus to the remaining items, which can be examined to see if they are the target of the memory retrieval.

When facts are learned, they are placed into a highly interconnected network of declarative memories. The facts that are directly or indirectly related to the retrieval cues are remembered and retrieved well. Well-rehearsed facts can be strengthened, so they can be retrieved more easily. Because of the interconnectedness of memory, it is important that facts and concepts be learned in a way that can be related to prior knowledge. The better connected a fact is to other facts and concepts, the better a student will be able to retrieve that fact. Miller and Gildea (as cited in Brown, Collins, and Duguid, 1989) found that an average 17-year-old learns vocabulary at a rate of 5,000 words per year by listening, talking and reading because learning is related to the learner’s prior knowledge and the context. On the other hand, learning words from lists without any connections is slow and generally unsuccessful.

Connections between new information and prior knowledge will be more easily established when the new material fits with students’ prior knowledge and when connections
with prior knowledge are highlighted (McNamara, Kintsch, Songer & Kintsch, 1996 as cited in; McGuire & Ritter, 2006).

Procedural knowledge is fast and requires little mental effort, which allows us to focus more of our mental energy on new learning or more complex and novel tasks (McGuire & Ritter 2006). However, procedural knowledge can also be fragile and context-specific. In the event that some procedural knowledge is forgotten, declarative knowledge can be used to reconstruct the procedural knowledge. Procedural knowledge consists of a large set of if-then rules. The “if” part of the rule specifies a condition under which a specific rule may be applied. The condition often specifies the user’s goal as well as some aspects of the context. The “then” part of the rule specifies some change to make a result of that particular rule. The action may dictate a change in mental state or it may specify an action. In algebra, procedural knowledge is a number of different rules for solving problems. These rules function as possible strategies or approaches to a problem. Students simultaneously possess both correct and incorrect approaches to a problem. McGuire & Ritter (2006) present an example of students’ rules to solve the equations of type “aX = b”

**Rule I:**
IF
the goal is to solve an equation for X
and
the equation is of the form aX = b
THEN
divide both sides of the equation by a

**Rule II**

IF
the goal is to solve an equation for X
and
the equation is of the form aX = b
THEN
Multiply both sides of the equation by 1/a
Rule III

If
the goal is to solve an equation for X
and
the equation consists of a term equal to a constant
and
that term contains a number in front of X
Then
Divide both sides of the equation by the number

Rules I and II are correct and contain the same conditions; so, either may be used when the conditions apply. However, the third rule relies on the surface feature of the equation that there is a number in front of X, rather than an understanding of the mathematical meaning that the number multiplies X. If a student has learned this rule, he/she may not be able to solve the equations of the form “-X = a”, because he/she does not see any number in front of X. Thus, the students simultaneously have correct and incorrect approaches to solve the problems. In order to strengthen correct procedures, it is important that students practice procedures in a number of different contexts and with problems containing varying characteristics.

Our memory consists of a large number of declarative facts and rule-based procedural knowledge, but most of our knowledge is inert. In order to use that knowledge, inert knowledge must be first activated. Referred to as “working memory,” there is a limit on the amount of information that can be activated at one time. The procedural knowledge that becomes stronger and automatic through practice, takes up less working memory, which frees up our mind to learn new information (McGuire & Ritter, 2006). Therefore, in the educational tasks, it is better to reduce working memory load, especially when the load is not related to the instructional goals. For example, when teaching equation solving, the use of small integers as coefficients reduces the working memory load associated with remembering and performing arithmetic on those coefficients, freeing up working memory for learning algebraic transformations (Anderson,
Reder & Lebiere, 1996). In addition, when new information is built upon the learner’s prior knowledge, it activates connected memory items. This reduces the memory load at the time of learning.

The Cognitive Tutors make the information relevant for the learner by presenting real world problems that are very similar to students’ real life experiences (Koedinger, & Corbett, 2006). Students are prompted to use their intuitive problem solving abilities in order to connect their informal prior knowledge to the more formal and sophisticated mathematical knowledge. The tutors help the students in sorting out the relevant information from the real world scenarios, and thus in reducing the working memory load. The following example (Figure 1) shows how the Cognitive Tutors build upon the student’s prior knowledge.

Figure 1. Cognitive Tutor presents problems that are relevant to learners’ prior knowledge.

From: http://www.carnegielearning.com/web_docs/intelligent_tutoring.pdf
Since these problems are relative to students’ real life experiences, students’ are more likely to catch on to the concept. These types of authentic tasks provide motivational benefits, in addition to the cognitive benefits.

**Application of principles.**

Although the ACT-R theory indicates the basic pedagogical strategies that are likely to be effective in instruction, it does not specify the particular skills that comprise the ability to solve complex problems (Ritter et al., 2007). The research group at Carnegie Mellon University spent years in identifying the particular skills and methods that students use to complete mathematical tasks. One technique that was used to understand how students approach mathematics problems was tracking their solution steps (Ritter et al., 2007). In Figure 2, Ritter et al. (2007) present the task of a student who is completing a table of values based on a real world problem.

![Figure 2. Partially completed word problem task used in an eye tracking study.](http://www.carnegielearning.com/web_docs/Ritter%20Anderson%20Koedinger%20Corbett%202007.pdf)
In Figure 2, the student has completed part of the table corresponding to the word problem, including the column headings, units of measure expression and the number of hours. Next, the student needs to calculate the amount of money remaining after two hours. The students might perform the task in at least two ways. First, they might imagine having $20 and then using repeated subtraction to calculate the amount left after spending $4 two times. The second method would be to use the algebraic expression, substitute 2 for \( x \) and then calculate the result. From the algebraic expression “\( 20 - 4x \)”, it was expected that students would then use the algebraic expression. It was found that in solving similar problems, about 13% of the time, students looked at the problem scenario but not the expression. About 54% of the time, students looked at the expression (sometimes along with the scenario). Almost 34% of the time, students looked in neither place (Gluck, 1999, as cited in Ritter et al., 2007). It is not clear in this research whether or not the 34% responded to the problem.

As a result of this, the Cognitive Tutor Curriculum encourages students to find the algebraic expression for simple word problems. Students are asked to solve two individual questions: First, 1) *How much money would be left after 2 hours?* and 2) *When will you run out of money?* Next, they are prompted to use a generalization of their reasoning to come up with the algebraic expression. In later units of the curriculum, as the situations become more complex, students are directed to make expressions from the word problems and then use the expression to compute specific values.

In addition to the design of mathematical tasks, the ACT-R theory guides instruction in the Cognitive Tutor through two techniques called *model tracing* and *knowledge tracing*. *Model tracing* is used to interpret student’s strategies, behavior and methods (Koedinger & Corbett, 2006). As students take steps to complete the problem (for example, by filling in cells in the
spreadsheet), the tutor considers whether or not those steps are consistent with a direct solution to the problem. If so, the tutor would remain silent, and the student will proceed. If the student's action is not recognized as being on some solution path, the tutor checks to see if the step is consistent with a common misconception. In such cases, the tutor is able to provide instruction tailored to that misconception. Since the tutor tracks the student's solution at each step, it is able to give help associated with the student's solution path. Each action that the student takes is associated with one or more skills, which are related to the knowledge components in the cognitive model. Individual students’ performance on these skills is tracked over time and displayed in the skillometer. The Cognitive Tutor uses each student’s skill profile to select problems that emphasize the skills on which the student is weakest (Corbett & Anderson, 1995). For example, a student who is skilled in writing equations with positive slopes and intercepts, but has difficulty with negative slope equations would be assigned problems involving negative slopes. In addition, the skill model is used to implement mastery learning. When all skills in a section of the curriculum are determined to be sufficiently mastered, the student moves on to the next section of curriculum, which introduces new skills (Koedinger & Corbett, 2006).

**Careful evaluations.**

The development process of Cognitive Tutor Curriculum included many formative evaluations of individual units of instruction (e.g. Aleven & Koedinger, 2002; Corbett, Trask, Scarpinatto & Hadley, 1998; Koedinger & Anderson, 1998; Ritter and Anderson, 1995). In addition, several large evaluations of the entire curriculum were conducted (Morgan & Ritter, 2002; Sarkis, 2004; Koedinger, Anderson, Hadley & Mark, 1997). Early evaluations of Cognitive Tutors showed great promise, with effect sizes of approximately 1 standard deviation (Anderson, Corbett, Koedinger & Pelletier, 1995).
Koedinger, Anderson, Hadley and Mark (1997) conducted a research in Pittsburgh and Milwaukee on Algebra I Cognitive Tutor curriculum. The students were divided into three groups: The comparison group received a traditional curriculum; the “PUMP+PAT” group received Cognitive Tutor Algebra 1 curriculum along with its software; and the “Scholar Comparison” group, which consisted of advanced students in upper track classes, also received a traditional curriculum. All the groups were tested on Iowa Algebra Aptitude test (IAAT), and a subset of the Math Scholastic Aptitude Test (SAT). Two other tests were designed to assess students’ problem-solving abilities. The Problem Situation Test was created to assess students’ abilities to investigate problem situations when presented verbally, and the Representations Test was created to assess students’ abilities to translate the content between verbal, graphic and symbolic representations. It was found that the PAT+PUMP (or Cognitive Tutor Algebra 1) students outscored the Comparison group on SAT and IAAT by an effect size of 0.3 standard deviations. On the two other tests, the Cognitive Tutor students outscored Comparison students by an effect size of 0.7 (Problem Situation Test) and 1.2 (Representations Test). Scholar Comparison students performed better than the Cognitive Tutor students, but their performance might have been enhanced by their prior superiority.

The Miami-Dade County school district studied the use of Cognitive Tutor Algebra I in ten high schools (Sarkis, 2004). An analysis of over 6,000 students taking the 2003 FCAT (Florida Comprehensive Assessment Test) showed that Cognitive Tutor students scored (mean = 279.1 out of 500 points possible) significantly higher ($p = 0.000$) than their counterparts (mean = 274.7). It shows that mean student performance was increased by 4.4 points out 500 possible points, which is about 0.9 percent. Because the control group included more African American students (22.2% black, 67.1% Hispanic, and 9.5% white) as compared to the Cognitive Tutor
group (17.7% black, 67.0% Hispanic, and 14.0% white), one might question the comparability of groups. Although the overall increase may not be very impressive, this program drastically benefited the Exceptional Students (ESE) and Limited English Proficiency students (LEP).

Figure 3 illustrates the comparison of ESE students’ FCAT scores between the two groups – the Cognitive Tutor group, denoted as Program in Figure 3 and the Comparison group, which used the traditional curriculum.

![Figure 3](http://www.carnegielearning.com/web_docs/sarkis_2004.pdf)

**Figure 3.** FCAT performance levels for Exceptional Students in Cognitive Tutor program group and the comparison group.


Figure 3 shows that a higher percentage of Exceptional Students attained level 3 (FCAT 296 – 331), level 4 (FCAT 332 – 366) and level 5 (FCAT 376 – 500) than did their conventional counterparts. For example, 13.4% of ESE students attained level 4 in the Program group as compared to 2.7% of ESE students in the Comparison group. Similar positive results were found
for the Program LEP students, who scored over 16 points higher on the mathematics portion of the FCAT than did their peers in Comparison group.

In Moore, Oklahoma, a similar study was conducted where teachers were asked to teach some of their classes using Cognitive Tutor and some classes with the textbook used previously (Morgan & Ritter, 2002). Students were randomly assigned to the Cognitive Tutor and traditional classes. Student achievement and attitude were assessed by ETS Algebra I End-of-Course exam, course grades, and a survey of attitude towards mathematics.

ETS Algebra I End-of-Course exam was worth 50 points. The national mean score for this exam was approximately 18 with a standard deviation of 9, in 2001. In this study, exam averages were 16.7 (standard deviation = 5.7) for the Cognitive Tutor students, and 15.1 (standard deviation = 5.5) for the comparison students. Although both groups performed below the national average, the difference between curricula was significant at p < .01. The advantage of Cognitive Tutor students was consistent across the schools, but not across the teachers.

Students’ course grades were converted to a standard numeric score (A = 4; F = 0). In order to control the teacher effect, Morgan and Ritter decided to restrict their analysis to the teachers who taught both curricula. It was found that the Cognitive Tutor students outperformed the traditional students in both semesters. Students’ confidence and their feeling about the usefulness of mathematics were measured by a 24 items survey. It was found that honors students were more confident of their mathematical abilities and they were more likely to rate mathematics as useful. Honor students were taking traditional algebra classes; their attitude might be more positive due to their prior achievements in mathematics. Therefore Morgan and Ritter (2002) compared Cognitive Tutor students’ attitude to the traditional students’ attitude, and found that the Cognitive Tutor students were more confident about their mathematical
abilities, and they were more likely to believe that mathematics is useful. True experimental
design of this study enhanced the validity of its results. This research was recognized by the US
Department of Education’s *What Works Clearinghouse* as having met the highest standards of
evidence.

From these evaluation studies, it is evident that the Cognitive Tutor students performed
better than their counterparts, but the overall differences were quite small. However, results were
more impressive for the lower ability (or exceptional) students. Cognitive Tutor students
performed slightly better than their counterparts on the standardized tests, and significantly better
in the tests that were designed to assess their problem-solving abilities. It shows that the
Cognitive Tutor Algebra I curriculum enhanced students’ problem solving abilities, but not at the
cost of the declarative knowledge that is measured by the standardized tests.

**Methodology for improvement.**

ACT-R provides guidelines for educational pedagogy and for constructing tasks that
increase learning (Ritter, et al. 2007). The theory also provides a way to test and improve
curriculum over time. Two strategies that stand out are *improved software prediction* and more
*efficient help models.*

**Improved software prediction.**

The Cognitive Tutor can function as a *Prediction Software*, which observes and tracks
student actions such as clicks, time spent, and answers, at approximately 10-second intervals
(Ritter et al. 2007). The cognitive model is continually evaluating the student and predicting
what the student knows and does not know. By aggregating these predictions across students, the
researcher can test whether the cognitive model is correctly modeling student behavior.
Ritter et al. (2007) discovered during the development of Algebra Cognitive Tutor that
the model was over-predicting student performance in solving equations of the form \( ax = b \). An
analysis of the data revealed that the over-prediction was, in part, due to the case where \( a = -1 \). In
the case where \( a = -1 \), the student needs to understand that the expression \(-x\) means \(-1\) times \( x\).
Some students might have learned a rule equivalent to “if the equation is of the form \( ax = b \), then
divide by the number in front of the variable.” But, when the coefficient is \(-1\), the student does
not see a number, but sees a negative sign, so the rule does not apply. Once recognition of \(-x\) as
\(-1\) times \( x\) was added to the cognitive model, the Cognitive Tutor automatically adjusts
instruction to test whether the student has mastered that skill and will automatically provide extra
practice on such problems to the student.

**Efficient help models.**

The Cognitive Tutor Curricula also provide guidance to help students become better
learners. In the development of Cognitive Tutor curricula, students’ meta-cognitive abilities were
taken into account to help them develop better help-seeking strategies. In 2006, Aleven,
McLaren, Roll, and Koedinger found that sometimes students do not effectively use the help
facilities offered by the Cognitive Tutor software. They developed a preliminary model of
adaptive help-seeking behavior with a Cognitive Tutor. The model specifies how a student
should ideally use the help facilities of a Cognitive Tutor, namely, multi-level context-sensitive
hints and a Glossary. This model forms the basis of the Help Tutor agent. The initial design of
the model is shown in Figure 4.
To summarize the model briefly, if the step looks familiar and the student has a sense of what to do, he/she should try the step without seeking help. If the student is somewhat familiar with the topic, he/she should use *Search Glossary*. In case the student is new to the given kind of step, he can use *ask for hint*. Although this is not indicated in the flow chart of Figure 4, if a student is not able to solve a step after using all sources of help, the model prescribes that he/she should ask the teacher. The model steers students towards the glossary in situations where students are likely to have some level of knowledge that they can bring to bear in deciding whether information found is helpful. The strategy for deciding between hints and the glossary
balances two concerns: the context-sensitive hints provide more specific help and thus make the student’s job easier, compared to the glossary. Effective glossary use requires search and judgments about the relevance of what was found. Thus, for students faced with an unfamiliar situation, context-sensitive hints may be more effective. On the other hand, using glossary helps students to learn mathematics in a broader context, but it may lead to higher cognitive load. Therefore, the context-sensitive hints are prescribed in unfamiliar situations and glossary use in situations where students have at least some minimal amount of knowledge.

Aleven et al. implemented this help seeking model in 2005 to see if students’ behavior is similar to the ideal student’s behavior in Figure 5. They created the taxonomy of errors as shown in Figure 5.

![Figure 5. A taxonomy of help-seeking bugs.](http://www.learnlab.org/uploads/mypslc/publications/aleven-toward%20meta-cognitivetutoring.pdf)
The first category: *Help abuse* covers situations in which the student misuses the help facilities or uses them unnecessarily. For example, moving to the next hint without spending enough time on the current hint (*Clicking Through Hints*), and requesting a hint when the student is knowledgeable enough to try a step (*Ask Hint when Skilled Enough to Try-Step, Ask Hint when Skilled Enough to use Glossary, & Glossary Abuse*). The second category: *Help Avoidance* has three bugs that involve trying a step without sufficient mastery and without seeking help. For example, when the student’s mastery level is low, and he/she tries a step too quickly (*Guess quickly*). The third category: *Try-Step Abuse* represents situations in which a student is sufficiently skilled, but he/she tries a step too quickly and gets it wrong. Finally, the category of *miscellaneous bugs* covers situations not represented in other categories.

Aleven et al. computed the correlation between the frequency of meta-cognitive errors and students’ learning outcomes. If a particular type of meta-cognitive error occurred with reasonable frequency, and was negatively correlated with learning, then the error was modeled adequately. When errors were highly frequent, and were not correlated with learning, then the model needed to be modified. This way, Aleven et al. were able to use these results to improve the model.

The overall percentage of help-seeking errors was 73%, which shows that students’ behavior was far from ideal. This implied that the Help Tutor would present an error message in approximately 3 out of every 4 actions taken by a student, which could be annoying and distracting to the student. Therefore, the model was updated in a number of ways.

First, the model was changed so that it would be less persistent in asking the students to modify their behavior. Previously, the tutor would comment on the same meta-cognitive bug each time it came up. In the current model, the Help Tutor typically does not comment on
repetitions of the same meta-cognitive bug. For example, previously if a student clicks on hints too quickly, the tutor would present a message and redisplay the same hint requiring that student again spend the same amount of reading/comprehending time as initially required. Also in the current model, the time threshold for re-reading a hint is reduced.

Second, the tutor was changed so that it no longer displays messages related to Glossary abuse on what are called Reason steps; in units where the students are required to explain their numeric answers by indicating which theorem or definition justifies the step, they can use glossary to choose a theorem, principle or definition to explain steps. Previously, if a student’s mastery level is high enough to try a step without using glossary, but he/she clicks on the glossary, the tutor would present an error message. This change illustrates that it is important to take into account the context in which the help facilities are used.

Third, the hint reading time was tuned, so that the Help Tutor would respond more appropriately to an estimate of actual reading time and skill level. The time threshold for deciding whether or not an attempt was “too quick” was reduced from 7 seconds to 2 seconds. Thus, the Help Tutor may not catch all fast attempts, but when it does point out to a student that he/she is working too fast, the message has a lot of face validity. Finally, it was found that Glossary abuse was not related to lower learning outcomes. Therefore, it was decided that if the likelihood of mastery of a skill is high, then it is ok if the student is trying steps rapidly. The rationale is that highly skilled students may respond more quickly and accurately at the same time.

In order to validate the model and Tutor further, a pilot study was conducted with the Help Tutor, involving four students (Aleven et al. 2006). With the updated model, the error rate dropped to 16% from 73%. In addition, the rate of help seeking errors declined from 18% to 14%
during the session, which shows that students adapted their behavior to the *Cognitive Tutor.* Three of the four students reported that they welcomed the Help Tutor’s input and found that the Help Tutor gave appropriate feedback. It is expected that the Help Tutor prepares students for better future learning. More research is needed to determine whether these improvements in the help-seeking model directly impact student learning outcomes. The process of analyzing learning curves and improving data has been laborious. Researchers at Pittsburgh Science of Learning Center are trying to explore the possibility of automating the process of discovering flaws in the cognitive model (Ritter et al., 2007). More research is being done to understand and accurately model students’ mathematical cognition. Ritter et al. (2007) have collected the data on over 7,000 students using the Cognitive Tutor in a pre-algebra class. These data comprise over 35 million observations, which amount to observing an action for each student about every 9.5 seconds. With a database of this size, it is expected to be able to detect other unknown factors affecting learning, including the effectiveness of individual tasks, hints and feedback patterns.

**Implementation of Cognitive Tutor Curriculum**

As a result of more than two decades of cognitive science research on how students think, learn, and apply new knowledge in mathematics, cognitive tutor curricula were developed at Carnegie Mellon University (Koedinger & Corbett, 2006). By combining computer-based training, text, and teacher-led classroom instruction, these curricula identify weaknesses in a student's mastery of mathematical concepts, customize prompts to focus on areas where the student is struggling, and provide the teacher with a report on each student's progress to aid in classroom instruction. Contemporary word problem scenarios and the *skillometer* keep the students engaged and positive. Pilot implementation led to a model where students used the software two days per week, with teacher-led instruction the other three days of the week.
The Cognitive Tutor curricula include:

1. *Bridge to Algebra*, designed as a prerequisite course for *Algebra I*. It can be implemented with students who lack fundamentals necessary for success in *Algebra I* as well as advanced middle school students.

2. *Algebra I*, designed as a first year Algebra course. It can be implemented with students at a variety of ability and grade levels.

3. *Geometry*, designed to be taken after an algebra course. The course assumes number fluency and basic algebra skills such as equation solving.

4. *Algebra II*, designed as a second-year Algebra course. The content in this course aligns to a high school math course for *Algebra II* and End of Course Exam.

5. *Integrated Mathematics*, a complete three course series including a blend of algebraic, geometric, and statistical curriculum strands.

Several research studies show the success of Cognitive Tutor Algebra I curriculum, but few studies are found on Cognitive Tutor Geometry curriculum. Implementation of Algebra I curriculum in Eastern Iowa has been evaluated by Mississippi Bend Area Agency in 2006, and is found to be very successful. Chapter 3, the Methodology describes the research plan to uncover implementation issues and improvement strategies for Cognitive Tutor Geometry Curriculum in Iowa.
Chapter 3. Methodology

This study used mixed methods in its research. A pre-test was administered by the Mississippi Bend Area Education Agency in October 2008. A post-test, which was a replicate of the pre-test, was given in May 2009. A quantitative analysis on pre-test and post-test scores was performed to analyze student progress. The qualitative analysis was based on teachers’ interviews about this curriculum as well as a review of the textbooks accompanying the Cognitive Tutor software.

The quantitative analysis began with the overall student growth, followed by the analysis of student-growth in the Multiple-choice and Constructed Response sections of the test. Research question 1 about whether or not the Cognitive Tutor Geometry Program increases student academic achievement will be addressed by the quantitative analysis.

The qualitative analysis is based on teachers’ comments about the Cognitive Tutor software and its accompanying textbook. Next, the textbook is analyzed for its overall goals, alignment with NCTM Curriculum and Evaluation Standards, and organization of topics. The qualitative analysis attempts to respond to research questions 2 through 4 as follows:

2. To what extent was the Cognitive Tutor Geometry curriculum implemented within adopting schools? How did the scope of implementation differ across schools?

3. What are the teacher’s views on the effectiveness, efficiency, and convenience of the curriculum?

4. If improvements are necessary, how can the Cognitive Tutor Geometry Curriculum be improved?
The results of this study may contribute to future longitudinal studies that track student progress from Algebra I through Algebra II. This section begins with a brief description of the study’s participants and measuring instruments. Next, the research design is presented and is followed by the analysis and results of the study.

Participants

The participants in this study included twelve Geometry teachers in eight schools in Iowa. Denoted in Table 1 below are the schools, A through H, and the corresponding teachers, $A_1$ through $H_4$. One school had two and another had a total of four geometry teachers. The remainder of the schools had one geometry teacher in each school. Table 1 shows the distribution of 549 students in eight schools.

Table 1

<table>
<thead>
<tr>
<th>Curriculum</th>
<th>School</th>
<th>Teacher</th>
<th>Number of Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cognitive Tutor (Full)</td>
<td>A</td>
<td>$A_1$</td>
<td>10</td>
</tr>
<tr>
<td>Cognitive Tutor (Full)</td>
<td>B</td>
<td>$B_1$</td>
<td>49</td>
</tr>
<tr>
<td>Cognitive Tutor (Full)</td>
<td>C</td>
<td>$C_1$</td>
<td>96</td>
</tr>
<tr>
<td>Cognitive Tutor (Full)</td>
<td>D</td>
<td>$D_1$</td>
<td>11</td>
</tr>
<tr>
<td>Cognitive Tutor (Full)</td>
<td>E</td>
<td>$E_1$</td>
<td>63</td>
</tr>
<tr>
<td>Cognitive Tutor (Full)</td>
<td>F</td>
<td>$F_1$</td>
<td>29</td>
</tr>
<tr>
<td>Cognitive Tutor (Partial)</td>
<td>G</td>
<td>$G_1$</td>
<td>29</td>
</tr>
<tr>
<td>Cognitive Tutor (Partial)</td>
<td>G</td>
<td>$G_2$</td>
<td>30</td>
</tr>
<tr>
<td>Traditional Curriculum</td>
<td>H</td>
<td>$H_1$</td>
<td>76</td>
</tr>
<tr>
<td>Traditional Curriculum</td>
<td>H</td>
<td>$H_2$</td>
<td>71</td>
</tr>
</tbody>
</table>
Table 1 Continued

<table>
<thead>
<tr>
<th>Curriculum</th>
<th>School</th>
<th>Teacher</th>
<th>Number of Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional Curriculum</td>
<td>H</td>
<td>H₃</td>
<td>50</td>
</tr>
<tr>
<td>Traditional Curriculum</td>
<td>H</td>
<td>H₄</td>
<td>35</td>
</tr>
</tbody>
</table>

*Cognitive Tutor (Full):* Cognitive Tutor software and accompanying textbook.  
*Cognitive Tutor (Partial):* Cognitive Tutor software with a traditional textbook.

According to Table 1, six teachers in schools A - F used the Cognitive Tutor Geometry software with its accompanying textbook; two teachers in school G used *Glencoe Geometry* textbook with the Cognitive Tutor software; and four teachers in school H used a traditional curriculum. In school G and H, several students switched class sections between pre- and the post-test. In this table, the number of students is recorded for each section at the time of the pre-test. Because the section changes did not affect the curriculum and this study is not determining teacher influence, the transfer of students from section to section is not expected to influence the evaluation of the curriculum. Since each school used only one type of curriculum, the unit of analysis is “school” in this study.

**Instruments**

Students were given a pre-test in the beginning of the academic year 2008-2009 and a post-test, which was a replicate of pre-test, at the end of the same academic year. The tests were designed by Mississippi Bend Area Education Agency. Because of a confidentiality agreement with the Mississippi Bend Area Education Agency in regards to the pre- and post-tests, the actual documents will not be made available in this study. For the purpose of this study, the pre- and post-test will be described.

These tests measured students’ abilities in the following seven areas:
i. Geometry formulas
ii. Basic shapes
iii. Similarity
iv. Transformations
v. Pythagorean Theorem
vi. Trigonometry
vii. Cartesian Coordinate System

The test consisted of sixty points; thirty points for the Multiple-choice portion and thirty points for the Constructed Response portion were awarded. Both tests included more questions on the abstract geometric concepts as compared to the real world problems. Student progress was measured by the difference between the pre-test score and post-test score. Microsoft Excel and S-PLUS were used to analyze variances, effect sizes, significance, etc.

In addition to these data, the teachers who taught the geometry classes were interviewed about the Cognitive Tutor’s effectiveness in the classroom, convenience in implementation, and improvement strategies (see Interview Questions in Appendix A). The interview questions were designed to investigate teachers’ views, comments and suggestions regarding the program. I intended to conduct the interviews by telephone, but a few teachers preferred to respond by e-mail. During the telephone interviews, notes were taken. Responses were recalled soon after and documented.

Research Design

The implementation of Cognitive Tutor Geometry Curriculum was started in 2005-2006 in Iowa. Mississippi Bend Area Education Agency organized initial training for teachers, where they experienced the Cognitive Tutor curriculum as teachers as well as students. The main goal
of the initial training was to help the teachers develop effective strategies for the full implementation of Cognitive Tutor curricula. Teachers were also encouraged to collaborate with each other and participate in the professional development activities over the Iowa Communication Network (http://www.carnegielearning.com/web_docs/E2T2%20White%20Paper_submitted%20to%20DE.pdf). Schools A-F only offered Cognitive Tutor Geometry classes, and used the software along with its accompanying textbook. All the students in these schools, except those who moved in from other places, had taken Cognitive Tutor Algebra 1 in previous year. School G offered two Geometry classes by two teachers; both teachers used Cognitive Tutor geometry software with a traditional textbook. Students in this school had received similar instruction for Algebra 1 i.e. Cognitive Tutor Software with a traditional textbook. School H did not use Cognitive Tutor Geometry software or the textbook, and it is referred to as control school. This school usually uses Cognitive Tutor software for the low-ability students and the traditional curriculum for the high-ability students. The reasons and procedures for categorizing the students are not clear. In academic year 2008-2009, school H only offered traditional Geometry classes for the high-ability students. The Cognitive Tutor Program Leader from Mississippi Bend Area Education Agency provided the pre-test and post-test scores for all eight schools. The classes in each school were already established. Therefore, any random assignment of students to Cognitive Tutor and traditional classes was not possible. Since true experimental design was not feasible in this study, a case study approach was used. It was decided to analyze student-growth separately for each school. Several factors besides the curriculum, such as teachers’ characteristics, schedules, and availability of computers might be associated with the difference in student achievement. Therefore this study can only make very humble claims.
Chapter 4. Results and Discussion

This section reports the results of the quantitative data analysis performed on the students’ pre- and post-test scores and qualitative analysis of teachers’ interviews and Cognitive Tutor Geometry textbooks. For quantitative analysis, average gains and effect sizes were calculated for students’ overall test scores, Multiple-choice section, and Constructed-response section. After that student growth for the low-ability and high-ability students was examined within each group.

The qualitative analysis begins with teachers’ interviews followed by a detailed analysis of Cognitive Tutor Geometry textbook.

Student Growth

The pre-test and post-test scores were available for 549 students from eight schools. Schools A-F used Cognitive Tutor Geometry textbook and its companion software. These schools are referred as Full-implementers. School E used a different textbook with the Cognitive Tutor Geometry software, and is referred as Partial-implementer. School H, which did not used the Cognitive Tutor textbook or the software, is referred as Control school. Because the geometry classes in school H did not include the low-ability students, the mean for school H only represents the high ability students who were following a traditional curriculum. Table 2 shows the classification of students in eight schools along with pre-test averages.
Table 2

Average Pre-Test Scores; Total = 90 points

<table>
<thead>
<tr>
<th>School</th>
<th>Number of Students</th>
<th>Pre-Test Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>10</td>
<td>19.6 (5.8)</td>
</tr>
<tr>
<td>B</td>
<td>49</td>
<td>17.7 (3.9)</td>
</tr>
<tr>
<td>C</td>
<td>96</td>
<td>14.3 (5.6)</td>
</tr>
<tr>
<td>D</td>
<td>11</td>
<td>14.2 (4.9)</td>
</tr>
<tr>
<td>E</td>
<td>63</td>
<td>17.4 (5.4)</td>
</tr>
<tr>
<td>F</td>
<td>29</td>
<td>14.9 (3.0)</td>
</tr>
<tr>
<td>G</td>
<td>59</td>
<td>14.6 (4.3)</td>
</tr>
<tr>
<td>H</td>
<td>232</td>
<td>17.8 (6.1)</td>
</tr>
</tbody>
</table>

Note: Standard Deviations in Parenthesis

The pre-test scores were extremely low because most students were unfamiliar with the symbols and postulates in Geometry. Most test questions assessed student’s knowledge of mathematical vocabulary and facts, and therefore students were unable to answer the questions without instruction. There were only four common-sense questions on perimeter, area and volume; students in each schools got higher scores on these four questions. Because the heterogeneity in variances and the average pre-test scores, it was decided to analyze student-growth separately for each school. A post-test worth 60 points, was given in May 2009. Student growth, illustrated in Table 3 below, is defined as post-test score minus the pre-test score. The distributions of percent growth for each school are provided in Appendix B. A matched sample t-test was used to determine if there was significant growth in student scores after one year of instruction. All the t-values were significant at alpha = 0.05. According to Cohen (1988), this
explanation for observed differences relies heavily on the sample size; therefore, Cohen’s effect sizes were calculated to determine the magnitude of students-growth in each participating school. Table 3 shows the average student-growth along with the t-values and effect sizes for each participating school.

**Table 3**

*Student Growth in Each School; Total = 60 points*

<table>
<thead>
<tr>
<th>School</th>
<th>Pre-Test M(SD)</th>
<th>Post-Test M (SD)</th>
<th>Gain M (SD)</th>
<th>Paired T-Test t (p)</th>
<th>Effect Size d</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (n = 10)</td>
<td>19.6 (5.8)</td>
<td>37.6 (6.8)</td>
<td>18.0 (2.4)</td>
<td>24.1 (p &lt; 0.05)</td>
<td>2.8</td>
</tr>
<tr>
<td>B (n = 49)</td>
<td>17.7 (3.9)</td>
<td>28.2 (8.6)</td>
<td>10.5 (7.2)</td>
<td>10.1 (p &lt; 0.05)</td>
<td>1.6</td>
</tr>
<tr>
<td>C (n = 96)</td>
<td>14.3 (5.1)</td>
<td>26.8 (9.0)</td>
<td>12.5 (7.1)</td>
<td>17.3 (p &lt; 0.05)</td>
<td>1.7</td>
</tr>
<tr>
<td>D (n = 11)</td>
<td>14.2 (4.9)</td>
<td>22.0 (6.2)</td>
<td>7.8 (5.6)</td>
<td>4.6 (p &lt; 0.05)</td>
<td>1.4</td>
</tr>
<tr>
<td>E (n = 63)</td>
<td>17.4 (5.4)</td>
<td>28.7 (8.5)</td>
<td>11.3 (7.2)</td>
<td>12.5 (p &lt; 0.05)</td>
<td>1.6</td>
</tr>
<tr>
<td>F (n = 29)</td>
<td>14.9 (3.0)</td>
<td>33.1 (9.4)</td>
<td>18.2 (8.4)</td>
<td>11.8 (p &lt; 0.05)</td>
<td>2.6</td>
</tr>
<tr>
<td>G (n = 59)</td>
<td>14.6 (4.3)</td>
<td>22.8 (9.2)</td>
<td>8.3 (6.9)</td>
<td>9.2 (p &lt; 0.05)</td>
<td>1.2</td>
</tr>
<tr>
<td>H (n = 232)</td>
<td>17.8 (6.1)</td>
<td>30.6 (11.2)</td>
<td>12.8 (8.6)</td>
<td>22.6 (p &lt; 0.05)</td>
<td>1.4</td>
</tr>
</tbody>
</table>

*M = Mean; SD = Standard Deviation; d = Effect Size*

Column 4 in Table 3 shows average gains ranging from 7.8 to 18.2; it does not show any pattern to compare full implementers, partial implementer, and control school. From column 6, the effect sizes for schools A-F (Full-implementers) are higher than the effect size for school G, which used the Cognitive Tutor software with a traditional textbook. The effect sizes for five out of six Full-implementers are higher than the effect size for school H (Control group); the remaining Full-implementer (school D) has the same effect size as school H. The average effect
size for all six high implementers is 1.95, which is higher than the effect size for school H (d = 1.4).

The test consisted of two sections: *Multiple-choice* section, and the *Constructed-response* section; each section was worth thirty points. In the next section, student growth in *Multiple-choice* and *Constructed-response* sections is analyzed separately.

**Analysis of student-growth in Multiple-choice section.**

The *Multiple-choice* section consisted of thirty problems; each problem was worth one point. It included questions on formulas, basic shapes, similarity, transformations, Pythagorean Theorem, and Cartesian Coordinates. The test was machine-graded, so there is no risk of differences in grading across schools. Table 4 shows the average gain in student scores with corresponding t-values and effect sizes for the *Multiple-choice* section.

**Table 4**

*Student Growth in Multiple-choice Section; Total = 30 points*

<table>
<thead>
<tr>
<th>School</th>
<th>Pre-Test M (SD)</th>
<th>Post-Test M (SD)</th>
<th>Gain M (SD)</th>
<th>Paired T-Test t (p)</th>
<th>Effect Size d</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (n = 10)</td>
<td>14.2 (2.3)</td>
<td>19.3 (1.9)</td>
<td>5.3 (1.6)</td>
<td>10.2 (p &lt; 0.05)</td>
<td>2.5</td>
</tr>
<tr>
<td>B (n = 49)</td>
<td>12.9 (2.4)</td>
<td>17.8 (4.0)</td>
<td>4.9 (4.1)</td>
<td>8.4 (p &lt; 0.05)</td>
<td>1.5</td>
</tr>
<tr>
<td>C (n = 96)</td>
<td>12.1 (3.8)</td>
<td>16.8 (4.2)</td>
<td>4.7 (4.0)</td>
<td>11.6 (p &lt; 0.05)</td>
<td>1.2</td>
</tr>
<tr>
<td>D (n = 11)</td>
<td>10.7 (3.7)</td>
<td>14.8 (3.3)</td>
<td>4.1 (3.1)</td>
<td>4.4 (p &lt; 0.05)</td>
<td>1.2</td>
</tr>
<tr>
<td>E (n = 63)</td>
<td>12.1 (2.9)</td>
<td>16.9 (3.7)</td>
<td>4.8 (4.2)</td>
<td>9.0 (p &lt; 0.05)</td>
<td>1.5</td>
</tr>
<tr>
<td>F (n = 29)</td>
<td>11.8 (2.1)</td>
<td>18.8 (3.5)</td>
<td>7.0 (3.4)</td>
<td>11.1 (p &lt; 0.05)</td>
<td>2.4</td>
</tr>
<tr>
<td>G (n = 59)</td>
<td>12.0 (3.0)</td>
<td>14.6 (4.3)</td>
<td>2.6 (3.6)</td>
<td>5.6 (p &lt; 0.05)</td>
<td>0.7</td>
</tr>
<tr>
<td>H (n = 232)</td>
<td>12.8 (4.0)</td>
<td>17.6 (4.5)</td>
<td>4.8 (4.1)</td>
<td>17.7 (p &lt; 0.05)</td>
<td>1.1</td>
</tr>
</tbody>
</table>

*M = Mean; SD = Standard Deviation; d = Effect Size*
From column 4, all the Full-Implementers had had higher average gain than school G (Partial-implementer). Three Full-Implementers (schools A, B, and F) had higher average gain than the Control-school; and two Full-Implementers (schools C and D) had lower average gain than the Control-school. The remaining one Full-Implementer (school E) had the same average gain (4.8) as the Control-school. No generalizations can be formed from the average gains.

From column six in Table 4, the effect sizes for Full-implementers (Schools A-F) are higher than the effect size for Partial-implementer (schools G; d = 0.7) and the Control-group (school H; d = 1.1). Next, student growth is analyzed for each topic to find out which topics are well-covered, and which topics need improvement in Cognitive Tutor Curriculum. Because the test included a different number of questions per topic, percent gains are used to compare student growth in each area. Figure 6 shows students’ percent growth, corresponding t-values, and effect sizes for the full-implementers.

![Cognitive Tutor Students' Pre-Test and Post-Test Scores by Topics](image)

Figure 6. Pre-Test and Post-Test Scores for Full-implementers
All the t-values are significant at alpha = 0.05. According to Cohen (1988), effect size of 0.2 is considered low, 0.5 is medium, and effect size of 0.8 is considered high. In Figure 6, the effect sizes are: 1) high for “basic shapes,” and “trigonometry;” 2) medium for “formulas,” “similarity,” “transformations,” and “Pythagorean” and 3) low for “Cartesian.” The test included only one question on Cartesian coordinates. If the student’s response is correct, the student gets 100%; otherwise he/she receives a zero. Therefore, the variance for this topic was higher as compared to other topics, which led to a lower effect size. Each of these topics would be analyzed qualitatively to determine the areas that need improvement in the Cognitive Tutor Geometry curriculum. Figure 7 shows growth for the Cognitive Tutor students in Full-implementers, as compared to the overall average growth in all groups.

Note: Insignificant t-values are not reported.

Figure 7. Student Growth in Full-implementers as Compared to Overall Growth
Student growth in Cognitive Tutor schools (Full-implementers) was significantly higher than overall growth for “formulas,” “Transformations,” “Pythagorean Theorem” and “Cartesian.” For “Basic Shapes” and “Trigonometry,” student growth for Full-implementers was approximately same as the overall growth (p > 0.05). Student growth for “Similarity” was significantly lower for Full-implementers as compared to overall growth (p < 0.05). In the qualitative analysis, the Cognitive Tutor textbook was analyzed to determine if the concept of similarity is covered well in this curriculum.

**Analysis of student-growth in Constructed-response section.**

The Constructed-response section of the pre- and post-test consisted of eight problems. It included three real-world problems and five problems over more abstract concepts such as congruence, similarity, and Cartesian coordinates. This section of the test was hand-graded by teachers. In order to keep grading uniform, a grading rubric was prepared, in which points were assigned for each step (explanation) of a question. If a student had a correct answer, but he/she was missing a step, points were deducted. This way, the students’ ability to write step-by-step solutions was also assessed. After both pre- and post-tests, four teachers paired up to grade the tests; each pair of teachers graded four questions. If any teacher had a doubt in grading, he/she was encouraged to collaborate with his/her partner. The same four teachers graded the pre-test and the post-test. This way, any differences in grading across the teachers were minimized. Table 5 shows the average growth for the constructed response portion of the test:
Table 5

Student Growth in Constructed Response Section; Total = 30 points

<table>
<thead>
<tr>
<th>School</th>
<th>Pre-Test M(SD)</th>
<th>Post-Test M (SD)</th>
<th>Gain M (SD)</th>
<th>Paired T-Test t (p)</th>
<th>Effect Size d</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (n = 10)</td>
<td>5.6 (4.3)</td>
<td>18.3 (5.1)</td>
<td>12.7 (1.7)</td>
<td>23.6 (p &lt; 0.05)</td>
<td>2.7</td>
</tr>
<tr>
<td>B (n = 49)</td>
<td>4.8 (2.9)</td>
<td>10.4 (5.7)</td>
<td>5.6 (5.3)</td>
<td>7.3 (p &lt; 0.05)</td>
<td>1.2</td>
</tr>
<tr>
<td>C (n = 96)</td>
<td>2.2 (2.2)</td>
<td>10.0 (5.8)</td>
<td>7.8 (5.2)</td>
<td>14.5 (p &lt; 0.05)</td>
<td>1.8</td>
</tr>
<tr>
<td>D (n = 11)</td>
<td>3.5 (1.8)</td>
<td>7.2 (4.2)</td>
<td>3.7 (4.4)</td>
<td>2.8 (p &lt; 0.05)</td>
<td>1.2</td>
</tr>
<tr>
<td>E (n = 63)</td>
<td>5.3 (3.9)</td>
<td>12.0 (5.8)</td>
<td>6.6 (4.5)</td>
<td>11.6 (p &lt; 0.05)</td>
<td>1.3</td>
</tr>
<tr>
<td>F (n = 29)</td>
<td>3.1 (2.2)</td>
<td>14.4 (6.6)</td>
<td>11.2 (6.5)</td>
<td>9.4 (p &lt; 0.05)</td>
<td>2.3</td>
</tr>
<tr>
<td>G (n = 59)</td>
<td>2.5 (2.2)</td>
<td>8.2 (5.9)</td>
<td>5.7 (4.9)</td>
<td>8.9 (p &lt; 0.05)</td>
<td>1.3</td>
</tr>
<tr>
<td>H (n = 232)</td>
<td>5.0 (3.2)</td>
<td>13.0 (7.6)</td>
<td>8.0 (6.5)</td>
<td>18.7 (p &lt; 0.05)</td>
<td>1.4</td>
</tr>
</tbody>
</table>

M = Mean; SD = Standard Deviation; d = Effect Size

From column 4 in Table 5, the average gain scores ranged from 3.7 to 12.7, which are lower than the Multiple-choice portion of the test. Four Full-implementers (Schools A, C, E and F) had higher average gain than the Partial Implementer. Two Full-implementers (Schools A and F) had higher average gain than the Control school.

From column six, the effect sizes for schools A, C and F are higher than the effect sizes for school G (Partial-implementer) and school H (Control school). The effect sizes for schools B and D are slightly lower than the effect sizes for schools G and H. The remaining Full-implementer (school E) has the same effect size as school G (d = 1.3), which is slightly lower than the effect size for school H (d = 1.4). The average effect size for schools A-F is 1.75, which is higher than the effect sizes for the Partial-implementer (d = 1.3) and Control school (d = 1.4).
The next section analyzes the progress of low-ability and high-ability students in each curriculum.

**Low-ability versus high-ability students.**

Student growth was analyzed for low-ability students versus high-ability students for each curriculum. Students in each curriculum program were divided into two groups by the median pre-test score of that program. Students whose scores were at the median for that curriculum were removed. Students, who scored above the median, are referred to as high-ability students, and the students who scored below the median are referred to as low-ability students.

Table 6 shows an average growth for low-ability and high-ability groups in *Full-implementers, Partial-implementers* and the *Control school*.

**Table 6**

**Low-Ability vs. High-Ability students**

<table>
<thead>
<tr>
<th>Curriculum Group</th>
<th>Pre-Test Median</th>
<th>Average Growth for Low-Ability Students</th>
<th>Average Growth for High-Ability Students</th>
<th>t (p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full-implementers</td>
<td>16</td>
<td>12.7 (n = 124)</td>
<td>12.5 (n = 111)</td>
<td>0.0 (p &gt; 0.05)</td>
</tr>
<tr>
<td>Partial-implementer</td>
<td>14</td>
<td>7.4 (n = 24)</td>
<td>10.0 (n = 26)</td>
<td>1.3 (p &gt; 0.05)</td>
</tr>
<tr>
<td>Control School</td>
<td>17</td>
<td>11.4 (n = 94)</td>
<td>14.6 (n = 116)</td>
<td>2.8 (p &lt; 0.05)</td>
</tr>
</tbody>
</table>

Based on Table 6, in Cognitive Tutor schools (*Full- and Partial-implementers*), the average growth for low-ability and high-ability students was approximately same (t = 0 for *Full-implementers*, and t = 1.3 for *Partial-implementers*). In the *Control school*, student growth was significantly higher for high-ability students as compared to the low-ability students. Figure 8 shows growth curves for the low-ability and high-ability students in each curriculum.
For Full-implementers, the average growths for the low-ability and high-ability students were almost equal, while the other two schools showed higher growth for the high-ability students. This shows that full implementation of Cognitive Tutor curriculum provides opportunities for the students at different levels.

Figure 8. Average Growth for Low-Ability and High-Ability Students
Student growth was analyzed for the Multiple-choice and Constructed-response sections of the pre- and post-tests, and for the low ability and high ability students. This leads to the first research question presented in chapter 1.

**Research question 1: Does the Cognitive Tutor Geometry curriculum increase student academic achievement as measured by post-test scores?**

Student achievement was measured by their gains from the pre-test to post test. Average gains and Effect sizes were calculated for each school. It was found that school D is the lowest performing school in the *Constructed-Response* portion (average gain = 3.7 out of 30 possible points), and school G is the lowest performing school (average gain = 2.6) in the *Multiple Choice* portion of the test. Average gains for all the participating schools are lower than expected. It is possible that the test items were not aligned with content covered in all the schools. Schools A and F had higher average gains than other schools in both portions. Because schools A, D and F used the same curriculum, we cannot make a generalization about the Cognitive Tutor Geometry curriculum. These differences might be explained by the ways teachers implemented the Cognitive Tutor Geometry curriculum in their classes.

The average effect size for the *Full-implementers* (d = 1.95) was higher than the effect sizes for the *Partial-implementers* (d = 1.2) and the *Control school* (d = 1.4). Next, student achievement in the Multiple-choice and Constructed-response portions of the test was analyzed separately. The average effect sizes for the *Full-implementers* in both portions were higher than the effect sizes for the *Low-implementer* and the *Control school*. Next, student growth was analyzed for the low-ability and high-ability students within each curriculum. It was found that student growth was more uniform for *Full-implementers*. 
Analysis of Teachers’ Interviews

Teachers are key to the success of curriculum reforms (Smith and Desimone, 2003; Spillane and Callahan, 2000; Stein, Remillard, & Smith, 2007), therefore they were contacted for interviews in order to understand the implementation of Cognitive Tutor curriculum in their classes. Schools A-F had one Geometry teacher in each school. School G had two Geometry teachers, and School H had four geometry teachers. One teacher from school G and two teachers from school H changed jobs; therefore, they could not be reached for an interview. The remaining nine teachers were contacted by email to set up the interview time. The email included interview questions, which were designed to access the level of implementation and to solicit their views about the Cognitive Tutor Geometry software and the textbook. Teachers from the Control school were not available for interviews. Three teachers from schools A, B and D preferred to respond to the interview questions by email; the other four set up interviews to be done by telephone. A new teacher, who is currently teaching Cognitive Tutor Geometry classes at school H, was interested in participating. Therefore, his comments are also included. He is referred to as “Teacher H” in this section. All three email responses were brief. Teachers who were interviewed by phone responded to the questionnaire in more detail and shared their experiences. The findings are examined in terms of the research questions. Research questions 2 and 3 are solely addressed by teachers’ responses in their interviews (see Appendix C for Summary of Teachers’ Responses), and research question 4 was addressed in teachers’ interviews as well as in the analysis of the Cognitive Tutor textbook.
Research question 2: To what extent was the Cognitive Tutor Geometry curriculum implemented in adopting schools? How did the scope of implementation differ across schools?

Interview Questions for Teachers 1-4 (see Appendix A) were designed to investigate how Cognitive Tutor Curriculum was implemented in participating schools. Schools A and G followed regular school schedules with 47-minute and 45-minute class periods every day, respectively. Students spent three days per week in classroom instruction with the Cognitive Tutor textbook, and practiced with the Cognitive Tutor software on the other two days of the week. Schools C – F followed block schedules with 80–90-minute class periods every other day. Longer class periods allowed teachers some flexibility with time, but most teachers shared that they tried to follow the standard recommendation (60% of the time for instruction from the textbook, and the remaining 40% time for practice with the software). School B followed a “swing-six” schedule, where students attend six out of the eight periods each day. Students attend Geometry classes 3-4 times a week; each class period was 60-minutes long, and every fourth day was spent with Cognitive Tutor software. Thus, students in school B spent only 25% of class time with the Cognitive Tutor software. All other schools (A and C–G) dedicated 40% of class time for the software as recommended by Carnegie Learning.

Schools A-F used the Cognitive Tutor software along with its accompanying textbook, but school G used a different textbook, Geometry: Applications and Connections from Glencoe, with the Cognitive Tutor software. Teachers from schools A and F used the Cognitive Tutor textbook along with another textbook, Discovering Geometry. When asked to explain, they stated that they like the hands-on activities offered in the Discovering Geometry textbook. From the quantitative analysis, it is clear that since schools A and F had higher effect sizes (2.8 and
2.6) as compared to other schools (See Table 3 in Chapter 3), they will perform at a higher rate. It is possible that the hands-on activities of Discovering Geometry textbook helped these students visualize geometric relationships from two different perspectives, which is considered to enhance learning (Siegler, 2005).

Teachers B and C used only the resources that accompanied the Cognitive Tutor Geometry packet. From Table 3, the effect sizes for schools B and C (1.6 and 1.7) are slightly lower than the average effect size for the full implementers (1.95). There might be several other reasons besides using the single curriculum. For example, in school B students and teachers have limited access to the computer labs, so these students were provided fewer opportunities to work on the problems with the software. Teachers D and E mentioned that they created worksheets for the students to provide more practice. Later, a skills worksheet was incorporated into the teacher material by Carnegie Learning. This worksheet was not available in 2008-2009 and therefore not offered in this study. From the quantitative analysis, the effect sizes for schools D and E (Table 3) are lower than other Cognitive Tutor schools. Teacher D and E might be teaching for skill efficiency at the cost of conceptual development. Several research studies show that too much emphasis on skill efficiency has negative impact on student learning (Hiebert and Grouws, 2007; Schoenfeld 1988). According to teachers from school D, “We do not seem to have much time for the homework activities, or if we do, we must skip something else. We do pick and choose the chapters and order them to our liking.” Table 7 shows the class time for Geometry classes in schools A-G along with the effect sizes.
Table 7

Time Spent in Geometry Classes

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Schedule</th>
<th>Geometry Class Periods in Four Weeks</th>
<th>Time Spent on Geometry</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>47 minutes everyday</td>
<td>20</td>
<td>940 min</td>
<td>2.8</td>
</tr>
<tr>
<td>B</td>
<td>Swing-six schedule with 60-minutes class periods</td>
<td>15</td>
<td>900 min</td>
<td>1.6</td>
</tr>
<tr>
<td>C</td>
<td>90 minutes class periods every other day</td>
<td>10</td>
<td>900 min</td>
<td>1.7</td>
</tr>
<tr>
<td>D</td>
<td>80 minutes class periods every other day</td>
<td>10</td>
<td>800 min</td>
<td>1.4</td>
</tr>
<tr>
<td>E</td>
<td>85 minutes class periods every other day</td>
<td>10</td>
<td>850 min</td>
<td>1.6</td>
</tr>
<tr>
<td>F</td>
<td>85 minutes class periods every other day</td>
<td>10</td>
<td>850 min</td>
<td>2.6</td>
</tr>
<tr>
<td>G</td>
<td>45 minutes everyday</td>
<td>20</td>
<td>900 min</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Table 7 shows that school D had the lowest class time among schools A-G, which might be a reason for the low effect size for school D. Increasing class-time, and more structured tasks might help the teacher from school D with the problem of insufficient class-time.

School G used Geometry: Applications and Connections from Glencoe with the Cognitive Tutor software. When asked about the factors that involved the decision about using a different textbook with Cognitive Tutor software, teacher G mentioned:

We adopted the Glencoe textbook in the spring before we decided to try cognitive tutor so it was partly because we had just bought a great deal of textbooks and plus we were just coming off of a core plus curriculum that both the administrators and the teachers felt was a lot like the cognitive tutor curriculum and we were trying the steer away from that teaching style at that time. We
wanted to go more traditional because our test scores had been going down ever since we left the traditional teaching style.

There were two reasons for not using the Cognitive Tutor textbook in School G: 1) the school had already bought *Glencoe Geometry* textbooks before deciding to “try” the Cognitive Tutor software; and 2) teachers and administrators believed that the reform-oriented curricula do not help students with preparation for standardized tests. Thus school G had implemented several changes to increase student achievement, but felt that it would be still identified as a “persistently lowest achieving” school by the Iowa Department of Education.

Several research studies show that Cognitive Tutor curricula increases student performance in standardized tests (Sarkis, 2004; Morgan & Ritter, 2002). The Cognitive Tutor textbook promotes exploration of mathematical concepts, while the software part implements mastery of facts and skills by practice. Emphasis on basic skills without conceptual understanding (from the textbook) might have impacted student achievement negatively (Hiebert and Grouws, 2007). The Cognitive Tutor software is part of a reform-oriented curriculum emphasizing constructivist theories; while in *Glencoe Geometry* textbook, important mathematical ideas are presented as prescribed rules (Plattner, 2009). Therefore, teaching and learning in school G might be inconsistent due a combination of curricula that are built on two different theoretical perspectives. According to Remillard, (2005), the textbooks influence teachers’ decisions, topics, and pedagogy in using a curriculum. It seems teacher G was aware of the inconsistency as he mentioned: “…for it to have an effect on their learning we have to really work hard into making the connection for them to the software in the regular classroom setting. We use it as just another way of delivering the same material in a different manner.” Based on
comments from teacher G and the quantitative analysis, instruction can be more effective when the Cognitive Tutor Curriculum is implemented along with its accompanying textbook. Although the enacted curriculum can be different from the written curriculum (Remillard, 2005), students perform better when a curriculum is implemented with fidelity.

Because the influence of curriculum materials on student learning cannot be understood without examining the curriculum as designed by teachers and as enacted in the classroom (Stein, Remillard and Smith, 2007), the next section brings teachers’ views on the effectiveness, efficiency, and effectiveness of the Cognitive Tutor Geometry curriculum, which leads to the research question 3, presented in chapter 1.

**Research question 3: What are the teachers’ views on the effectiveness, efficiency, and convenience of the Cognitive Tutor Geometry curriculum?**

All the responding teachers had very positive comments about the Cognitive Tutor software. They liked Cognitive Tutor software for three main reasons:

1) The software paces instruction according to student level. It allows students to work slowly if needed, and more advanced students to move fast.

2) The software provides prompt feedback to the students; therefore, students do not have to wait for the teacher’s attention. As a result, class time is used more effectively and efficiently.

3) Students spend about 40% of class time working on the problems rather than listening to a lecture. As a result, the software prompts hands-on and active learning.

Teacher F shared a few management problems with the software. According to her, when a student misses a class, he/she can check out the CD to work at home. She continued to share
that sometimes students get perfect solutions from friends and siblings, which can lead to academic dishonesty. Teacher F added that it would be nice to have password protection to avoid such problems. Another problem she mentioned were cases where students arrive in the middle of the school year. Usually, these students quickly adjust to the textbook, but the software is new to them. Although she shared these problems with the software, she appreciated its individualized support and flexible pace. On the other hand, several teachers shared some concerns about the textbook in the following responses:

“The textbook is good for advanced students only; the software works well for all types of students. I am teaching a low level class; my students have difficulty in reading. I think the way the textbook shows information, is good for only advanced students.” (Teacher H)

“Sometimes the textbook takes two pages to cover something that I can cover in minutes in class.” (Teacher E)

The Cognitive Tutor textbook is structured around collaborative investigations of problems that are set in contexts designed to allow students to uncover mathematics. On one hand, these contextual problems help students build connections between the material learned in class and their real-life experiences. On the other hand, this type of instruction might marginalize the students who have difficulty in reading, for example in English proficiency. Buchanan and Helman (1997) shared several strategies math teachers can use to help the students with limited English proficiency. One suggestion is that teacher pay attention to the English language in addition to mathematical language. According to authors, when teaching an obtuse angle that is
greater than 90 degrees, teachers should not only teach the word “obtuse,” but they may also have to teach the use of “-er” suffix to show the comparison in the work “greater.” Other comments about the textbook include inaccurate sequences of topics and redundant information. For example, teacher C shared that Right Triangle Geometry is presented in chapter 4, while the Right Triangle Trigonometry is offered in chapter 11. These two concepts build on each other; therefore they should be in either same chapter, in two consecutive chapters. Teacher F mentioned: “In the textbook, sometime they take a simple idea and ask so many questions. That way they make simple concepts more complicated.” The next section presents research question 4 and a few improvement strategies in Cognitive Curriculum Geometry curriculum shared by the teachers.

**Research question 4: If improvements are necessary, how can the Cognitive Tutor Geometry curriculum be improved?**

Interview Question 12 was asked to explore the areas of improvement in Cognitive Geometry curriculum. Teachers shared several suggestions and concerns. Teacher C suggested that school administrators provide more support for teacher training. Sometimes when a curriculum is started without proper training of the teachers, the curriculum can be unsuccessful. The Mississippi Bend Area Education Agency organizes teachers’ training but school administrators do not always encourage teachers to attend summer workshops and ICN sessions. Several teachers suggested a change in the order of topics in the Cognitive Tutor Geometry textbook. The current Cognitive Tutor textbook follows this sequence:

Chapter 1: Perimeter and Area

Chapter 2: Volume and Surface Area

Chapter 3: Angles and Triangles
Chapter 4: Right Triangle Geometry
Chapter 5: Parallel and Perpendicular lines
Chapter 6: Simple Transformations
Chapter 7: Similarity
Chapter 8: Congruence
Chapter 9: Quadrilaterals
Chapter 10: Circles
Chapter 11: Right Triangle Trigonometry
Chapter 12: Extensions in Area and Volume

Teachers shared three main concerns about the above sequence: 1) Right Triangles are introduced in Chapter 4, but Right Triangle Trigonometry is in Chapter 11. These two topics build upon one another and therefore should be either in the same chapter or in consecutive chapters; 2) Chapter 2 covers volume and surface areas of three-dimensional figures. Students are typically not ready for this concept in the beginning of the academic year. They should comprehend the material of one-dimensional figures such as circles and quadrilaterals before moving onto three-dimensional geometry. Therefore, volume and surface concepts should be introduced later in the textbook; and finally, 3) Chapter 3 covers very basic material on angles and triangles thus, should be covered in the first chapter in the textbook.

Based on teacher comments, Carnegie Mellon University decided to revise the sequence of topics in the newer edition of the Cognitive Tutor Geometry textbook. In addition, Teacher C, who is a certified Implementation Specialist for Carnegie Learning and a liaison between teachers and the Cognitive Tutor developers, shared that a revised edition, one more coherent in the order of topics, will be released for the academic year 2010-2011.
Based on the qualitative analysis, the Cognitive Tutor software is more popular among teachers as compared to the Cognitive Tutor textbook. Teachers appreciate the fact that the software paces instruction according to the student’s level, and it assists in implementing active learning. However, teachers have two main concerns about the textbook: one is the lack of coherence based on the poor sequence of the topics, and the second is making simple concepts more complicated and lengthy. The content of a coherent curriculum should evolve from simple concepts to more complicated and deeper structures (Bruner, p. 12 & 13). While teaching Cognitive Tutor Geometry classes in 2008-2009, several teachers changed the sequence of chapters. It is expected that the sequence of topics in the newer edition of the textbook would be more coherent and in accordance with teachers’ recommendations. The next section presents my views about the Cognitive Tutor textbook.

**Review of Cognitive Tutor Textbooks**

Student learning opportunities are the product of ongoing interaction among the text, the student, and the teacher (Stein, Remillard, and Smith, 2007). Therefore, the review of the Cognitive Tutor textbook was important. Chris Scott from Carnegie Learning provided access to the electronic textbook and the accompanying resources, which include:

i) Geometry Student Text

ii) Geometry Teachers Implementation Guide Volume I

iii) Geometry Teachers Implementation Guide Volume II

iv) Geometry Teachers’ Resources and Assessments

v) Geometry Student Assignments

vi) Geometry Homework Helper

vii) Skills Worksheets
For the purpose of this research, I will focus this section on the first three resources listed above: *Geometry Student Text, Geometry Teachers Implementation Guide Volume I, and Volume II*. However, for cohesiveness, the *Teachers Implementation Guide* will be presented first, followed by the *Geometry Student Text*, and concluding with the impact that each has on the individual student.

According to Carnegie Learning the goal of this curriculum is to improve students’ understanding of basic foundational skills as well as higher order concepts. The curriculum is based on ACT-R theory of learning, which emphasizes “learning by doing.” In the teachers’ guide, references are made to NCTM Curriculum and Evaluation Standards in the beginning of each section. A few warm-up questions are provided for teachers to initiate thinking among the students.

**Teachers Implementation Guide.**

In the *Teacher’s Implementation Guide*, each lesson starts with a one-page *Get Ready* section, which includes the list of materials, key terms, references to NCTM standards, and essential questions. This page helps teacher tie new concepts to the previous and future lessons. The next page is labeled as *Show the Way*; it includes warm-up review questions with answers and a *Motivator* to get students start thinking about the coming topic. This page is followed by a smaller version of student textbook pages with solutions. The margins of these pages are used for annotations, for example, as *Exploring Together* sections, which suggest a grouping of students that will work for the lesson, *Guiding Questions* for the teacher to pose, and *Key Formative Assessment Questions* that allow the teacher to ensure that groups or individual students are on track. Notes about particular questions include suggestions for key actions on the part of the
teacher, common student errors, and information about alternative solution paths. Each lesson ends with a one-page Wrap-Up section and a reflections section. The Wrap-Up section provides suggestions to review key concepts, and helps teachers facilitate students’ practice with the Cognitive Tutor Software. The Reflections section encourages teachers to review the lesson and note what parts of the lesson went well and what parts should be reviewed.

My assertion here is that the combination of student textbook and teachers’ material apply Cognitively Guided Instruction (Secada, 1992) to introduce the new concepts and that using the Teacher’s Implementation Guide along with Cognitive Tutor textbook offers professional development and supports the application of Cognitively Guided Instruction. According to Secada (1992, p. 649), Cognitively Guided Instruction or CGI is based on four interlocking principles: (a) teacher knowledge of how mathematical content is learned by their students, (b) problem solving as the focus of instruction, (c) teacher access to how students are thinking about specific problems, and (d) teacher decision-making based on teachers knowing how their students are thinking.

In the Teacher’s Implementation Guide, teachers are directed to have students solve some of textbook questions as a whole class and the rest in smaller groups. Occasionally, teachers are directed to bring the larger group (or whole class) together then have a representative from each of the smaller groups present the findings. Once students develop an understanding of a new formula or concept from the textbook as a group, then as individuals, they are ready to use the Cognitive Tutor software to apply these concepts and solve the problems. Thus, the Cognitive Tutor software and the accompanying textbook can facilitate whole-class instruction, small group learning, and ultimately, individual learning.
**Geometry Student Text.**

The student textbook emphasize Discovery learning, Collaborative learning and *Learning by Doing*. Each chapter’s opening page includes a photo related to a real-world problem and a list of key terms with page references. The real world problems help students develop important definitions, concepts, and formulas. The problems are divided into several parts with very clear step-by-step directions, which enable students become familiar with the concepts slowly. Several questions are presented to help the students make generalizations.

Throughout the text, icons are used to emphasize the collaborative learning instruction model by which students construct their own meaning of math concepts. Students are directed to *Discuss to Understand, Think for Yourself, Work with Your Partner, Work with Your Group, or Share with the Class*. Directions such as: *Explain how you solved the problem to your partner* and *Share what your group discovered with the entire class* encourage students to communicate and collaborate with their peers.

Each section in the students’ textbook introduces the real-world problem related to the earlier photo followed by several questions. These problem scenarios make geometry more interesting and relevant for the students (Brown Collins & Duguid, 1989; Koedinger & Corbett, 2006, Stuart, 2000). Sometimes a single problem leads to several important concepts, which can prove practical and effective to student learning. For example on page 381, the following problem leads to the definitions of *Point of Congruency, incenter, circumcenter, medians, orthocenter* and *centroid*. 
A restaurant owner has three restaurants in one city. The owner is looking for some warehouse space to store extra supplies and equipment that won’t fit in the restaurants. The space should be located where it is central to all three restaurants.

The restaurants are represented by the vertices of a triangle, and then the students are directed to draw the *incenter, circumcenter, medians, orthocenter* and *centriod*. The last problem leads students to the decision that the *circumcenter* is the best location for the warehouse. This approach is in accordance with constructivist theories in which students are expected to establish a connection between prior and new knowledge. One might argue that the textbook controls students’ solution path, but it might be necessary to introduce formal mathematical theorems and concepts.

In 2006, Ma and Papanastasiou identified *problems-based instruction* as the most effective method to begin a new topic, but they warned mathematics teachers about the excessive use of story problems and related questions. According to Ma and Papanastasiou, teachers should carefully study the new topic and make a reasoned decision regarding which method best suits the new topic. Excessive questions surrounding one concept might be one reason for reluctance to use the Cognitive Tutor by some teachers. According to Teacher H, the textbook does not work for low-ability students who may have difficulty in reading and writing. Figure 9 shows the page from the textbook on the volume of a pyramid.
Figure 9. Volume of a Pyramid.

Note. From Geometry student text (p. 79), by Carnegie Learning. Copyright 2008 by Carnegie Learning Inc.
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The above illustration shows four questions surrounding this topic. Several other questions are asked on the following pages. The goal of these questions is to help the students
understand the relationship between the volumes of a rectangular prism and a rectangular pyramid that has the “same base.” The last set of questions on this topic, ask students to make a rectangle and a pyramid, fill the pyramid with rice or beans, and then dump the rice or beans into the rectangular prism. Students are expected to find that the volume of a pyramid is equal to one third of the volume of the prism. This inquiry could work fine without questions A, B and D shown in the above figure. Question D is not clear about the type of prism students should “start with,” or how they “might form a pyramid” from a prism. The language used in question D can be confusing, because even if students think about slicing off the wedges from the prism, they might have difficulty in explaining how to do so in complete sentences. The following, Figure 10, shows a pyramid within a rectangular prism. This image could have been used in the text to provide better insight for the students and help them understand question D and the relationship between the volume of a pyramid and a rectangular prism.

![Pyramid within a rectangular prism](image)

*Figure 10. Pyramid within a rectangular prism.*

In addition to the poor use of language, students might lose focus and purpose due to the excessive number of questions (Ma and Papanastasiou, 2006). Some of the questions have no purpose or relevance to learning and understanding the concept. For example, in chapter 5, after the students explore the relationship between the slopes of perpendicular lines, they are asked on page 218:
“Do you think that the $y$-intercepts of perpendicular lines tell you anything about the relationship between the perpendicular lines? Use a complete sentence to explain your reasoning.”

The $y$-intercepts of lines tell us where the lines intersect the $y$-axis, but there is no relationship between the $y$-intercepts of perpendicular lines. Therefore, the above question seems irrelevant. Similarly, chapter 4 on Right Triangle Geometry starts with the scenario shown in figure 11:
Figure 11. Lots of Tiles.

Note. From *Geometry student text* (p. 69), by Carnegie Learning. Copyright 2008 by Carnegie Learning Inc.

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It is important to once again reference the *Teacher Implementation Guide* and teachers concerns from the study here. According to the Teachers’ Guide, this problem is supposed to prepare students for a lesson on right triangles; however, the problem in the textbook does not show a clear connection to the geometry of right triangles and instead addresses the relationship between the units of length and area. If the intention is to introduce the expressions involving square roots, it might be more appropriate to give the area of a square tile and ask for the dimensions of that tile.

Discussed earlier was the concern that teachers had with the textbook’s sequence of topics in current geometry textbook. Teacher C mentioned in her interview that the concepts Right Triangle Geometry and Right Triangle Trigonometry should build upon each other. Therefore, these topics should either be in the same chapter or in the consecutive chapters. Instead, in the current Cognitive Tutor Textbook, Right Triangle Geometry is covered in chapter 4, and the Right Triangle Trigonometry is in chapter 11.

Figure 12 presents the concept of right triangles using $45^\circ - 45^\circ - 90^\circ$ Triangle Theorem and $30^\circ - 60^\circ - 90^\circ$ Theorem from chapter 4 to respond to a question in chapter 11.

*Figure 12. Right Triangles.*

If Right Angle Trigonometry and this question were presented right after chapter 4, students would be able to recall and apply the $45^\circ – 45^\circ – 90^\circ$ Triangle Theorem and $30^\circ – 60^\circ – 90^\circ$ Triangle Theorem to build the trigonometric relationships. Hence, there would be no need to provide the lengths of the sides of these triangles. This proposed approach would be more consistent with the constructivist philosophy and would offer a more coherent way of learning for students.

According to the Third International Mathematics and Science Study (TIMSS), there is a direct relationship between students’ exposure to coherent content, and their performance on achievement tests. Schmidt, and Houang (2005) explain coherence as:

Content standards, taken together, are coherent if they are articulated over time, as a sequence of topics and performances consistent with the logical and, if appropriate, hierarchical nature of the disciplinary content from which the subject matter derives...for a set of content standards ‘to be coherent’ they must evolve from the particulars (e.g. simple mathematics facts and routine computational procedures associated with whole numbers and fractions) to deeper structures. It is these deeper structures by which the particulars are connected (such as an understanding of the rational number system and its properties.) This evolution should occur both over time within a particular grade level and as the student progresses across the grades.

**In-depth look at three prevailing textbooks.**

To offer a more in depth look at the value of coherency in textbooks, I compared the sequence of topics in the three prevailing textbooks used across the schools in this study. Table 8
shows the comparison of the order of topics in the *Cognitive Tutor Geometry* textbook (2008), *Glencoe Geometry* (2010), and *Discovering Geometry* (2008).

**Table 8**

*Sequence of Topics in Three Textbooks*

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic definitions in Geometry</td>
<td>Chapter 1</td>
<td>Chapter 1</td>
<td>Chapter 1</td>
</tr>
<tr>
<td>Reasoning</td>
<td>Chapter 2</td>
<td>Chapter 2</td>
<td></td>
</tr>
<tr>
<td>Perimeter and Area</td>
<td>Chapter 1 &amp; 11</td>
<td>Chapter 8</td>
<td></td>
</tr>
<tr>
<td>Volume and Surface Area</td>
<td>Chapter 12</td>
<td>Chapter 8 &amp; 10</td>
<td></td>
</tr>
<tr>
<td>Angles and Triangles</td>
<td>Chapter 1 &amp; 5</td>
<td>Chapter 1, 3 &amp; 4</td>
<td></td>
</tr>
<tr>
<td>Right Triangle Geometry</td>
<td>Chapter 8</td>
<td>Chapter 9</td>
<td></td>
</tr>
<tr>
<td>Parallel and Perpendicular Lines</td>
<td>Chapter 1 &amp; 3</td>
<td>Chapter 1 &amp; 3</td>
<td></td>
</tr>
<tr>
<td>Simple Transformations</td>
<td>Chapter 9</td>
<td>Chapter 7</td>
<td>Chapter 11</td>
</tr>
<tr>
<td>Similarity</td>
<td>Chapter 7</td>
<td>Chapter 7</td>
<td></td>
</tr>
<tr>
<td>Congruence</td>
<td>Chapter 1 &amp; 6</td>
<td>Chapter 1 &amp; 5</td>
<td></td>
</tr>
<tr>
<td>Quadrilaterals</td>
<td>Chapter 10</td>
<td>Chapter 10</td>
<td></td>
</tr>
<tr>
<td>Circles</td>
<td>Chapter 11</td>
<td>Chapter 8</td>
<td>Chapter 12</td>
</tr>
<tr>
<td>Right Triangle Trigonometry</td>
<td>Chapter 12</td>
<td>Chapter 11 &amp; 12</td>
<td>Chapter 8 &amp; 10</td>
</tr>
<tr>
<td>Extension in Area and Volume</td>
<td>Chapter 13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Probability and Measurement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geometry as a Mathematical System (Proofs)</td>
<td></td>
<td></td>
<td>Chapter 13</td>
</tr>
</tbody>
</table>

One prominent difference between Cognitive Tutor Geometry textbook and other two books is that the other two geometry textbooks introduce basic definitions and symbols in the first chapter, and use those definitions and symbols in subsequent chapters. *Glencoe Geometry*
and *Discovering Geometry* textbook introduced students with the definitions for *line segments, rays, angles, congruence, polygons* and *Cartesian Coordinates* in the first chapter. Later these topics are discussed in detail in subsequent chapters. Thus, both of these books follow a spiral design. In a spiral curriculum, students are not expected to master the topic the first time it is introduced, but rather are expected to deepen their understanding and attain eventual mastery over time as the topics are revised (Hiebert and Grouws (2007). According to Snider (2004), covering so many topics superficially in a single chapter has a negative impact student learning, as they might lose interest due to redundant definitions and symbols. The opposite of spiral organization is modular approach, in which topics can be separated. Most standard based curriculum materials follow modular organization in which each module presents a big idea (Hiebert and Grouws (2007). In the Cognitive Tutor textbook, the definitions are presented as they come along, and real-world scenarios are used to introduce students to new definitions and symbols. This slow progression of definitions and symbols could allow teachers and students more time to comprehend the material before moving to the next definition. Theories in spiral and modular organization of curriculum might be the basis the sequences found in these three textbooks.

Chick (2007) suggests the following sequence to make geometry more coherent.

*Figure 13. Chick’s model*
Chick follows this model in his paper to draw a *tesseract* (four-dimensional figure). If we follow this sequence, we should start by the concepts of Cartesian coordinates of a point (zero dimensional), and then move to one, two and three dimensional figures. Based on Chick’s model, I developed the following sequence of topics and find them ideal for the Cognitive Tutor textbook:

*Table 9*

*Proposed Sequence of Topics*

<table>
<thead>
<tr>
<th>Category</th>
<th>Comprehensive List of Topics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero- dimensional</td>
<td>Cartesian Coordinates of a Point</td>
</tr>
<tr>
<td></td>
<td>Transformations</td>
</tr>
<tr>
<td>One- dimensional</td>
<td>Parallel and Perpendicular Lines</td>
</tr>
<tr>
<td>Two- dimensional</td>
<td>Angles and Triangles</td>
</tr>
<tr>
<td></td>
<td>Similarity</td>
</tr>
<tr>
<td></td>
<td>Congruence</td>
</tr>
<tr>
<td></td>
<td>Quadrilaterals</td>
</tr>
<tr>
<td></td>
<td>Right Triangle Geometry</td>
</tr>
<tr>
<td></td>
<td>Right Triangle Trigonometry</td>
</tr>
<tr>
<td></td>
<td>Circles</td>
</tr>
<tr>
<td>Three-dimensional</td>
<td>Volume and Surface Area</td>
</tr>
</tbody>
</table>

The list of topics above is a comprehensive list developed from the Cognitive Tutor textbook categorized by dimension based on Chick’s theory and simplified for coherency.

Chapter 1 on *Perimeter and Area* in the Cognitive Tutor Textbook (Table 8) can be distributed across the chapters on two-dimensional figures i.e. *Angles and Triangles, Quadrilaterals* and
Circles. The proposed sequence of topics was compared with the list of geometry topics found at www.corecurriculum.iowa.org. Following list of essential topics is found at this website:

- Coordinates
- Transformations
- Geometric properties and relationships
- Trigonometric relationships
- Vertex-edge graphs

The order of topics in the proposed sequence of topics (Table 9) is similar the order of topics to the above list. Table 10 shows relationship between the proposed sequence of topics and Geometry topics in Iowa Core Curriculum.

**Table 10**

*Proposed Sequence of Topics Compared with Iowa Core Curriculum*

<table>
<thead>
<tr>
<th>Category</th>
<th>Comprehensive List of Topics</th>
<th>2009 Topics in Iowa Core Curriculum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero-dimensional</td>
<td>Cartesian Coordinates of a Point</td>
<td>Coordinates</td>
</tr>
<tr>
<td></td>
<td>Transformations</td>
<td>Transformations</td>
</tr>
<tr>
<td>One-dimensional</td>
<td>Parallel and Perpendicular Lines</td>
<td>Geometry Properties and Relationships</td>
</tr>
<tr>
<td>Two-dimensional</td>
<td>Angles and Triangles</td>
<td>Geometry Properties and Relationships</td>
</tr>
<tr>
<td></td>
<td>Similarity</td>
<td>Geometry Properties and Relationships</td>
</tr>
<tr>
<td></td>
<td>Congruence</td>
<td>Geometry Properties and Relationships</td>
</tr>
<tr>
<td></td>
<td>Quadrilaterals</td>
<td>Geometry Properties and Relationships</td>
</tr>
<tr>
<td></td>
<td>Right Triangle Geometry</td>
<td>Trigonometric relationships</td>
</tr>
<tr>
<td></td>
<td>Right Triangle Trigonometry</td>
<td>Trigonometric relationships</td>
</tr>
</tbody>
</table>
If we compare the existing sequence of topics (Table 8) with the proposed sequence, and Iowa Core Curriculum, we see four main concerns about the existing Cognitive Tutor Geometry curriculum:

1) Cartesian representation of a point, which is connected with the concept of transformations, is introduced in chapter 4 in the current curriculum. Using Chick’s theory, it would be more logical to introduce this topic earlier, and build other spatial concepts (i.e. lines and symmetry) from Cartesian representation.

2) The concepts of volume and surface area should be introduced after students comprehend one-dimensional geometry (i.e. lines and angles). The current textbook seems to introduce area and volume too early.

3) Right Triangle Trigonometry is built on the geometry of Right Triangles. Therefore, the chapter on Right Triangle Trigonometry (chapter 11 in current textbook) should follow Right Triangle Geometry (chapter 4). After that unit circle approach can be used to enhance students’ understanding of trigonometric relationships.

4) Vertex-edge graphs are missing in the Cognitive Tutor Geometry curriculum. “Students should understand, analyze, and apply vertex-edge graphs to model and solve problems related to paths, circuits, networks, and relationships among a finite number of elements, in real-world and abstract settings.” (www.corecurriculum.iowa.org)
Tying this to the quantitative analysis (refer to Figure 6), it is apparent that the effect size for *Cartesian Coordinates* is low (\(d < 0.5\)), and the effect sizes for *Transformations* and *Formulas* (under the topic of *Volume and Surface Areas*) are lower as compared to other topics. Non-intuitive sequence might be one reason for the lower effect sizes in these three areas.

**Traditional versus constructivist philosophies.**

The Cognitive Tutor Geometry textbook emphasizes student thinking; it uses real world scenarios and students’ prior knowledge to develop important geometrical formulas and theorems. These are the main principles of constructivist philosophy. The opposite of constructivism is traditional philosophy, which is based on direct transfer of knowledge from the teacher to the student. Teacher D had the following comments about chapter 5 in the Cognitive Tutor textbook on *Parallel and Perpendicular Lines.*

“They [students] are always eager and ambitious for the software. The textbook varies from chapter to chapter. As I said, chapter 5 is traditional and their least favorite.”

Each topic in this chapter starts with real world scenarios, but it includes more mathematical terminology, for example *Transitive Property, Reflexive Property* and *Symmetric Property of Congruence.* Students are provided the picture of scissor lifts (Figure 14) to draw these properties.
After the students derive the properties of congruence, they are introduced to the symbol “$\cong$” for congruence. This chapter follows constructivist philosophy – helping the students construct their own knowledge. This could probably be the students’ “least favorite” chapter because of the two-column proofs concept on page 202 – 204, which lead to the Congruent Supplements Theorem, Congruent Complements Theorem, and the Vertical Angles Congruence Theorem. These proofs are based purely on mathematical knowledge and are not connected to any shape that students see in the real-world. Figure 15 shows how students are directed to construct a two-column proof for the Congruent Supplements Theorem.
**Figure 15.** Two-column Proof for the Congruent-Supplements Theorem.


This proof is very similar to the *two-column proofs* in other traditional geometry books. According to Driver et al. (1994): “If everyday representations of particular natural phenomena are very different from scientific representations, learning may prove difficult – students will need to be aware of the varied purposes of scientific knowledge, its limitations, and the basis on which its claims are made.” Driver et al. provide two pedagogical suggestions for teachers to
resolve this issue: 1) Introduce new ideas and cultural tools where necessary and to provide support and guidance for the students to make sense of these for themselves 2) Listen and diagnose the ways in which instructional activities are being interpreted to perform further action.

Going back to the Constructed-response section of the pre- and post test, one question on two-column proofs was included, but separate scores for each question were not available for the Constructed-Response section like there were on the Multiple-choice section. Therefore, it was not possible to measure student understanding of two-column proofs. From the qualitative analysis and from earlier research presented, we can conclude that relating two-column proofs to the shapes that students see in their daily lives, can increase motivation and thus enhance student understanding. “People are much smarter when they can relate what they are learning to situations or phenomena which are real to them” (Thurston, 1990).

From the quantitative analysis of student growth, the Cognitive Tutor students showed more gain in all the areas except for Similarity (see Figure 7). Therefore, chapter 7 on Similarity in the Cognitive Tutor textbook was reviewed in detail to see if it aligned with the contents in pre- and post-test. The Cognitive Tutor textbook discussed Similarity in real-world authentic problems, but the pre-and post test accessed students’ knowledge in more abstract format.

Figure 16 shows a page from the Cognitive Tutor textbook on Similarity:
**Figure 16. Similarity**


Students are expected to use *Side-Angle-Side Similarity Postulate* to solve this problem.

Most textbook questions on *Side-Angle-Side Postulate* are embedded in real-world context and require higher-order critical thinking. Pre- and post-tests included two questions on *Side-Angle-Side Postulate*. In the first question, students were given that two right triangles are isosceles, and they are asked which postulate would prove that these triangles are similar. Only 48%
Cognitive Tutor students answered this question correctly as compared to 70% control students. This implies that the chapter on Similarity in the Cognitive Tutor textbook was not aligned with the content on pre-and post-test. The second question in pre-and post-test is similar to the question presented in Figure 17.

Which postulate could you use to prove that ΔABC and ΔDBE are similar?

Figure 17. Question on Similarity.

Note: Actual Test question is not presented for test security purpose.

Only 40% Cognitive Tutor students answered this question correctly as compared to 46% in control group. The Cognitive Tutor students might have understood Side-Angle-Side Similarity Postulate, but have difficulty in applying this postulate in very abstract format without context, or they might have difficulty with mathematical vocabulary (i.e. isosceles triangles, side-angle-side similarity postulate). The reason could be that students need contextual as well as abstract mathematical concepts in order to succeed in higher level mathematics courses (Schoenfeld, 2004). Therefore, it might be helpful to include a few questions in the textbook where students apply this postulate without the real-world context. Mostly, the Cognitive Tutor textbook uses real-world scenario to introduce the new concepts, followed by purely mathematical questions on the newly learned material. Only chapter 7 lacks practice for the side-angle-side similarity postulate in more abstract format. Although there are few concerns for redundant information, incorrect sequence of topics and lack of skill-development, the Cognitive
Tutor textbook shows progress towards finding a balance between reform-oriented and traditional mathematics curricula. Examination, enhancement and implementation of this curriculum must be encouraged to accomplish our goal of better mathematics education for all students.
Chapter 5. Conclusion

With the ongoing threat of students’ continuous struggle in mathematics, schools have begun to implement the Cognitive Tutor Curriculum, which incorporates tutoring software for individual students into teacher-led classroom instruction. The initial goals of this study were threefold: 1) to examine different ways of implementing the Cognitive Tutor Geometry curriculum; 2) to evaluate the impact of the Cognitive Tutor Geometry curriculum on student achievement; and 3) to find out teachers’ perspectives about this curriculum. A fourth goal of reviewing the textbook was added in this study due to teachers’ dissatisfaction with the Cognitive Tutor Geometry Textbook. Students’ pre- and post-test scores were analyzed to evaluate student growth in each participating school, and the teachers who taught geometry classes in 2008 – 2009 were interviewed in order to study the different ways to implement the curriculum. Several challenges arose in evaluating student progress. For example, the reliability and validity of pre-and post-tests proved questionable. Because most of the test items assessed students’ knowledge of specific facts and terminology, students could have guessed their answers randomly, which can pose a serious threat to internal consistency of the test. In addition, because the same test was used for the pre- and post-test, students were forewarned about the topics emphasized in the test. Thus, student improvement could be a result of testing threat, not the curriculum. An estimate of the reliability coefficient could have enhanced the researcher’s confidence in instruments.

The comparability of schools was another challenge. As shown in table 7, each school implemented the Cognitive Tutor Geometry curriculum in a different way. Several other factors such as teacher effect, class size, schedule, and class time might have contributed to or refrained student improvement from the pre-test to post-test. For example, the lower gain in School D
might be the result of lesser class time, and the performance of students in school B might be
refrained due to unavailability of computer labs. Teacher training and experience had a
significant impact on student achievement. Therefore, the variation in student gains in tables 3, 4
and 5 might be due to the differences in teacher quality. Thus, any causal inferences about the
effectiveness of Cognitive Tutor Geometry curriculum cannot be made. It is important to
mention that using Cohen’s standards for the low, medium, and high effect sizes might not be
reasonable for this study. Cohen (1988) used effect sizes to compare the effect of two different
treatments, while in this study, the effect sizes are calculated to find the degree of improvement
within each school. Due to several extraneous variables, this study is reluctant to make cross
sectional comparisons among schools. This chapter summarizes the findings from both the
quantitative and qualitative analyses in the study. Then, the chapter offers limitations of the study
followed by recommendations for further research.

Cognitive Tutor Geometry Curriculum and Student Achievement

The literature offered several studies that evaluated the impact of the Cognitive Tutor
Algebra curriculum and showed positive results. It was expected that the implementation of
Cognitive Tutor Geometry curriculum along with its accompanying textbook would share the
similar results; however, the results obtained in this study were not as impressive. A comparison
of average gains in Table 3 showed that all the full implementers had higher gains as compared
to the partial implementer, but only two full implementers had higher gain than the control
school. There might be several reasons for this. For example, the sample from the control school
did not include the low ability students. So, the average gain for the control school might be
enhanced by several other factors, including more parental involvement and student motivation.
Thus, a conclusion cannot be drawn based on the average gains. On the other hand, a comparison
of effect sizes showed on average higher effect size for the full-implementers than for the partial implementers and the control school. Student achievement in the multiple-choice and constructed-response portions of the pre- and post-test was analyzed separately and also showed no pattern for the mean scores, but the average effect sizes for the full-implementers were higher than those of partial-implementer and the control school. Lower variances for the full-implementers might be a reason for the higher effect sizes.

Student overall growth in the partial-implementer school turned out to be the lowest among all the participating schools. The reasons could be the excessive emphasis on the skills and procedures with the Glencoe Geometry Textbook along with the Cognitive Tutor software. Therefore, the students may have lacked conceptual understanding. According to Hiebert et al. (1997), “…the tasks must allow the students to treat the situations as problematic, as something they need to think about rather than as a prescription they need to follow” (p. 18). The control school, which used only the Glencoe Geometry curriculum without any software assistance performed slightly better than the partial-implementer school. The reasons for this might be that the control school assigned high-ability students to the Glencoe Geometry classes. Therefore, the growth for these high-ability students could also be enhanced by other factors, including parents’ involvement, students’ motivation, etc.

Overall, it is difficult to find much evidence to support or refute the claims that have been made in prior research about the effectiveness of Cognitive Tutor curricula. However, it can be concluded that the Cognitive Tutor software is more effective when used along with its accompanying textbook than when it is used without it.
Cognitive Tutor Geometry Curriculum and Student Levels

According to the literature, the Cognitive Tutor curriculum is more beneficial for students who are academically at-risk. But the research showed approximately equal gains for the high-ability and low-ability students for the full-implementer schools. For the partial-implementers, student growth was higher for the high-ability students, but the difference in growth for high- and low-ability was not statistically significant ($t = 1.3$, $p > .05$). In the control school, student growth for the high-ability students was significantly higher than the low-ability students ($t = 2.8$, $p < .05$). The implication here is that the Cognitive Tutor curriculum can allow more uniform growth for all students at different levels, which contradicts the control school’s (teacher H’s comment) idea that the Cognitive Tutor textbook is effective for advanced students only. This contradiction might be due to the difference in ways that low- and high-ability students are categorized. This research separated low- and high-ability students based on their pre-test scores, but Teacher H defined the low-ability students as the students with limited English proficiency. The control school usually assigned low-ability students to the Cognitive Tutor classes, but it is not clear which criteria was used to separate the low- and high-ability students. More research is needed to uncover reasons for assigning low-ability students to the Cognitive Tutor classes in the control school.

Cognitive Tutor Geometry Software

The Cognitive Tutor software proved to be convenient and effective. Because the Cognitive Tutor software is built on cognitive models, which are used to tutor individual students like human tutors (Koedinger & Corbet, 2006) and have knowledge of students’ prior knowledge and misconceptions, the Cognitive Tutor is able to follow a student’s reasoning step by step, and hence understand when and where a student lacks knowledge or understanding. Both the
literature and the research concluded that the software provides appropriate scaffolding, feedback, and assistance to students promptly. It is convenient because, students do not have to wait for the teacher’s attention to move forward. Thus, class time is used more efficiently. The software proved to also benefit the under-confident student, who might be too shy to ask for help from teachers or classmates. It was found that the software was more beneficial for the students when it was accompanied by the *Cognitive Tutor* textbook, which implies that the software should not be used without the accompanying textbook.

**Cognitive Tutor Textbook**

In the teachers’ interviews, some teachers shared concerns about the redundant information and the sequence of topics in the *Cognitive Tutor Geometry* textbook; so, the textbook was evaluated in the study. It was found that teachers’ concerns were genuine. A new sequence of Geometry topics was developed in the research based on Chick’s model (2007), which suggested that teaching geometry should start with zero dimensional Cartesian coordinates then move to one, two and three dimensional figures. In addition to teachers’ concerns about the sequence, a few areas were found that might be responsible for students’ loss of focus and purpose due to its use of excessive questions and vague language. The research suggests a need to clarify the language and to ask fewer questions. Although there were a few concerns, the *Cognitive Tutor* textbook includes well-designed tasks that allow students to induce mathematical concepts based on their reasoning and thinking. In addition to the student textbook, a *Teachers’ Implementation Guide*, which provides resources to implement Cognitively Guided Instruction, was evaluated. The purpose of the guide is to help teachers to promote active learning and tie new lessons to previous and future lessons. The guide seemed to serve its purpose when used. Even with its deficiencies, the *Cognitive Tutor* textbook used along with the
software helped schools perform better. The research showed that a program that is implemented according to its design may prove to be more consistent and coherent, which can lead to increased motivation and ultimately enhanced student learning.

This research might convince teachers and administrators to move towards full implementation of mathematics curricula according to teachers’ guides and curriculum intentions. Combining the components from different curricula might cause inconsistent instruction and disparity among students. Teacher involvement in implementing and updating the curriculum materials and providing feedback should be continued in order to attain more well-balanced, well-structured, and rigorous mathematics curricula in schools.

Limitations

The quantitative and qualitative analysis approaches used in this study have a number of limitations, which include variability among schools, lack of random assignments, inappropriate pre-and post-tests, the difference between written and enacted curriculum, and the absence of students’ perspectives.

The most significant problem in measuring the impact of the *Cognitive Tutor Geometry* curriculum was variability in the ways this curriculum was implemented in different schools. For example the *control school* (School H) assigned the high-ability students to the traditional classes, while schools A – G did not separate students based on their ability levels. School D had lower class time among all participating schools. School B did not have enough access to the computer labs. Several other factors such as class environment and socioeconomic status might have played a role in variance in student achievement.

Absence of random assignments of teachers and students into different groups was another concern. There is a chance that higher student achievement was associated with
unmeasured teacher characteristics and experiences. Due to this confounding variable, only humble claims can be made about the effectiveness of the Cognitive Tutor curriculum on student achievement. An additional concern comes from the pre-existing differences among students. Several other factors, besides the curriculum reform, including parents’ involvement, student motivation, and study habits, might have impacted student achievement.

Inconsistency between the test questions and the curriculum material was another limitation. The Cognitive Tutor curriculum has a heavy emphasis on solving real-world problems, but most of the test questions assessed students’ knowledge of mathematical facts and vocabulary. The multiple-choice portion of the test included only two real-world problems, and Cognitive Tutor students did slightly better than the other groups on those questions. The constructed-response portion included three real-world problems, but separate scores for the problems were not available for this portion of the test. Therefore, students’ total scores were used, but they might have failed to accurately measure student achievement.

Another limitation of this study is the difference between the written and enacted curriculum (Stein, Remillard and Smith, 2007). Although teachers were interviewed to find the level of implementation and their instructional practices, the research does not offer a complete picture of classroom environment, discourse, and pedagogy. In addition, three teachers changed jobs during the study and could not be reached for interviews. The researcher might not have captured the extent to which the teachers were implementing the core principles of this curriculum, such as emphasis on student thinking, group work, and learning by doing, as recommended by Carnegie Learning. According to Stein, Remillard and Smith (2007), the tasks that place a more cognitive demand on students, are less likely to be implemented in the classrooms as intended. Thus, the cognitively demanding tasks might not have been implemented
as recommended by Carnegie Learning. The interviews only provided a limited understanding of what was actually happening in the classrooms. Because this study involved a secondary analysis, the researcher was unable to find students’ perspectives about this curriculum. The next section presents some recommendations that may enhance further research and the ability to make inferences about this curriculum.

**Recommendations**

After reviewing the existing literature on curriculum evaluation, a few recommendations for researchers and developers should be considered. Because each school implemented the *Cognitive Tutor* curriculum in a different way, strong claims cannot be made in this type of study. For example in school G, several other factors such as teacher quality, low parental involvement, or low student motivation might have lowered student achievement. A longitudinal study is recommended and should follow student progress from Algebra I through college level math. This way, student characteristics are likely to remain unchanged overtime. This will allow researchers to make stronger claims about the impact of the *Cognitive Tutor* curriculum on student achievement. If a high ratio of students succeeds in college without having to take remedial classes, it may be concluded that the *Cognitive Tutor* curriculum actually benefited students. Another suggestion is to find the correlation between the math portion of students’ ACT or SAT scores and students’ cumulative *Cognitive Tutor* scores from Algebra I, Geometry and Algebra II.

The level of implementation and fidelity of the *Cognitive Tutor Geometry* curriculum should be evaluated by classroom observations in addition to the use or un-use of the accompanying textbook. Different teachers teach the same material differently. Classroom observations would enhance researcher’s understanding of classroom environment and cognitive
load on student. Another important consideration is to record individual students’ experiences with the *Cognitive Tutor* curriculum, which may differ due to their study habits, the attributes their peers may bring to the class (especially group activities), and teachers’ actions. This information can be gathered through student surveys, reflections, and an examination of their work. It is important to note that the students’ experiences, capacities, and attitudes should be respected in every curriculum reform (Dewey, 1902, p. 209).
References


Appendix A. Interview Questions for Teachers

1. Tell me about your implementation of the program. About how much time did students spend in the computer lab?

2. Did you implement the Cognitive Tutor textbook along with the software? Or you supplemented your own instruction with the Cognitive Tutor software?

3. Which factors were involved in your decision to implement or supplement the Cognitive Tutor software?

4. What was the schedule of your classes? Block schedule or regular schedule?

5. Does this program provide opportunities for advanced students to accelerate in Mathematics? If so how? If not, why not? How can it provide more opportunities for advanced students to accelerate in mathematics?

6. Were computers available during entire time of instruction?

7. Does this program allow you more time to assist students individually?

8. In what ways, does this program make geometry more interesting or relevant for students?

9. What is the impact of this program on student motivation to learn Geometry?

10. What is the effect of this program on student learning?

11. What other resources did you use in your classes?

12. Can you provide your comments and suggestions about this program, workbooks, software, and its implementation in your school?
Appendix B. Distributions of Percent Growth

![Graph of Percent Growth in School A](image)

![Graph of Percent Growth in School B](image)

![Graph of Percent Growth in School C](image)
### Appendix C. Summary of Sample Statements from Teachers’ Interviews

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Q1: Implementation</th>
<th>Q2: Textbook</th>
<th>Q3: Factors involved</th>
<th>Q4: Schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>40% with software and 60% with textbook</td>
<td>Used Cognitive Tutor textbook and occasionally supplemented with another textbook for more practice</td>
<td>Got a grant; computers were available for each student</td>
<td>47 minute periods everyday</td>
</tr>
<tr>
<td>B</td>
<td>Every 4th day with the software (25%)</td>
<td>Used Cognitive Tutor software and textbooks only</td>
<td>Software reinforces student learning</td>
<td>Swing-six schedule; 60 minutes class periods</td>
</tr>
<tr>
<td>C</td>
<td>40% with software and 60% with textbook</td>
<td>Totally used Cognitive Tutor curriculum</td>
<td>Were looking for something new to teach math; started pilot program nine years ago. Really liked it.</td>
<td>90 minute class periods every other day</td>
</tr>
<tr>
<td>D</td>
<td>40% with software and 60% with textbook</td>
<td>Use Cognitive Tutor Textbook almost solely as the classroom resource</td>
<td>Got a grant; computers were available for each student</td>
<td>Block schedule; meet every other day for about 80 minutes</td>
</tr>
<tr>
<td>E</td>
<td>40% with software and 60% with textbook</td>
<td>With Cognitive Tutor Textbook</td>
<td>Got a grant; The superintendent watched my classes and we decided to continue</td>
<td>Block schedule; meet every other day for about 85 minutes</td>
</tr>
<tr>
<td>F</td>
<td>40% with software and 60% with textbook</td>
<td>Used Cognitive Tutor software and textbooks</td>
<td>Our school got a grant</td>
<td>Block schedule; meet every other day for about 85 minutes</td>
</tr>
<tr>
<td>G</td>
<td>40% with software and 60% with textbook</td>
<td>Glencoe Geometry Textbook</td>
<td>Scores were low. Wanted to reach students in a different manner than traditional methods</td>
<td>47 minute periods everyday</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Teacher</th>
<th>Q5: Opportunities for Advanced Students</th>
<th>Q6: Computer availability</th>
<th>Q7: Time for Individual Assistance</th>
<th>Q8: Interest and Relevance</th>
</tr>
</thead>
</table>

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Teacher Q 5: Opportunities for Advanced Students

Teacher Q 6: Computer availability

Teacher Q 7: Time for Individual Assistance

Teacher Q 8: Interest and Relevance
<table>
<thead>
<tr>
<th>Teacher</th>
<th>Q9: Impact on Student Motivation</th>
<th>Q10: Impact on Student Learning</th>
<th>Q11: Other Resources Used</th>
<th>Q12: Suggestions for Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>The advanced students could get faster through the software, but had all students just work on the units according to the book.</td>
<td>Had computers twice a week.</td>
<td>On computer days I spent a lot of time with students who struggled.</td>
<td>Each lesson started out with a practical application using the concepts of the lesson.</td>
</tr>
<tr>
<td>B</td>
<td>There need to be more in the software for advanced students.</td>
<td>Have to schedule lab time, but math gets priority over other classes.</td>
<td>Same as with any other program; some days it allows time for individual assistance, and some days it doesn’t.</td>
<td>More discussion and interaction with other students make it interesting.</td>
</tr>
<tr>
<td>C</td>
<td>The textbook has challenging exercises at the end. I give those questions to advanced students</td>
<td>Yes, each student had a computer.</td>
<td>Yes, since students who know the material, don’t need much help, I can spend more time with students who are struggling</td>
<td>Students are more interested in real world problems and examples.</td>
</tr>
<tr>
<td>D</td>
<td>The Cognitive Tutor is best for middle or slow learners…. You need to supplement to challenge the top students.</td>
<td>Yes, we have laptops always available</td>
<td>Yes, especially with the lab work. It does somewhat depend on the number of students.</td>
<td>The problems are hands-on and real world. The one traditional chapter is No. 5, which is probably their least favorite.</td>
</tr>
<tr>
<td>E</td>
<td>I am bit disappointed with Geometry curriculum - it’s shallow, but I know it is being revised.</td>
<td>Yes, I am lucky that computers are always available</td>
<td>Yes, usually when they get stuck, I ask them to read me the problem. Most of the time when they read the problem, they say “Go away, I got it!”</td>
<td>Yes, but sometimes the textbook takes two pages to cover something that I can cover in minutes.</td>
</tr>
<tr>
<td>F</td>
<td>The software allows advanced students to work ahead, but everybody is pretty much at the same topic.</td>
<td>Used Cognitive Tutor software and textbooks.</td>
<td>Our school got a grant.</td>
<td>Block schedule; meet every other day for about 85 minutes.</td>
</tr>
<tr>
<td>G</td>
<td>Yes, for instance, a student completed algebra 1 software, last year; he started on Algebra 2.</td>
<td>Yes, because I can work with them one-on-one.</td>
<td>The lab is dedicated to Cognitive Tutor four days a week.</td>
<td>It gives them chance to use their knowledge in a different way. They can see the progress and they can see the process.</td>
</tr>
<tr>
<td></td>
<td>All students were forced to be active learners. This was particularly true when using the software.</td>
<td>All students made gains from pre-test to post-test. No one failed!</td>
<td>We used Geometry sketchpad and Discovering Geometry.</td>
<td>The material did not allow enough homework practice to master the skills. They need more practice.</td>
</tr>
<tr>
<td>---</td>
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<td>---</td>
</tr>
<tr>
<td>B</td>
<td>They [students] seem to have stronger understanding once they grasp the concepts.</td>
<td>Requires more independent thinking</td>
<td>None.</td>
<td>Sometimes standardized testing keeps us out of the computer lab.</td>
</tr>
<tr>
<td>C</td>
<td>Students are motivated and they look forward for this class.</td>
<td>Good impact on all students, since they can work on their own pace</td>
<td>None</td>
<td>Schools should support Teacher training</td>
</tr>
<tr>
<td>D</td>
<td>They are eager and ambitious for the software. The textbook varies from chapter to chapter</td>
<td>A positive impact overall — it looks encouraging at this point.</td>
<td>I supply worksheets and reviews as needed.</td>
<td>Good program. We don’t seem to have much time for the homework activities.</td>
</tr>
<tr>
<td>E</td>
<td>It empowers them, when they realize they did it on their own.</td>
<td>I do not have any research on that.</td>
<td>I used Glencoe Geometry and made my own worksheets.</td>
<td>I have talked to teacher C about the order of topics, now the teachers have ability to adjust the topics.</td>
</tr>
<tr>
<td>F</td>
<td>The software helps students as they can work on their own pace.</td>
<td>I don’t think that the curriculum significantly improved their performance. There are several other reasons that some students can’t do well in school.</td>
<td>I occasionally use Discovering for hands-on activities with patty papers.</td>
<td>The textbook makes simple concepts more complicated. – it would be nice to have a password protection for the software.</td>
</tr>
<tr>
<td>G</td>
<td>I don’t know if it has increased their motivation at all. We are using it as a tool to strengthen their skills.</td>
<td>Have seen some increase in student learning but for it to have an effect on their learning we have to really work hard into making the connection for them to the software in the regular classroom setting.</td>
<td>We use graphing calculators, overhead, board and computers.</td>
<td>The geometry software needs to be beefed up. The Algebra needs to stop worrying about kill and drill exercises.</td>
</tr>
</tbody>
</table>
Appendix D. Permission to Reprint the Material from Student Textbook

Cognitive Tutor Geometry

Sally Rigeman  Hi Taqir, Chris Scott, our Carnegie Learning regional accounts manager is he...
Feb 9

Taqir Bibi  Thanks Sally! That would be very helpful.
Feb 9

Mail Delivery Subsystem  Delivery to the following recipient failed permanently: Technical details of...
Feb 9

Scott, Chris  Taqir: Here are the PDF files Dr. Rigeman is referring to. There are also Sk...
Feb 9

Taqir Bibi  Thank you!
Feb 11

I need your permission to use any example or picture from the student textbook in my dissertation. Let me know if that's okay.

On Tue, Feb 9, 2010 at 7:19 PM, Scott Chris <cscott@carnegielearning.com> wrote:
- ChooseQuickStart -

Scott, Chris to me
Feb 11

Yes, you may use examples or pictures from our Geometry materials in your dissertation.

Thanks,

Chris Scott
Regional Account Manager, Midwest
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412.992.5102 (fax)
cscott@carnegielearning.com