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Students' Epistemological Beliefs of Mathematics When Taught Using Traditional Versus Reform Curricula in Rural Maine High Schools

Glenn T. Colby

STUDENTS' EPISTEMOLOGICAL BELIEFS OF MATHEMATICS WHEN TAUGHT USING TRADITIONAL VERSUS REFORM CURRICULA IN RURAL MAINE HIGH SCHOOLS

By

Glenn T. Colby

B.S. Georgia Institute of Technology, 1990

B.S. Georgia State University, 1992

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Advisory Committee:

John E. Donovan II, Assistant Professor of Mathematics Education, Advisor

Eric A. Pandiscio, Associate Professor of Education

Michael C. Wittmann, Assistant Professor of Physics

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Glenn T. Colby

Thesis Advisor: Dr. John E. Donovan II

An Abstract of the Thesis Presented
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This study compared students' epistemological beliefs of mathematics after completing 3 years of a reform-oriented curriculum developed by the Core-Plus Mathematics Project (CPMP) versus a more traditional curriculum developed by Glencoe Mathematics. The Conceptions of Mathematics Inventory (CMI; Grouws, Howald, & Colangelo, 1996) was administered to 11th-grade students in four rural Maine high schools (n=102) to measure student beliefs of mathematics. CPMP was used as the primary textbook series in 2 of the schools, while the other 2 schools used Glencoe Mathematics. A variation of the Reformed Teaching Observation Protocol (RTOP; Piburn & Sawada, 2000) and teacher questionnaires were used to characterize the level of reform-oriented instruction occurring in each of the schools.

The results indicated that the students who were taught using the traditional curriculum combined with reform-oriented teaching practices expressed the most positive

beliefs of mathematics, while the students who were taught using the reform-oriented curriculum expressed less healthy beliefs of mathematics, especially when taught using reform-oriented teaching practices. Some of the differences in beliefs appeared to be gender-related.

This study extends the previous research of Grouws et al. (1996), Walker (1999), and Star and Hoffmann (2005) by demonstrating the feasibility of using instruments such as the CMI to assess students' epistemological beliefs of mathematics in order to expand the notion of impact of reform-oriented curricula beyond students' performance on achievement tests. This study also illustrates the importance of determining what is actually happening in the classrooms when performing such research.

DEDICATION

To my wife, Barbara, and to my step-son and amigo, Berkeley. You have made my life complete.

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I wish to thank Drs. Douglas Grouws and Carol Howald for granting me permission to use the Conceptions of Mathematics Inventory (CMI) in my study. In addition, several researchers who have used the CMI shared their experiences with me as

I designed this study: I wish to thank Drs. Jon Star, Amanda Jansen, and Rebecca Walker for their encouragement and valuable advice.

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Glenn T. Colby

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Chapter 1

INTRODUCTION

This thesis is a report of a study of students' epistemological beliefs of mathematics when taught using a traditional curriculum, *Glencoe Mathematics* (Holliday et al., 2003a, 2003b; Boyd, Burrill, Cummins, Kanold, & Malloy, 2001) versus a reform-oriented curriculum, *Contemporary Mathematics in Context* (Coxford et al., 1998). The study was based primarily on responses to a questionnaire administered to 11th-grade students in four rural Maine high schools. Direct observations and teacher questionnaires were also used to assess the level of reform-oriented teaching practices occurring in each school. The goal of the study was to determine if students' epistemological beliefs of mathematics are correlated with curriculum, teaching practices, and other variables such as gender.

This first chapter discusses the general background of the study, specifies the problem of the study, describes its significance, and presents an overview of the methodology used. Finally, the delimitations of the study are discussed.

1.1. General Background of the Study

In the past 20 to 25 years, epistemological beliefs research has come to be viewed as essential to mathematics education research (Lester, 2002; McLeod, 1992). Epistemological beliefs help provide a context for learning mathematics and they affect how students conceptualize and engage in mathematical activities (Schoenfeld, 1985, 1992; King & Kitchener, 1994; Kardash & Scholes, 1996; Grouws, Howald, & Colangelo, 1996; Schommer, 1990, 1993; Clarebout, Elen, Luyten, & Bamps, 2001). Although students' attitudes toward mathematics have been researched extensively, students' epistemological beliefs of mathematics have only recently been explored. How do students view the field of mathematics? What do students think it means to "do mathematics?" How do beliefs vary between groups of students? Such questions have important implications for mathematics education. For example, students who view mathematics as a collection of isolated facts rather than as a meaningful system of connected concepts have been shown to have difficulty solving non-routine problems and understanding mathematical procedures (Schoenfeld, 1985; Schommer, 1990; Schommer, Crouse, & Rhodes, 1992).

Based on constructivist theories of learning, many current mathematics education researchers and reformers view mathematics as a dynamic field that is best learned through an active process of construction in which students are empowered to explore, conjecture, and reason logically (Frykholm, 1995). Researchers have identified common beliefs of mathematics which many students have that are considered unhealthy and not aligned with the vision of mathematics instruction described in *Curriculum and Evaluation Standards for School Mathematics* (National Council of Teachers of Mathematics [NCTM], 1989; Frank, 1988; Spangler, 1992). Mtetwa and Garofalo (1989) and Schoenfeld (1992) conjectured that such beliefs are perpetuated by teachers, textbooks, and classroom experiences. Schoenfeld provided a compilation of the students' typical beliefs of mathematics:

- Mathematics problems have one and only one right answer.
- There is only one correct way to solve any mathematics problem – usually the rule the teacher has most recently demonstrated to the class.
- Ordinary students cannot expect to understand mathematics; they expect simply to memorize it and apply what they have learned mechanically and without understanding.
- Mathematics is a solitary activity, done by individuals in isolation.
- Students who have understood the mathematics they have studied will be able to solve any assigned problem in five minutes or less.
- The mathematics learned in school has little or nothing to do with the real world.
- Formal proof is irrelevant to processes of discovery or invention.

Schoenfeld argued that "these beliefs shape [students'] behavior in ways that have extraordinarily powerful (and often negative) consequences" (p. 359), and according to the *Curriculum and Evaluation Standards for School Mathematics*, students' beliefs "exert a powerful influence on students' evaluation of their own ability, on their willingness to engage in mathematical tasks, and on their ultimate mathematical disposition" (NCTM, 1989, p. 233). Therefore, it is important that educators consider students' beliefs (Lester, 2002).

Based on the notion that learning environments provided by teachers may shape students' beliefs about mathematics, most research on epistemological beliefs of mathematics has focused on teachers' beliefs of mathematics and how those beliefs influence instruction (Chval, Grouws, Smith, Weiss, & Ziebarth, 2006; Herbel-Eisenmann, Lubienski, & Id-Deen, 2006; Frykholm, 1995; Ernest, 1994; Greeno, 1989;

Prawat, 1992; Thompson, 1984; Cooney, Sheally, & Arvold, 1998; Brosnan, Edwards, & Erickson, 1996; Cooney, 1985). For example, a teacher who views mathematics as a collection of simple isolated facts may subdivide tasks into separate components that are taught and practiced in isolation (Arredondo & Rucinski, 1996). Thompson (1992) provided a summary of earlier research on the complex relationships between teachers' beliefs of mathematics and instruction.

Traditional mathematics instruction is based on the traditional philosophical view of epistemology in which our knowledge is the sum total of what we know. From this perspective, learning mathematics can be defined as "mastering, in some coherent order, the set of facts and procedures that comprise the body of mathematics" (Schoenfeld, 1992, p. 342). Mathematics instruction is usually characterized as *traditional* if it "provides clear, step-by-step demonstrations of each procedure, restates steps in response to student questions, provides adequate opportunities for students to practice the procedures, and offers specific corrective support when necessary" (Smith, 1996, p. 390; cited in Herbel-Eisenmann, Lubienski & Id-Deen, 2004, p. 1). For example, traditional algebra instruction features teacher explanation and students practicing routine symbol-manipulation rather than student exploration of real world problems that incorporate algebra concepts (Kieran, 1992). Traditional assessment also focuses on symbol-manipulation rather than the application of algebra concepts to problem-solving (Huntley, Rasmussen, Villarubi, Sangtong, & Fey, 2000). One limitation often associated with traditional mathematics instruction is that students come to view mathematics as a collection of facts and rules that must be memorized (Schoenfeld, 1992; Boaler, 1999).

Reform-oriented instruction, on the other hand, is based on the view that knowledge comes from the development of complex cognitive skills and processes. From this perspective, learning mathematics is best accomplished through students' active participation in their own learning with a curriculum that emphasizes problem-solving, communication, reasoning, and mathematical connections, along with grade-specific content standards (McCaffrey, Hamilton, Stecher, Klein, & Robyn, 2001). The teacher's role is that of a "facilitator who selects tasks, models important mathematical actions, guides student thinking, and encourages classroom discourse" (Herbel-Eisenmann et al., 2004, p. 1). This vision has been promoted through curriculum standards and guidelines published by the National Research Council (1996), the American Association for the Advancement of Science (1993), and the National Council of Teachers of Mathematics (NCTM, 1989, 1991, 2000).

Most research comparing traditional and reform-oriented curricula has focused on achievement as measured by students' performance on standardized tests of procedural or problem-solving skills. Such research has generally found that students taught using reform-oriented curricula have greater conceptual understanding and problem-solving abilities than students taught using traditional curricula, while performance on traditional standardized tests of procedural skills is comparable (Senk & Thompson, 2003; see also Thompson and Senk, 2001; Boaler, 1999; Huntley et al., 2000; Chung, 2004; Stein, Boaler, & Silver, 2003). Most curricular research that has considered students' beliefs or attitudes has focused on elementary or middle school levels (e.g., Cobb, Wood, Yackel, & Perlwitz, 1992). Some studies have found that students taught with reform-oriented, problem-centered instruction are more likely to have healthier beliefs and attitudes about mathematics (Stein et al., 2003), although conceptual and methodological problems have made the results less than conclusive (Smith & Star, 2007).

Efforts to assess the impact of reform programs must expand beyond students' performance on standardized tests (Smith & Star, 2007; Star & Hoffmann, 2002). One goal of reform-oriented mathematics instruction in recent years has been to promote healthy beliefs and attitudes about mathematics. This study hoped to contribute to the field of research on the impact of reform programs by assessing students' beliefs of mathematics when taught using different curricula and teaching practices.

1.2. Problem Statement

The general question this study attempted to answer was as follows: "Do high school students' epistemological beliefs differ when using traditional versus reform-oriented curricula?" That general question subsumed the following related questions:

1. Are there differences related to teaching practices?
2. Are there differences related to demographic factors such as gender or parents' level of education?
3. Are there differences related to academic achievement?

Researchers have conjectured that curriculum can influence students' beliefs of mathematics (Gresalfi, Boaler, & Cobb, 2004; Star & Hoffmann, 2005). Since one of the goals of reform-oriented mathematics instruction is to promote healthy beliefs and attitudes, one might expect that schools using reform-oriented curricula and teaching practices develop students with healthier beliefs. However, no such assumptions were made in the design of this study with respect to the influence of reform-oriented instruction on students' beliefs of mathematics.

1.3. Professional Significance of the Problem

Research on epistemological beliefs has provided insight into how students learn and engage in mathematics. For example, beliefs about doing mathematics have been shown to influence students' problem-solving abilities (Schoenfeld, 1989), and students who believe that all mathematics problems can be solved in a few minutes often give up quickly on challenging problems (Schoenfeld, 1988). This study aimed to contribute, in a variety of ways, to the important line of research exploring the complex relationships between learning environments and students' beliefs.

This study addressed some of the conceptual and methodological problems that have prevented previous studies from yielding conclusive results (Smith & Star, 2007). Hammer (1994) illustrated the importance of using an a priori framework when assessing students' beliefs. Hammer also suggested that providing a specific mathematical context is more likely to yield meaningful results. Researchers have developed methodologies to address those concerns, but more consideration of the learning environment is necessary (Hammer; see also Star & Hoffmann, 2005; Herbel-Eisenmann, et al., 2006). This study explored the feasibility of extending the research methodologies used in recent studies by including classroom observations and other methods to measure aspects of the instructional context that may affect beliefs.

Another significant aspect of this study was its unique setting: rural Maine high schools. The stark reality of teaching mathematics in Maine stands in contrast to the settings for curriculum field studies in which teachers are provided extensive training, technology, and other support. While most teachers and administrators who participated in this study expressed strong interest in research on the impact of different curricula on students' beliefs, several participants felt that choosing a more typical setting would yield results that are more meaningful for educators in Maine.

Finally, there are dozens of curricula used in Maine high schools, and there are very few resources available to help teachers, administrators, and other policy makers in these schools decide which curriculum to implement. Standardized achievement test scores are often the primary evidence for making those decisions. This study aimed to provide additional evidence for educators in Maine who are concerned with students' learning beyond their performance on exams (Hoffmann, 2003).

1.4. Overview of the Methodology

This cross-sectional correlation study was designed to analyze the relationships between two curricula and the epistemological beliefs of mathematics held by students in four schools after studying three years of those curricula. One curriculum in this study was an NSF-funded, *Standards*-based curriculum; the other was a more popular traditional curriculum. Other variables, such as teaching practices and students' gender, were also considered.

The research perspective for this study was quantitative primary, qualitative first. The study began with a qualitative approach, using a series of informal interviews, classroom observations, and questionnaires to characterize the teaching practices occurring in the schools. That qualitative data on teaching practices was then used as a basis for collecting and interpreting the quantitative data (the primary method) on students' epistemological beliefs of mathematics.

The primary method used in this study was a questionnaire that was administered to 11th-grade students in four rural Maine high schools to assess their beliefs of mathematics. The specific instrument used was the Conceptions of Mathematics Inventory (CMI; Grouws et al., 1996). Secondary methods used included classroom observations, questionnaires, and informal interviews to describe the level of reform-oriented teaching occurring in the schools. Teachers were observed using a variation of the Reformed Teaching Observation Protocol (RTOP; Piburn & Sawada, 2000; Sawada & Piburn, 2000). Teachers also completed questionnaires to study their backgrounds and teaching practices.

The methodologies used in this study are discussed fully in Chapter 4.

1.5. Delimitations of the Study

Several delimitations should be considered before generalizing the findings of this study. First, the unique setting of rural Maine high schools created restrictions on the nature and size of the sample population. Although the setting provided an opportunity for survey participation by most 11th-grade students and teaching observations for most teachers and in the four schools, it also limited the number of available participants. Observed class sizes ranged from 6 to 17 students, and each school had only 2 to 4 mathematics teachers. Schools with greater enrollment might have yielded different results.

Second, there are questions about the validity of assessing 11th-grade students' beliefs of mathematics without first establishing some sort of baseline. The premise that students' beliefs at the end of 11th-grade are the result of the learning environment provided to them in high school ignores the fact that students may have different beliefs before entering high school. This study assumed that students' beliefs are somewhat malleable, an assumption that may or may not be true. Anecdotal evidence indicated that the curricula and teaching practices used in high schools and their feeder schools were similar (reform-oriented versus traditional). Future researchers may consider longitudinal methods to address this concern.

Finally, the use of questionnaires is an efficient and convenient method of gathering large amounts of data, but there are concerns about using this approach. Although the CMI framework is useful for conceptualizing students' beliefs of mathematics, "it may be difficult to assume that a continuum of epistemological beliefs can be represented or measured by simply stating extreme positions and registering degrees of agreement" (Hofer & Pintrich, 1997, p. 110). Furthermore, some researchers have expressed concern about using such a predetermined framework to extract students' epistemological beliefs since "inevitably, that [framework] will be constructed, not out of the child's conceptual elements, but out of conceptual elements that are the [researcher's] own…. The [researcher] can never compare the model [the researcher] has constructed of a child's conceptualizations with what actually goes on in the child's head" (Glaserfield, 1987, p. 13).

1.6. Organization of the Thesis

This chapter has described the general background of the study, the research problem, the significance of the problem, and the methodology used in the study. The remaining chapters of this thesis are organized as follows: Chapter 2 provides a review of the relevant literature, including theoretical perspectives and empirical research; Chapter 3 describes the influence and use of high school mathematics curricula, including a comparison of the two textbooks used in this study; Chapter 4 provides details on the methodology used, including the research setting, the participants, the instruments used, the procedures followed, and the data analysis made; Chapter 5 presents the results of the study; and Chapter 6 presents a summary and discussion of the findings.

Chapter 2

LITERATURE REVIEW

Although epistemological beliefs have only been viewed as essential to mathematics education research for the past 20 to 25 years, a large body of literature on the subject provides a basis for this study. This chapter begins with a description of the search process that was used to review the literature. Next, a review of the relevant theoretical literature is provided, including discussions of constructivist learning theories, the reform movement, epistemological beliefs, and epistemological beliefs theories. Finally, a review of empirical research is presented, including efforts to measure epistemological beliefs and selected studies of epistemological beliefs of mathematics.

2.1. Search Process

The literature review was performed using a systematic process conducted in three phases. First, a broad scan was conducted to identify review articles, books, and other resources to help identify and develop the research problem. Second, a focused review was conducted to develop a research prospectus. This phase involved searching online resources such as the Education Resources Information Center (ERIC™), Google™ Scholar, and Dissertations Abstracts. Finally, a comprehensive critique was conducted as an ongoing process throughout the remainder of the thesis project to identify any research related to this study.

Several research practices were followed throughout the focused review and the comprehensive critique. First, a record of search terms and results was maintained in a spreadsheet, allowing for periodic updates of search results. An annotated bibliography was maintained as a web page, each entry consisting of a reference, a brief indication of why the reference was selected, any relevant instrumentation used, a usefulness score from 1 (not useful) to 10 (essential) indicating the level to which the reference directly applies to the thesis, and a hypertext link to an electronic version of the reference if possible. Thesis committee members were provided access to the annotated bibliography by posting it on a web page, along with meeting notes and other resources related to the thesis. Printouts or photocopies of all sources, along with full bibliographic information, were placed in a series of three-ring binders.

Next, the reference list of each source located was checked for leads to other sources. This practice, known as *ancestor searches*, helped identify several essential resources, such as doctoral dissertations and conference proceedings. Additional resources, such as the Mental Measurements Yearbook (Buros et al., 1938–2005), were identified by asking experts for help and from online reference lists found.

Finally, the contents of several journals (e.g., Journal for Research in Mathematics Education) and conference programs (e.g., American Educational Research Association) were scanned periodically to identify relevant articles.

2.2. Theoretical Literature

The modern reform movement in mathematics education is based on the theory of *constructivism* (Glasersfeld, 1989), which assumes that “knowledge is not transmitted directly from one knower to another, but is actively built up by the learner" (Driver, Asoko, Leach, Mortimer, & Scott, 1994, p. 5). As described earlier, the primary purpose of this study was to explore relationships between reform-oriented (constructivist) mathematics instruction and students' epistemological beliefs. This discussion on theoretical literature is divided into three sections: constructivism and the reform movement, epistemological beliefs and learning, and models of epistemological beliefs.

2.2.1. Constructivism and the Reform Movement

Many educators consider Jean Piaget to have been the "first constructivist" (Glasersfeld, 1989, p. 125). Piaget (1954) argued that students learn by either assimilating new experiences to what they already know, or accommodating their ideas to incorporate new information. Instruction based on this theory therefore "often attempted to induce dissonance, or disequilibrium, that was designed to create conceptual conflict and then to help the student resolve that conflict" (Piburn & Sawada, 2000). Another perspective on constructivism was provided by Vygotsky (1978), who viewed learning as a socio-linguistic activity that involves active participation in the negotiation and resolution of meaning. Socio-cultural constructivists (e.g., Cobb, 1995) later expanded this perspective to include the role of culture in learning.

From the variety of theoretical perspectives on constructivism, Piburn and Sawada (2000) provided a useful description of a constructivist classroom:

> A constructivist classroom would be one in which people are working together to learn…. It would be a place where inquiry was conducted. Discourse would be the primary mode by which participants engaged in negotiations of meaning.

> Cognitive, social and cultural differences among participants would be honored and alternative world-views respected. A high level of rigor, and an accompanying demand for evidence and argument, would be a hallmark of such a community. Conventions would be established for negotiating meaning but only as they facilitated the knowledge-building priorities already honored within the community (p. 4).

By the mid-1980s, constructivism was widely accepted in the research community, as evidenced by the Romberg and Carpenter (1986) statement, “The research shows that learning proceeds through *construction*, not *absorption*” (p. 868; see also Schoenfeld, 1992). As a result, several mathematics education professional organizations, such as the National Council of Teachers of Mathematics (NCTM, 1989, 1991, 1995, 2000), recommended the following changes: a) design of curricula with a common core of broadly useful mathematics for all students, b) emphasis on student-centered instruction that engages students in exploration of mathematical facts and principles through collaborative work on authentic problems, and c) assessment of student learning through a variety of strategies that are embedded in regular classroom activity (Huntley et al., 2000, pp. 1–2).

2.2.1.1. The NCTM *Standards.* A constructivist perspective was evident in *Principles and Standards for School Mathematics* (NCTM, 2000), where a vision of a classroom was presented as follows:

> Imagine a classroom … [in which] students confidently engage in complex mathematics tasks chosen carefully by teachers. They draw on knowledge from a wide variety of mathematical topics, sometimes approaching the same problem

> from different mathematical perspectives or representing the mathematics in different ways until they find methods that enable them to make progress. Teachers help students make, refine, and explore conjectures on the basis of evidence and use a variety of reasoning and proof techniques to confirm or disprove those conjectures…. Alone or in groups and with access to technology, they work productively and reflectively.… Orally and in writing, students communicate their ideas and results effectively. (p. 3)

The Piagetian view of constructivism was also apparent in *Principles and Standards for School Mathematics* when it stated that "Students must learn mathematics with understanding, actively building new knowledge from experience and prior knowledge" (The Learning Principle; p. 20) and "Assessment should support the learning of important mathematics and furnish useful information to both teachers and students" (The Assessment Principle; p. 22).

McCaffrey et al. (2001) provided an overview of the changes that were proposed in *Professional Standards for Teaching Mathematics* (NCTM, 1991). Some of those changes directly addressed students' epistemological beliefs of mathematics, such as (a) using logic and mathematical evidence to validate results rather than relying on the teacher, (b) emphasizing mathematical reasoning rather than memorizing procedures, and (c) making connections among mathematical ideas and applications. Beliefs were also addressed in *Curriculum and Evaluation Standards for School Mathematics* (NCTM, 1989), where mathematical disposition, including beliefs, was considered to be an important component of students' mathematical knowledge.

Ultimately, *Principles and Standards for School Mathematics* (NCTM, 2000) was based on a variety of constructivist and epistemological belief theories, as seen in the *Standards* themselves:

- Problem Solving: "Teachers play an important role in the development of students' problem-solving dispositions by creating and maintaining classroom environments, from prekindergarten on, in which students are encouraged to explore, take risks, share failures and successes, and question one another" (p. 53).
- Reasoning and Proof: "By developing ideas, exploring phenomena, justifying results, and using mathematical conjectures in all content areas and – with different expectations of sophistication – at all grade levels, students should see and expect that mathematics makes sense" (p. 56).
- Communication: "Listening to others' explanations gives students opportunities to develop their own understanding. Conversations in which mathematical ideas are explored from multiple perspectives help the participants sharpen their thinking and make connections" (p. 60).
- Connections: "When students can connect mathematical ideas, their understanding is deeper and more lasting. They can see mathematical connections in the rich interplay among mathematical topics, in contexts that relate mathematics to other subjects, and in their own interests and experience" (p. 64).
- Representation: "The importance of using multiple representations should be emphasized throughout students' mathematical education … As students become

mathematically sophisticated, they develop an increasingly large repertoire of mathematical representations as well as a knowledge of how to use them productively" (p. 69).

2.2.1.2. The Influence of the NCTM *Standards*. Although constructivist learning theories and the NCTM *Standards* have been widely accepted by mathematics educators and researchers, mathematics instruction in school continues to be dominated by the traditional transmission view of knowledge (Brosnan et al., 1996). According to the Report of the 2000 National Survey of Science and Mathematics Education (Weiss, Banilower, McMahon, & Smith, 2001) roughly half of elementary, middle, and high schools are reportedly implementing changes based on the NCTM *Standards*, while only 30 percent of respondents indicated that the *Standards* had been thoroughly discussed by teachers in the school.

Despite the consensus that emerged when *Curriculum and Evaluation Standards* was released in 1989, there has been some dissent (e.g., Addington & Roitman, 1996; Wu, 1997); this has usually been related to the issue of balancing conceptual and procedural knowledge in algebra (Huntley et al., 2000). Even during the early development of the *Standards*, some mathematicians expressed concern about reducing emphasis on computational skills. McCleod (1999) described NCTM's efforts to reform curricula, including some of the cultural barriers encountered for curriculum reform.

Another barrier for curriculum reform has been the lack of consensus on what it means for a curriculum to be effective. This issue was addressed by Reys (2001):

> With mathematics curriculum materials, determining what is effective depends on the evidence one values. Some people place the highest priority on skill

> development, so any evidence of improved skill is judged positively. Others may value understanding mathematical concepts, while still others may view problem solving as most important. While these goals are not mutually exclusive, obtaining valid and reliable evidence to support them all is very difficult (pp. 256–257).

Epistemological beliefs could potentially be considered when determining the effectiveness of curricula. However, belief is a “messy construct” (Pajares, 1992; Schommer-Aikens, 2004), and there are many unanswered questions about beliefs and learning. A review of recent theories about epistemological beliefs and learning follows.

2.2.2. Epistemological Beliefs and Learning

Epistemological beliefs have been associated with constructivism since the pioneering work of Piaget (1950; cited in Sinatra, 2001) and Perry (1970). Educational psychologists interpret epistemological beliefs as beliefs about the nature of knowledge, which may include beliefs about the certainty, source, acquisition, and structure of knowledge (Duell & Schommer-Aikins, 2001). In mathematics education research, epistemological beliefs are often interpreted as “an individual’s understanding and feelings that shape the ways that the individual conceptualizes and engages in mathematical behavior…. They establish a psychological context for what it means to know and do mathematics” (Schoenfeld, 1992), and may “ultimately … prove the most valuable psychological construct to teacher education” (Pajares, 1992; cited in Star & Hoffmann, 2005).

Although researchers have used a variety of terms and definitions when discussing epistemological beliefs (see Schommer-Aikins, 2004), Breiteig, Grevholm, and Kislenko (2005) addressed the notion of a *definition* as follows:

> The definition does not play a major part in research, and thus every scientist will ascribe the importance of different aspects related to particular investigations. It means that the definition is affected by the questions and the motive of the research. Hence one cannot say that some definition is wrong and the other is right, they can be considered to be more or less suitable (Definition of beliefs section, para. 4).

In the present study, epistemological beliefs are more or less defined by the instrument used to measure beliefs (see section 4.4.1) and the framework from which it was developed.

In the last 20 to 30 years, many researchers have explored connections between epistemological beliefs and learning (e.g., Dweck & Leggett, 1988; Hammer, 1994; Schommer & Walker, 1995; Hofer & Pintrich, 1997; Kloosterman, 2002; Lester, 2002); several excellent reviews are available on the subject (e.g., Hoffmann, 2003; Lester, 2002; Hofer & Pintrich, 1997). However, many questions about epistemological beliefs remain unanswered (e.g., the dimensions encompassed and their domain-specificity, the connections to other constructs in cognition and motivation, and the actual construct of belief; see Hofer & Pintrich, 1997; Schommer-Aikens, 2004). Exactly how beliefs are involved in the learning process is unclear: according to Schoenfeld (1985), “Belief systems shape cognition, even when one is not consciously aware of holding those beliefs" (p. 35), while Kardash & Sinatra (2003) state, "Learning involves the awareness of and regulation of knowledge, beliefs, and goals" (p. 3).

Despite unanswered questions, research has consistently shown that epistemological beliefs are an important part of learning, thinking, information processing, and problem-solving (Schommer, 1990, 1993; King & Kitchener, 1994; Kardash & Scholes, 1996; Schoenfeld, 1985; Clarebout et al., 2001; Gfeller, 1999). According to *Curriculum and Evaluation Standards for School Mathematics* (NCTM, 1989), "[Students'] beliefs exert a powerful influence on students' evaluation of their own ability, on their willingness to engage in mathematical tasks, and on their ultimate mathematical disposition." (p. 233). Stated broadly, "Epistemological beliefs affect comprehension in important ways" (Schommer, 1990, p. 498).

Some researchers have associated beliefs with other constructs, such as motivation and conception. Kloosterman (2002) described the connection between belief and effort: "Student's belief is something the student knows or feels that affects effort – in this case effort to learn mathematics" (p. 248). However, personal goals also come into play in mathematics:

> Many students believe that mathematics is boring, and strong effort is needed to learn it, but still find it important for life. This is a paradox. The reason for seeing mathematics as important can be practical – needs for a better profession and to some degree for a better life (Breiteig et al., 2005, Definition of beliefs section, para. 1).

Spangler (1992) described the cyclic relationship between beliefs and learning: "Students' learning experiences are likely to contribute to their beliefs about what it means to learn mathematics. In turn, students' beliefs about mathematics are likely to influence how they approach new mathematical experiences" (p. 19). Spangler suggested that the cycle of influence could be broken by providing mathematical experiences that enrich students' beliefs. Many researchers have considered how beliefs of teachers themselves can influence those mathematical experiences (e.g., Greeno, 1989; Prawat, 1992). For example, a teacher who views mathematics as simple may decide to subdivide mathematics content into component skills that are learned in isolation (Arredondo and Rucinski, 1996).

2.2.3. Models of Epistemological Beliefs

Hammer (1994) illustrated the value of an a priori framework in characterizing epistemological beliefs. A variety of useful models of epistemological beliefs have been developed from diverse perspectives (Hofer & Pintrich, 1997). Although beyond the scope of this thesis, some researchers have expanded those models into systemic models of *belief systems* and their interactions with other constructs (Schommer-Aikens, 2004; Malmivuori, 2001). This section describes three types of theoretical models that have been used as frameworks for empirical research on students' beliefs: (a) multidimensional models, (b) hierarchical models, and (c) separate and connected knowing.

2.2.3.1. Multidimensional Models. Perry (1968) and other researchers (e.g., Ryan, 1984) assumed that epistemological beliefs are unidimensional, developing in a fixed progression of stages (Schommer, 1990). Other researchers have argued that epistemological beliefs are too complex to represent in a single dimension. For example, Oaks (1987) classified epistemological beliefs of mathematics along several dimensions as either dualistic or relativistic (see Table 1).

Table 1. Dimensions of epistemological beliefs defined by Oaks (1987).

Dualistic	Relativistic
Mathematics is a process for finding answers to problems in a single prescribed way where the solutions to these problems are strictly right or wrong.	Not all problems have exact answers, and depending on the context, they might have different answers in different situations.
Mathematics is an exact body of knowledge over which students have no control, and the purpose of class activity is recording correct algorithms as provided by a higher authority.	Results and processes can be deduced rather than memorized.
Students view understanding new concepts as being able to recall each step in an algorithm.	The primary goal in learning mathematics is to know the meaning behind problems as well to solve them.

Borasi (1990) proposed four belief categories based on her own and Oaks' work: (a) the scope of mathematical activity (providing correct answers to well defined problems), (b) the nature of mathematical activity (appropriately recalling and applying learned procedures), (c) the nature of mathematical knowledge (right or wrong), and (d) the origin of mathematical knowledge (existing only as a finished product to be absorbed as it is transmitted) (Grouws et al., 1996).

Schommer (1990) proposed that there are at least five more or less independent dimensions: a) structure of knowledge, b) certainty of knowledge, c) source of knowledge, d) control of knowledge acquisition, and e) speed of knowledge acquisition. The structure, certainty, and source of knowledge dimensions were derived from the work of Perry, the control of knowledge acquisition dimension was derived from Dweck's research (e.g., Dweck & Leggett, 1988) on beliefs about the nature of intelligence, and the speed of knowledge acquisition dimension was derived from

Schoenfeld's (1985) work showing that some high school geometry students believe in quick, all-or-none learning. Although there are conceptual and measurement issues that remain unresolved, (see Clarebout et al., 2001), Schommer's model and its related questionnaire for assessing students' beliefs initiated an important line of research linking epistemological beliefs to learning (Hofer & Pintrich, 1997).

Hammer (1994) developed an analytic framework for studying beliefs about physics with three dimensions: (a) beliefs about the structure of physics knowledge as either a collection of isolated pieces or as a coherent system, (b) beliefs about the content of physics knowledge as either formulas or as concepts that underlie the formulas, and (c) beliefs about learning physics, as either receiving information from an authority or as an active process of reconstructing one's understanding. Hammer demonstrated the importance of context in analyzing student beliefs and introduced three criteria for evaluating his framework: recognizability, evident involvement, and consistency.

Grouws et al. (1996) incorporated the research of Oaks (1987), Schoenfeld (1989), Borasi (1990), and Fennema and Sherman (1976) to develop the *Student Conceptions of Mathematics Framework*. This mathematics-specific model was used as a basis for a questionnaire, the *Conceptions of Mathematics Inventory* (CMI), in order to gather data on a large number of students and to facilitate analysis of students' beliefs of mathematics in a systemic manner. The model includes seven more or less independent dimensions: composition, structure, status, doing, validating, learning, and usefulness. The seven dimensions are grouped into four themes: (a) what students see as the nature of mathematical knowledge, (b) the character of mathematical activity, (c) the essence of learning mathematics, and (d) the usefulness of mathematics. Although some researchers have argued that the fourth theme, usefulness of mathematics, should not be considered a part of epistemological beliefs, it was added as a dimension after considering research that used the Fennema-Sherman Mathematics Attitudes Scales (Fennema, Wolleat, Pedro, and Becker, 1981). The Student Conceptions of Mathematics Framework was selected as the framework for this study and is discussed more fully in section 4.4.1.

2.2.3.2. Hierarchical Models. In contrast to the dualistic versus relativistic models described above, some researchers have extended Perry's work by proposed hierarchical models of epistemological beliefs. Based on Thompson's (1984) observations of students' conceptions of mathematics, Ernest (1994) proposed a three-level hierarchy. The lowest level is instrumentalism, where mathematics is viewed as an accumulation of unrelated but utilitarian rules and facts. The next level is the Platonist view of mathematics as a consistent, connected and objective body of certain knowledge that is discovered, not created. At the highest level, there is the problem-solving view of mathematics as a dynamic, continually expanding field of human creation and invention in a social and cultural context. Mathematics is seen as a process of inquiry and coming to know, not a finished product.

King and Kitchener (1994) proposed the *Reflective Judgment Model*, a seven-stage model examining "the ways that people understand the process of knowing and the corresponding ways they justify their beliefs about ill-structured problems" (p. 13). Their model contains seven stages of development divided into three sequential, hierarchical phases: pre-reflective, quasi-reflective, and reflective. The Reflective Judgment Model examines how epistemological beliefs affect thinking and reasoning processes (Whitmire, 2004).

Baxter Magolda (1992) proposed the *Epistemological Reflection Model* to address gender biases found in other models of epistemological beliefs. Four *ways of knowing* were arranged into three levels:

1. Absolute knowing – Knowledge is certain or absolute.
2. (a) Transitional knowing – Knowledge is partially certain and partially uncertain; and (b) Independent knowing – Knowledge is uncertain, everyone has individual beliefs.
3. Contextual knowing – Knowledge is contextual, judged on basis of evidence in context.

Based on constructivist learning theories, the Epistemological Reflection Model was developed to examine how individuals make sense of their educational environments based upon their epistemological beliefs (Whitmire, 2004).

2.2.3.3. Separate and Connected Knowing. Belenky, Clinchy, Goldberger, & Tarule (1985, 1986) described five different epistemological positions, or *Women's Ways of Knowing*, based on interviews with 135 women at educational institutions. The position that has received the most attention is that of *procedural knowing*, modes of thinking in which an individual constructs or adopts one or more means of "obtaining, reflecting on, evaluating, and communicating knowledge" (p. 19). Procedural knowing was further categorized into two distinct types called *separate* and *connected knowing* (Belenky et al., 1985, 1986; Ryan & David, 2002). Separate knowing involves objective, analytical, detached evaluation of an argument or piece of work. It often takes on an adversarial tone, involving argument, debate, playing devil's advocate, "shooting holes" in another's position, or critical thinking (Clinchy, 1990, as cited in Galotti, Clinchy, Ainsworth, Lavin, & Mansfield, 1999). Connected knowing, in contrast, involves trying to look at things from the another's point of view, in the another's own terms, and trying first to understand another's point of view rather than evaluating it. The two modes are not mutually exclusive and "can and do coexist within the same individual" (Clinchy, 1996, p. 207, as cited in Galotti, et al., 1999).

2.3. Empirical Research

As theories of epistemological beliefs have evolved over the last 20-25 years, so have the empirical methods and research goals. Some researchers have used interviews, observations, or open-ended questions to assess epistemological beliefs (e.g., Oaks, 1987; Glasersfeld, 1987; Baxter Magolda, 1992; Belenky et al., 1986; King & Kitchener, 1994), while others have used questionnaires in order to gather larger amounts of data and to facilitate analysis (e.g., Schoenfeld, 1985; Schommer, 1990; Spangler, 1992; Kloosterman and Stage, 1992; Grouws et al., 1996; Kardash & Wood, 2000). (See Duell and Schommer-Aikins, 2001, for an overview of the major epistemological belief instruments and a discussion of issues in selecting an instrument.) The focus of research of epistemological beliefs has expanded from beliefs about the nature of knowledge (Perry, 1968) to include relationships to learning (e.g., Schommer, 1990), social interactions (e.g., Baxter Magolda, 2004; Schommer-Aikins, 2004), and classroom practices (e.g., Lester, 2002).

This section is divided into three parts. First, a brief review of the domain-independent empirical research is presented, focusing on the major instruments used in the field. Second, mathematics-specific studies on epistemological beliefs are described, including the instruments used and important findings. Finally, studies that focus on the relationships between reform-oriented instruction and epistemological beliefs are described.

2.3.1. Domain-Independent Studies

Much empirical research on epistemological beliefs has made use of Schommer's (1990) *Epistemological Belief Questionnaire*, a 63-item Likert scale instrument with four scales based on Schommer's framework described earlier (see section 2.2.3.1). This questionnaire provides an efficient method for collecting large amounts of data (Hofer & Pintrich, 1997). Studies have investigated correlations between epistemological beliefs and mathematical text comprehension (Schommer, 1990); confidence, academic performance, gender, and level of education (Schommer, 1993; Schommer, Crouse, & Rhodes, 1992; Schommer, Calvert, Gariglietti, & Bajaj, 1997); gifted versus other students (Schommer & Dunnell, 1994); different domains (Schommer & Walker, 1995); "learned helplessness" and conceptual change learning (CCL; Qian & Alvermann, 1995); and learning strategies (Dahl, Bals, & Turi, 2005).

Despite widespread usage, some researchers have raised questions about the construction and use of Schommer's questionnaire. Factor analysis by Schommer yielded four factors: Fixed Ability, Quick Learning, Simple Knowledge, and Certain Knowledge (Schommer, 1990; Hofer & Pintrich, 1997). However, other researchers have expressed concerns about the psychometric properties (Clarebout et al.; 2001; Qian & Alvermann, 1995) and possible cultural bias (Arredondo & Rucinski, 1996) of the instrument. Hofer and Pintrich (1997) suggested that the theoretical framework itself may be a problem, particularly the dimensions of quick learning and source of knowledge. Hofer and Pintrich also questioned the relevance of some items, such as one item that refers to the value of self-help books as an indicator of belief in the ability to learn how to learn. Some researchers (e.g., Wood & Kardash, 2002) have made efforts to improve and expand Schommer's questionnaire, and it continues to be used widely for large-scale quantitative assessment.

Several other instruments have been developed from the theoretical models discussed in section 2.2.3. Galotti et al. (1999) used the *Ways of Knowing* model as a basis for developing the *Attitudes toward Thinking and Learning Survey* (ATTLS), a 50-item Likert scale questionnaire consisting of statements illustrating *separate* (critical, detached) and *connected* (empathic) knowledge. Several studies have used the ATTLS to explore differences between male and female students (Galotti et al., 1999; Ryan & David, 2003; Schommer-Aikins & Easter, 2006).

Baxter Magolda (1992, 2004) developed the *Measure of Epistemological Reflection* (MER) instrument based on her Epistemological Reflection Model to explore reasoning patterns in male and female students, and King and Kitchener (1994) developed the *Reflective Judgment Interview* (RJI) based on their Reflective Judgment Model to measure reasoning ability. Whitmire (2004) used both the MER and the RJI to examine correlations between undergraduate students' epistemological beliefs and information-seeking behavior.

Wood and Kardash (2002) developed the *Kardash Epistemological Belief Scale*, a 36-item Likert scale questionnaire that measures both cognitive disposition and epistemological belief constructs. This questionnaire includes five scales: *speed of* *knowledge acquisition* (speed), *the structure of knowledge* (structure), *knowledge construction and modification* (construction), *characteristics of successful students* (success), and *attainability of truth* (truth). Initial studies using the questionnaire have indicated considerable overlap between the constructs (Kardash & Sinatra, 2003; Kardash & Wood, 2000). Schommer-Aikins & Easter (2006) used the Kardash Epistemological Belief Scale in their study of how ways of knowing relate to beliefs about knowledge and learning.

2.3.2. Studies of Students' Beliefs of Mathematics

Much of the early research on epistemological beliefs of mathematics focused on the beliefs of teachers (e.g., Thompson, 1984), often demonstrating strong relationships between teachers' beliefs and instructional behavior (Ernest, 1994; Frykholm, 1995). As theories and instruments for studying epistemological beliefs have evolved, more emphasis has been placed on students' beliefs of mathematics and their relationships to learning and cognition. Although some researchers have used context-free instruments to explore students' epistemological beliefs of mathematics (e.g., Schommer et al., 1992; Schommer & Walker, 1995), other researchers have shown that providing a specific mathematical context can be more effective (Schoenfeld, 1989; Hammer, 1994; Grouws et al., 1996; Lester, 2002).

Early studies of students' epistemological beliefs of mathematics often focused on individual beliefs; those studies provided the foundation for many of the theoretical models described earlier in section 2.2.3 and instruments developed from those models. Oaks (1987) interviewed college students enrolled in remedial mathematics classes, finding that students who fail those classes often view mathematics as rote manipulation of symbols, focusing on memorization rather than conceptualization. Frank (1988; cited in Hoosain, 2003) used a questionnaire, interviews, and observations to study the relationship between mathematically-talented middle school students' beliefs and their problem-solving practices. Frank found that many students believed that if a problem could not be solved in under 5 to 10 minutes, it could not be solved at all; either something was wrong with them or the problem. Another common belief of students was that the purpose of mathematics was to obtain correct answers. Spangler (1992) used a series of open-ended questions to assess students' beliefs of mathematics (e.g., "If you and your friend got different answers to the same question, what would you do?"), finding that many students believe that a mathematical problem has only one correct answer and that students preferred one method of solving a problem.

In another line of research, Schoenfeld (1985, 1988, 1989) used an 81-item questionnaire dealing with students' attributions of success and failure to explore a variety of beliefs about mathematics in the context of high school geometry classes. Schoenfeld identified a number of students' beliefs about the nature of mathematical thinking that appeared to be a factor in some of their learning problems. For example, students who believed that mathematics consists of isolated facts often have difficulty understanding mathematical concepts and procedures (1985). Many students believed that solving mathematics problems depends on knowing rules, and mathematics is presumed to be more rule-bound than English or social studies (1989). Schoenfeld also found that students' beliefs about the nature of mathematical thinking could prevent them from solving problems that they are capable of solving.

The first large-scale study of students' beliefs of mathematics was conducted as part of the 1992, 1996, and 2000 mathematics assessments of the National Assessment of Educational Progress (NAEP). This study reported 4th-, 8th-, and 12th-grade students' beliefs about the nature of mathematics as indicated by their level of agreement with statements such as "Learning mathematics is mostly memorizing facts," "There is only one correct way to solve a mathematics problem," "Mathematics is useful for solving everyday problems," and "All students can do well in mathematics if they try." Although the statements used were of a general nature and the responses were not analyzed with respect to achievement or curricula used, significant differences by age and gender (Lubienski, McGraw, & Strutchens, 2004) as well as race and ethnicity (Strutchens, Lubienski, McGraw, & Westbrook, 2004) were found for some items.

In 1992, Kloosterman and Stage introduced the *Indiana Mathematics Belief Scales*, the first empirically-validated instrument for measuring secondary school and college students' beliefs about mathematics and learning mathematics. This 36-item Likert scale questionnaire focused on six beliefs related to motivation and problem-solving: (a) I can solve time-consuming mathematics problems; (b) there are word problems that cannot be solved with simple, step-by-step procedures; (c) understanding concepts is important in mathematics; (d) word problems are important in mathematics, (e) effort can increase mathematical ability; and (f) mathematics is useful in daily life. The purpose of the questionnaire was to allow mathematics instructors to measure the beliefs of their students, "modifying instruction to improve beliefs if needed" (p. 109). The six measured scales were based on previous research (e.g., Schoenfeld, 1985), and the sixth scale (mathematics is useful in daily life) was a reworded subset of the

Fennema-Sherman Mathematics Attitudes Scales (Fennema & Sherman, 1976; Fennema, Wolleat, Pedro, & Becker, 1981). Although the Indiana Mathematics Belief Scales questionnaire has been used by many researchers to explore relationships between beliefs about mathematics and problem-solving (e.g., Stage & Kloosterman, 1991), some researchers have raised questions about its reliability (e.g., Mason, 2003), and Kloosterman has shifted his focus onto constructing interview instruments that ask students directly about their beliefs (Lester, 2002).

In 1996, Grouws et al. introduced the *Conceptions of Mathematics Inventory* (CMI), a 56-item Likert scale questionnaire for measuring high school students' beliefs of mathematics. (The CMI was selected as the primary instrument for this study, and it is described fully in section 4.4.1.) The CMI was based on the *Student Conceptions of Mathematics Framework* described earlier in section 2.2.3.1, and Grouws et al. used the CMI to study two groups of high school students: one consisting of "typical" students and one consisting of "mathematically talented" students. The major goals of the study were to develop a framework for studying students' beliefs of mathematics, to gather baseline data about the two groups of students, and to generate hypotheses about the relationships between students' beliefs and learning. Summarizing the results,

> Mathematically talented students tended to view mathematics as a field composed of a system of coherent and interrelated concepts and principles, which is continuously growing. Doing mathematics is a sense-making process in which one must rely on personal thought and reflection to establish the validity of that knowledge. Algebra students also viewed mathematics as a dynamic and growing

field, but they were much more likely to see it as a discrete system of facts and procedures that requires more memorizing than thinking (p. 32).

Although Grouws et al. did not consider the impact of curricula or teaching practices on students' beliefs of mathematics, the CMI authors have indicated to other researchers that the students were all taught using "traditional" curricula (Star & Hoffmann, 2005). Other researchers (e.g., Walker, 1999) have used the CMI to assess the impact of reform-oriented curricula; those studies are discussed in the next section.

The KIM project (Streitlien, Wiik, & Brekke, 2001; cited in Kislenko, Grevholm, & Lepik, 2005) collected data on students' understandings of key concepts in the Norwegian mathematics curriculum and developed a 125-item Likert scale questionnaire designed to expose students' beliefs about mathematics and mathematics teaching and learning. The *KIM Questionnaire* includes 13 groups of questions concerning beliefs about the following: mathematics as a subject; learning mathematics; own mathematical abilities; own experiences (security) during mathematics lesson; teaching of mathematics; learning a new topic in mathematics; environment in class; environment in school; differences between boys and girls; teaching tools in mathematics lesson; own evaluation for importance of mathematics; evaluation for teaching mathematics; and mathematics and the future (Breiteig et al., 2005). In a recent pilot study carried out in Norway, Kislenko et al. performed factor analysis to identify five groups of statements about mathematics: interest, usefulness, self-confidence, diligence, and security. One striking result from the pilot study was that although 97% of ninth-grade students said that mathematics is important, more than half said that mathematics is boring. Numerous researchers have adopted the KIM Questionnaire as a primary instrument for studying mathematical beliefs and attitudes.

2.3.3. Studies of Reform-Oriented Instruction

Most research comparing the effectiveness of reform-oriented curricula has focused on students' achievement (e.g., Schoen, Hirsch, & Ziebarth, 1998). Although several studies have focused on the relationships between curricula and students' epistemological beliefs of mathematics (e.g., Boaler, 1999), most of those studies did not consider the teaching practices used to deliver the curricula (e.g, Hirschhorn, 1993; Walker, 1999; Star & Hoffmann, 2005). Other studies have suffered from methodological limitations (e.g., Hofer, 1994), or focused on elementary school students (e.g., Wood & Sellers, 1997; Franke & Carey, 1997). This section reviews the empirical research on the relationships between reform-oriented instruction and students' beliefs, emphasizing research directly relevant to this study.

Hirschhorn (1993) compared achievement and attitudes of students who completed the reform-oriented University of Chicago School Mathematics (UCSMP) high school mathematics curriculum to those of two groups of comparable students who completed a traditional mathematics curriculum. Hirschhorn developed a 25-item Likert scale *Student Opinion Survey* consisting of items from various field studies (e.g., "Mathematics is an interesting subject," "I enjoy working word problems," and "Using a calculator helps me learn math"). Unfortunately, no evidence was collected on the instructional practices used to implement the curricula. Although no correlation was found between the use of UCSMP and students' attitudes toward mathematics, the belief that mathematics is useful was positively correlated with higher achievement on standardized tests. Hirschhorn did not examine epistemological beliefs as defined by the theoretical models discussed earlier (see section 2.2.3), but the study did signify researchers' increasing interest in affective outcomes of curricula and instruction.

Hofer (1994) explored relationships between epistemological beliefs, motivation, and cognition with two groups of undergraduate first-semester calculus students: one group was taught using instructional practices that focused on word problems and emphasized active and collaborative learning; the other group was taught using a traditional lecture and demonstration approach. Hofer developed a questionnaire that includes six Likert scale items from a list of typical student beliefs about mathematics, such as "Mathematics problems have one and only one right answer" and "Math is a solitary activity done by individuals in isolation" (Lampert, 1990; Schoenfeld, 1992). Other items assess students' motivation, learning strategies, and achievement. Hofer found that students enrolled in the classes that focused on word problems and emphasized active and collaborative learning were more likely to have sophisticated beliefs about mathematics than students enrolled in the traditional classes. However, Hofer reported several major limitations to the findings, including problems with reliability and validity of the questionnaire, a low response rate (25.2%) with disproportionate response among students of higher achievement, nonrandom assignment to the two groups, and no assessment of beliefs prior to enrollment.

Wood and Sellers (1997) performed a longitudinal study of the mathematical achievement and beliefs of three groups of elementary school students: the first group received two years of problem-centered mathematics instruction, the second group received one year of problem-centered instruction and one year of textbook instruction, and the third group received two years of textbook instruction. Wood and Sellers developed the *Personal Goals and Beliefs Questionnaire* (see also Thompson & Senk, 2001), which includes five subscales for students' beliefs about reasons for success in mathematics: working hard and being interested in mathematics (Effort); persisting and collaborating to understand (Understand and Collaborate); conforming to the solution methods of others (Conform); being superior to peers (Competitiveness); and being lucky, neat, or quiet (Extrinsic). Wood and Sellers found that students who participated in two years of problem-centered instruction had better scores on standardized achievement tests, better conceptual understanding, and more task-oriented beliefs about learning mathematics than those who participated in textbook instruction.

Boaler (1999) performed a three-year longitudinal case study comparing the mathematical perceptions and behaviors of students in two UK high schools where mathematics was taught using different instructional practices: one school used a traditional lecture and demonstration approach; the other school used a project-based approach. Research methods included teacher and student interviews, lesson observations, questionnaires, contextualized assessment questions, and other achievement tests. Boaler concluded that the differences in instructional practices had a significant impact on the students' mathematical perceptions and behaviors. Students taught using the project-based approach enjoyed mathematics more and viewed mathematics as a flexible subject that involved thinking about real world situations. Students taught using the traditional approach viewed mathematics as a collection of rules, formulas, and equations that require memorization rather than thinking. Gresalfi et al. (2004; cited in

Star & Hoffmann, 2005) extended this line of work with high school students in the United States, examining the epistemological beliefs of students taught with traditional versus reform-oriented approaches, arguing that the students' beliefs are determined more by the curriculum than the learning preferences of the students.

Walker (1999) extended Grouws' line of research (see section 2.3.2) by using the CMI to characterize the epistemological beliefs of mathematics held by students after completing four years of the CPMP curriculum. Walker measured students' beliefs as they completed high school, and again after they completed one semester of college mathematics. The goal of the study was to determine how strongly the students held their beliefs of mathematics as they made the transition from reform-oriented high school mathematics to college mathematics. In addition to the CMI results, case studies described how six of the students reacted as they made the transition to college mathematics. The study did not take into account how the curriculum was implemented, and Walker had no way of determining how students' beliefs of mathematics would have differed if they had been taught using a more traditional curriculum. However, Walker explored the validity and reliability of the CMI, providing guidance for future researchers examining the relations between curricula and students' epistemological beliefs of mathematics.

Star and Hoffmann (2005) used the CMI to explore the beliefs of ninth-grade students' who had been taught with a middle school reform-oriented curriculum, the Connected Mathematics Project (CMP Educational Program, 2001; Lappan, Fey, Fitzgerald, Friel, & Phillips, 1997). The results were compared to results obtained from an earlier study (Grouws et al., 1996) that involved students taught with a traditional curriculum. Star and Hoffmann found that "students at the *Standards*-based site expressed more sophisticated epistemological conceptions of mathematics than those of the students from the non-*Standards*-based site" (p. 25), particularly with the Usefulness scale of the CMI. There were two major limitations of the study. First, although the authors believed that the reform-oriented curriculum was "extremely well enacted" (p. 29), there was no evidence of the teaching practices (e.g., classroom observations) that were used to implement the traditional curriculum in the earlier study. Second, the authors had limited access to the data set for the traditional students. Despite these and other limitations, the study demonstrated the feasibility of using the CMI to assess the impact of reform-oriented curricula on students' epistemological beliefs of mathematics. Star and Hoffmann also described procedures for analysis of CMI responses, including reliability and effect size (see also Star & Hoffmann, 2002).

2.4. Summary of the Previous Research

As the previous discussion illustrates, constructivism is widely accepted in the research community, and NCTM and other organizations have promoted reform-oriented curricula and instruction based on constructivist principles. Epistemological beliefs are an important part of constructivist theories of learning, and a variety of theoretical models and research methodologies from diverse perspectives have been developed to study those beliefs.

Empirical research has consistently shown that the epistemological beliefs held by students and teachers can impact learning in a variety of ways. Although there are many unanswered questions about the construct of epistemological beliefs, research has helped to expand the notion of impact of reform-oriented curricula and instruction beyond students' achievement and attitudes (Smith & Star, 2007).

NCTM's *Principles and Standards for School Mathematics* (2000) clearly recommended that mathematics curricula promote healthy epistemological beliefs of mathematics. However, there has been little empirical evidence demonstrating whether the use of reform-oriented curricula actually impacts students' beliefs. Such evidence is needed by teachers, administrators, and other policy-makers making decisions about curricula.

The present study takes into account many lessons learned from previous studies of the relations between curricula and students' epistemological beliefs, such as the value of using a framework when studying beliefs, the importance of assessing the instructional context and practices used to deliver the curricula, and the reliability and validity of the instrument used. Those lessons helped determine the methods used in this study, including the specific instruments used, procedures followed, and analyses performed.

Chapter 3

HIGH SCHOOL MATHEMATICS TEXTBOOKS

In the U.S., school districts spend more than $4 billion each year on textbooks, and schools typically adopt new mathematics textbooks every five to seven years. Unlike most industrialized countries, the selection of textbooks and other curriculum materials is usually a local decision, and the federal government does not provide national curriculum standards to guide those decisions (Reys, Reys, & Chavez, 2004). This chapter discusses high school mathematics textbooks in the U.S., and is divided into five sections: (a) the influence of mathematics textbooks in the U.S., (b) an overview of the CPMP, (c) research on the effectiveness of CPMP, (d) research on the effectiveness of Glencoe Mathematics, and (e) an example contrasting CPMP and Glencoe Mathematics.

3.1. The Influence of Mathematics Textbooks in the U.S.

The textbook selected by a school district strongly influences both what and how mathematics is taught (Tarr, Chávez, Reys, & Reys, 2006). Teachers often use the textbook as a set of lesson plans, and the proportion of the textbook devoted to a particular topic influences the amount of time spent on that topic. In addition, the textbook often determines the sequence for presenting mathematics content (Reys et al., 2004).

Most mathematics textbooks have been practically indistinguishable until recent years. Each unit typically provides examples that the teacher demonstrates, followed by exercises for the students to try and homework problems similar to those already demonstrated. Mathematical ideas are typically presented as facts to memorize. The NCTM's *Curriculum and Evaluation Standards for School Mathematics* (1989) provided a K-12 curriculum framework for mathematics, and the National Science Foundation funded several efforts to create new mathematics textbooks based on that framework. Some publishers have also incorporated elements of that framework into their textbooks. However, research has indicated that teachers' implementation of reform-oriented curricula varies widely (Reys et al., 2004).

The Report of the 2000 National Survey of Science and Mathematics Education (Weiss et al., 2001) described market share of commercial mathematics textbook publishers and usage of mathematics textbooks as reported by school mathematics program representatives. Three publishers—McGraw-Hill/Merrill Co.; Houghton Mifflin/McDougall Littell/D.C. Heath; and Addison-Wesley Longman, Inc./Scott, Foresman—accounted for 61% of the mathematics textbook usage in grades 9–12. McGraw-Hill/Merrill Company, the publisher of both the Glencoe Mathematics and CPMP textbooks used in this study, accounted for 22% of the market share at the high school level, although CPMP accounted for only 1% of the market share at the high school level. Reys et al. (2004) reported that 10-15% of U.S. classrooms use reform-oriented textbooks based on the NCTM curriculum framework.

Research on the usage and impact of textbooks in the U.S. has been limited, but there is one consistent finding: textbooks impact students' mathematics experience in important ways (Tarr et al., 2006).

3.2. The Core-Plus Mathematics Project (CPMP)

In 1992, the National Science Foundation funded several projects to produce elementary, middle, and high school mathematics textbooks based on the principles outlined in the NCTM's *Curriculum and Evaluation Standards for School Mathematics* (1989; Reys, Robinson, Sconiers, & Mark, 1999; Ziebarth, 2003). The Core-Plus Mathematics Project (CPMP) is one of four high school projects funded, and the resulting textbook is published under the title *Contemporary Mathematics in Context: A Unified Approach* (Coxford et al., 1998), commonly referred to as CPMP or Core-Plus.

CPMP is based on the theme of using mathematics as a tool for making sense of the world around us. Investigations of real-life questions lead students to develop mathematical understanding and skills. Rather than the traditional Algebra I, Geometry, Algebra II sequence of topics, each year of CPMP includes topics in algebra and functions, geometry and trigonometry, statistics and probability, and discrete mathematics. Those four interwoven content strands are unified by the common themes such as symmetry, functions, matrices, and data analysis and curve fitting. While traditional algebra curricula have focused on symbolic manipulation and procedures to solve rational and polynomial procedures, CPMP uses a function perspective where algebra is presented as a tool for problem-solving and modeling (Schoen, Cebulla, & Winsor, 2001). CPMP also promotes several *habits of mind*, including visual thinking, recursive thinking, reasoning with multiple representations, and providing convincing arguments (Hirsch, Coxford, Fey, & Schoen, 1995; Huntley et al., 2000).

The underlying principle apparent throughout CPMP is the constructivist view that "exploration and experimentation necessarily precede and complement theory" (Schoen, Finn, Cebulla & Fi, 2003, p. 7). CPMP also recognizes the importance of small-group collaborative learning, social interaction, and communication in the construction of mathematical ideas, particularly for females and underrepresented minorities (Schoen & Hirsch, 2003a). Each lesson is launched with a real world situation and questions for the entire class to think about, setting the context for the student work. Students then explore more focused problems related to the launch situation, and a shared understanding of concepts, methods, and approaches is developed during class discussions. Each lesson also includes tasks for students to complete on their own, engaging students in modeling with, organizing, reflecting on, and extending their understanding. CPMP incorporates the principles on teaching and learning mathematics listed below (Schoen, Hirsch, et al., 1998; Ziebarth, 2003; Schoen & Hirsch, 2003a):

1. Mathematics is a vibrant and broadly useful subject to be explored and understood as an active science of patterns.
2. Each part of the curriculum should be justified on its own merits.
3. Computers and calculators have changed not only what mathematics is important, but also how mathematics should be taught.
4. Problems provide a rich context for developing student understanding of mathematics.

5. Deep understanding of mathematical ideas includes connections among related concepts and procedures, both within mathematics and to the real world.
6. Classroom cultures of sense-making shape students' understanding of the nature of mathematics as well as the ways in which they can use the mathematics they have learned.
7. Social interaction and communication play vital roles in the construction of mathematical ideas.
8. Small-group cooperative learning environments encourage more female participation in the mathematics classroom, and encourage a variety of social skills that appear particularly conducive to the learning styles of females and underrepresented minorities.

Another significant distinguishing feature of CPMP is the frequent presentation of algebraic ideas through tabular, graphic, and symbolic representations using technology (Huntley et al., 2000; Schoen, Hirsch, et al., 1998; Schoen et al., 2001; Schoen, Finn, et al., 2003). Because of equity considerations, graphing calculators are used rather than computers. This and other features of CPMP that distinguish it from more traditional curricula were summarized by Schoen & Hirsch (2003b):

- Each course advances students' understanding of mathematics along interwoven strands of algebra and functions, statistics and probability, geometry and trigonometry, and discrete mathematics.
- These mathematical strands are developed in coherent, focused units that are connected by fundamental ideas such as function, symmetry, and data analysis;

and by mathematical habits of mind such as visual thinking, recursive thinking, and searching for and explaining patterns.

- Mathematics is developed in context with an emphasis on problem solving and mathematical modeling.
- Graphing calculators are used as tools for developing mathematical understanding and for solving authentic problems.
- Instructional materials promote active learning and teaching centered around collaborative small-group investigations of problem situations followed by whole-class summarizing activities that lead to analysis, abstraction, and further application of underlying mathematical structures.
- Conceptual understanding, reasoning with multiple representations, and oral and written communication are emphasized.
- Mathematical thinking and reasoning are central to all courses; with formal proof developed "semilocally" in Courses 3 and 4.
- The design of Course 4 permits tailoring of seven-unit courses around core units (1-4) plus options so as to keep all college-bound students in the mathematics pipeline, whether their intended undergraduate program is calculus-based or not.
- Assessment of students is an integral part of the curriculum and instruction.

The broad differences between CPMP and traditional mathematics textbooks are presented in Table 2.

Table 2. Comparison of Core-Plus Mathematics Project (CPMP) and Traditional Mathematics textbooks (Herbel-Eisenmann et al., 2006).

Traditional Algebra Sequence	CPMP Sequence
• Mathematics strands are studied separately, one each year. • Teacher demonstrates. • Students practice.	• Mathematics strands are integrated each year. • The teacher guides and assesses (using multi-dimensional assessment). • Students investigate real-life contexts (often in groups) and apply the mathematics from these problems to new problems

The design, theoretical framework, and student outcomes for CPMP were discussed in more detail by Schoen & Hirsch (2003a) and in many field study reports on CPMP (e.g., Hirsch et al., 1995; Hirsch & Coxford, 1997; Huntley et al., 2000; Schoen, Finn, et al., 2003; Schoen, Hirsch, et al., 1998; Schoen et al., 2001; Schoen & Hirsch, 2003b; Ziebarth, 2003). Schoen & Pritchett (1998) provided a bibliography of CPMP publications.

3.3. Research on the Effectiveness of CPMP

Some educators have argued that CPMP and other reform-oriented curricula do not have a research base to support their use (Reys, 2001) or that the existing research may be biased because it was performed by the curriculum developers themselves (Latterell, 2006). Others have cited research that reform-oriented students may not perform as well as traditional students on college entrance exams. This section addresses those concerns and provides an overview of the research comparing CPMP and traditional textbooks.

A large amount of quantitative and qualitative data has been generated during CPMP field tests and several focused research studies conducted in CPMP classrooms

(Schoen & Pritchett, 1998). Studies and reports comparing CPMP and traditional students have focused on a variety of outcomes such as achievement on standardized achievement tests (Schoen, Hirsch, et al., 1998; Schoen & Hirsch, 2003a; Schoen et al., 2001), teachers' and students' perceptions and attitudes about mathematics (Schoen & Hirsch, 2003a; Schoen & Pritchett, 1998), students' preparation for college mathematics (Schoen & Hirsch, 2003a; Schoen et al., 2001), and understanding, skill, and problem-solving ability in algebra (Huntley et al., 2000).

Although college entrance exams such as the SAT and ACT generally measure algebraic manipulation skills and are not aligned with the content goals of the CPMP curriculum, field tests have generally found that CPMP students perform at least as well as traditional students on those assessments (Schoen et al., 2001), and CPMP students perform better than traditional students on measures of conceptual understanding, interpretation of mathematical representations and calculations, and problem-solving in applied contexts (Schoen & Hirsch, 2003b). Ziebarth (2003) provided a summary of the main findings from eight studies, and several other reports have also included summaries of findings (Latterell, 2006; Huntley et al., 2000; Schoen, Finn, et al., 2003; Schoen & Hirsch, 2003a; Schoen, Hirsch, et al., 1998; Schoen & Pritchett, 1998).

In an independent study, Latterell (2006) found no significant differences in problem-solving abilities for students in three CPMP and three traditional Algebra 2 classes. Latterell also found that the ability to solve routine algebraic problems without a context was considerably lower for the CPMP students than for the traditional students. One specific concern of some educators, including many teachers participating in the present study, is the perception that traditional students often perform better than reform-oriented students on standardized tests, such as college entrance exams. Although the CPMP authors have made efforts to address that concern, a fundamental problem is that "curricula like CPMP may be penalized by the content, format, and administration procedures of tests designed to align with traditional curricula" (Schoen et al., 2001, p. 24). Much CPMP content, such as statistics, probability, and discrete mathematics, is seriously underrepresented in both the SAT and the ACT, and some topics on the SAT and ACT are not introduced in CPMP until the fourth course, penalizing CPMP students taking those exams during their third year of high school.

It is an unfortunate fact that college entrance exams that focus on manipulation of algebraic symbols are often the primary measure of success for students' achievement in mathematics. Many educators who might otherwise adopt reform-oriented instructional practices are unwilling to risk the consequences of having their students perform poorly on standardized tests, despite some evidence that reform-oriented students perform at least as well as traditional students.

Concern about students' performance on standardized tests and possible bias in the research is valid, but the argument that CPMP and other reform-oriented curricula are not supported by research is unfounded for two reasons. First, CPMP and several other reform-oriented curricula have been piloted, revised, and field-tested extensively as described earlier. Reys (2001) summarized this point: "To criticize these curricula because of the philosophy they embody or the mathematical content of the materials is one thing. To suggest that they have not been extensively field-tested with teachers and students is blatantly untrue and irresponsible." Second, the claim that reform-oriented curricula are not supported by research implies that traditional curricula have been successful and are supported by research. Most publishers of traditional textbooks simply do not gather scientific evidence during the development of textbooks (Reys et al., 2004), as illustrated in the next section.

3.4. Research on the Effectiveness of Glencoe Mathematics

Despite an exhaustive literature search, no scientific evidence on the effectiveness of Glencoe Mathematics was found. The publishers of Glencoe Mathematics simply have not reported any scientific studies, such as randomized field trials, demonstrating the effectiveness of the curriculum. When asked about research supporting the curriculum, representatives of the publisher provided four documents that address the design principles, research base, and research reports for Glencoe Mathematics. This section summarizes those four documents.

The first document was a white paper entitled *Glencoe Mathematics White Paper: Research-Based Strategies Used to Develop Glencoe Algebra 1, Glencoe Algebra 2, and Glencoe Geometry* (McGraw-Hill Companies, n.d.). This document began with a brief overview of the NCTM's *Principles and Standards for School Mathematics* (2000), followed by a discussion of how Glencoe Mathematics meets those principles and standards. The discussion on the NCTM principles was cursory. For example, the curriculum principle was only addressed as follows: "Glencoe's *Algebra 1*, *Algebra 2*, and *Geometry* were developed with a philosophy, scope and sequence to ensure a continuum of mathematical learning that builds on prior knowledge and extends concepts toward more advanced mathematical thinking" (Principles section, para. 1). The discussion on the NCTM content standards was more substantive: a two-page table was provided that lists each of the NCTM *Standards* along with specific page numbers in the Glencoe Mathematics textbooks that meet those standards. Finally, a summary of research-based instructional strategies was presented; none of the research described examined Glencoe Mathematics directly.

The second document provided by the publisher was entitled *Glencoe Mathematics High School Learner Verification Research Summary* (McGraw-Hill Companies, n.d.). This document summarized four studies representing the publisher's "in-depth and quantitative research surveys, commentaries, and testing results" (p. 4). The first study was a survey mailed to randomly selected high schools from all fifty states over five years. The survey included approximately 70 questions on topics such as what mathematics textbook is used, whether students' ACT or SAT scores have changed, and how the mathematics program could be improved. The study found that teachers using Glencoe Mathematics reported ACT and SAT score increases ranging from 15% to 23% over a five year period. It is difficult to draw conclusions from this study since no results are presented for teachers using other textbooks, and the primary instrument was a teacher self-report survey with a 32% response rate. In the second study, teachers in several schools administered a pre-test to over 200 students prior to teaching Chapter 3 from *Glencoe Algebra 1*. A post-test was administered after completing the chapter, and a post-study questionnaire was completed by participating teachers. Results indicated that test scores increased for eight out of ten students. However, without a comparison group it is impossible to determine whether Glencoe Mathematics was more or less effective than other textbooks. For the third study, over fifty geometry teachers reviewed the manuscript and design for new editions of Glencoe Mathematics textbooks, rating their effectiveness in a ten categories.

The third document, *Results with Pre-Algebra, Algebra 1, Geometry, and Algebra 2* (McGraw-Hill Companies, 2004), presented anecdotal evidence of the effectiveness of Glencoe Mathematics in eleven schools. Much of the evidence consisted of statements from teachers such as, “Our scores improved in 2002, with 65% of our students scoring proficient to basic, and in 2003, 72% of our students scoring proficient to basic” (p. 21). Some schools provided figures of students’ performance on achievement tests, but there was no mention of comparison groups.

The fourth document was entitled *Glencoe Mathematics Qualitative Pre-Development Research: Proven education strategies, based on current and confirmed research, incorporated into Glencoe’s mathematics programs* (McGraw-Hill Companies, 2005). This document described educational research supporting the Glencoe Mathematics textbooks, including research on educational principles (e.g., curriculum and instruction), instructional strategies (e.g., cooperative learning), mathematical concepts and skills (e.g., proportional reasoning), and mathematical processes (e.g., reasoning and proof). Each topic was discussed in four parts: (a) *What Are They?*, (b) *Why Is It Important?*, (c) *What the Research Says*, and (d) *In the Glencoe Curriculum*. A selection of widely recognized studies was presented throughout the document. As in the other documents, no scientific evidence on the effectiveness of Glencoe Mathematics was presented: “Although the studies noted here did not make use of Glencoe textbooks or other specific curriculum materials, they provide the best available guide to what works” (p. iv).

It is ironic that the introduction section of the fourth document, *Glencoe Mathematics Qualitative Pre-Development Research*, discussed the need for research, the use of randomized trials in education research, the types of research designs used, and what constitutes *good research*. The following criteria were presented for evaluating research (p. viii):

- What type of research study was conducted? Was it an experiment or another type?
- Is it reliable research? Do the design and the analysis of the data support the conclusions?
- Is it relevant? Are the circumstances of the research setting similar to ours?
- Is it generalizable? Have the results been replicated in other settings?
- Has it been published in a peer-reviewed journal or book?

By those criteria, no good research on the effectiveness of Glencoe Mathematics exists.

3.5. An Example Contrasting CPMP and Glencoe Mathematics

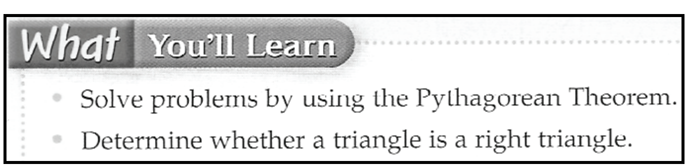
One way to compare curricula is by examining how they present particular topics. Reys et al. (2004) compared reform-oriented and traditional textbook presentations on the topic of finding the volume of cylinders and cones. In another study, one teacher explained that ideas such as the Pythagorean Theorem "are simply given to students in the Algebra text and then students are asked to apply them," whereas integrated materials "pose problems to help students discover the Pythagorean Theorem and connect it to their previous knowledge" (Herbel-Eisenmann et al., 2006, Results section, para. 14). This section explores that example by contrasting the CPMP and Glencoe Mathematics presentations of the Pythagorean Theorem.

3.5.1. Glencoe Mathematics: Presenting the Pythagorean Theorem

Glencoe Mathematics first introduces the Pythagorean Theorem in *Algebra 1* (Holliday et al., 2003a, pp. 605-610). Like all lessons in that textbook, it begins with a statement of "What you'll learn" (see Figure 1), followed by an example of how the topic is used in real life (see Figure 2). Next, a definition of the Pythagorean Theorem is presented (see Figure 3), and an example of using the Pythagorean Theorem to find the length of the hypotenuse of a right triangle is demonstrated (see Figure 4).

The pages that follow present more examples, a corollary to the Pythagorean Theorem, a "Check for Understanding" section containing problems similar to the examples, and a "Practice and Apply" section consisting of many more problems similar to the examples. It is not until exercise 41 (see Figure 5) in the "Practice and Apply" section that the roller coaster context introduced at the beginning of the lesson (see Figure 2) is revisited. Finally, "Standardized Test Practice" and "Maintaining Your Skills" exercises are provided.

Figure 1. Statement of "What you'll learn" at the beginning of Pythagorean Theorem lesson in Glencoe Mathematics *Algebra 1* (Holliday et al., 2003a, p. 605).


What You'll Learn

- Solve problems by using the Pythagorean Theorem.
- Determine whether a triangle is a right triangle.

Figure 2. Example of how the Pythagorean Theorem is used in real life in Glencoe Mathematics *Algebra 1* (Holliday et al., 2003a, p. 605).

How **is the Pythagorean Theorem used in roller coaster design?**

The roller coaster *Superman: Ride of Steel* in Agawam, Massachusetts, is one of the world's tallest roller coasters at 208 feet. It also boasts one of the world's steepest drops, measured at 78 degrees, and it reaches a maximum speed of 77 miles per hour. You can use the Pythagorean Theorem to estimate the length of the first hill.

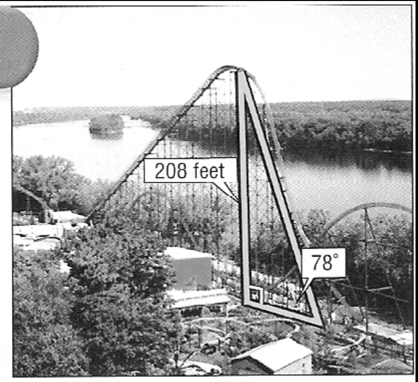
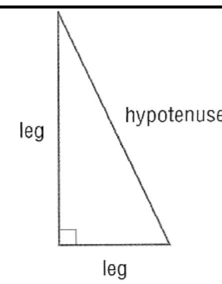


Figure 3. Definition of Pythagorean Theorem presented in Glencoe Mathematics *Algebra 1* (Holliday et al., 2003a, p. 605).

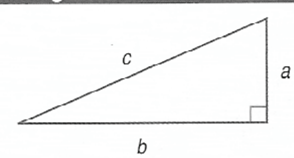
THE PYTHAGOREAN THEOREM In a right triangle, the side opposite the right angle is called the **hypotenuse**. This side is always the longest side of a right triangle. The other two sides are called the **legs** of the triangle.

To find the length of any side of a right triangle when the lengths of the other two are known, you can use a formula developed by the Greek mathematician Pythagoras.



Key Concept *The Pythagorean Theorem*

- **Words** If a and b are the lengths of the legs of a right triangle and c is the length of the hypotenuse, then the square of the length of the hypotenuse is equal to the sum of the squares of the lengths of the legs.



- **Symbols** $c^2 = a^2 + b^2$

Figure 4. Example of using the Pythagorean Theorem presented in Glencoe Mathematics *Algebra 1* (Holliday et al., 2003a, p. 605).

Example 1 *Find the Length of the Hypotenuse*

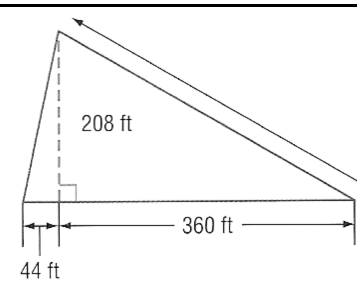
Find the length of the hypotenuse of a right triangle if $a = 8$ and $b = 15$.

$c^2 = a^2 + b^2$	Pythagorean Theorem
$c^2 = 8^2 + 15^2$	$a = 8$ and $b = 15$
$c^2 = 289$	Simplify.
$c = \pm\sqrt{289}$	Take the square root of each side.
$c = \pm 17$	Disregard -17. Why?

The length of the hypotenuse is 17 units.

Figure 5. Exercises relating Pythagorean Theorem to the real-life context introduced earlier in Glencoe Mathematics *Algebra 1* (Holliday et al., 2003a, p. 609).

ROLLER COASTERS **For Exercises 41–43, use the following information and the figure.**
Suppose a roller coaster climbs 208 feet higher than its starting point making a horizontal advance of 360 feet. When it comes down, it makes a horizontal advance of 44 feet.



41. How far will it travel to get to the top of the ride?

42. How far will it travel on the downhill track?

43. Compare the total horizontal advance, vertical height, and total track length.

3.5.2. CPMP: Presenting the Pythagorean Theorem

CPMP introduces the Pythagorean Theorem in *Course 1 Part B* (Coxford et al., 1998, pp. 362-372). Like Glencoe Mathematics, CPMP begins by presenting a real-life problem that involves using Pythagorean Theorem: in this case, determine the diagonal measurement of a television (see Figure 6). Then, rather than presenting a definition of the Pythagorean Theorem along with examples, a radically different approach is used: students work in groups to model the real-life example using notebook paper (see Figure 7). Further student exploration follows, with students considering the areas of squares constructed on the sides of right triangles (see Figure 8). After students have discovered the relationship between the legs and hypotenuses of right triangles, the term *Pythagorean Theorem* is given and subsequent activities use the term (see Figure 9). Students are not presented the definition of the Pythagorean Theorem until after the investigation is complete (see Figure 10).

After a brief "On Your Own" problem designed to assess students' understanding of the Pythagorean Theorem, CPMP presents a series of tasks to be completed individually where students engage in modeling with, organizing, reflecting on, and extending their understanding.

Figure 6. Example of using the Pythagorean Theorem in real-life presented in Core-Plus Mathematics Project (CPMP) *Course 1 Part B* (Coxford et al., 1998, p. 362).

2 Television Screens and Pythagoras

Television manufacturers often describe the size of their rectangular picture screens by giving the length of the diagonal. The set pictured here has a 25-inch diagonal screen. Several companies also advertise a 50-inch diagonal color stereo television. How well does giving the measure of the diagonal describe the rectangular screen?

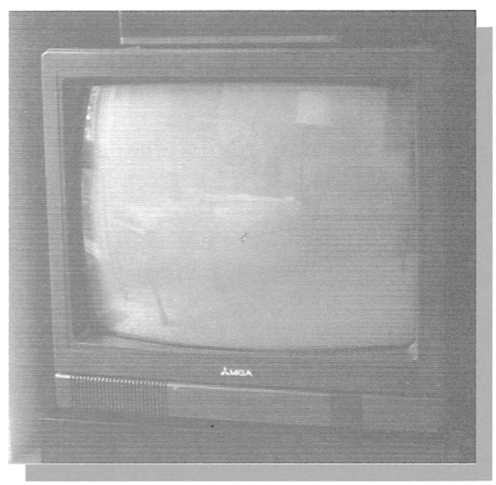
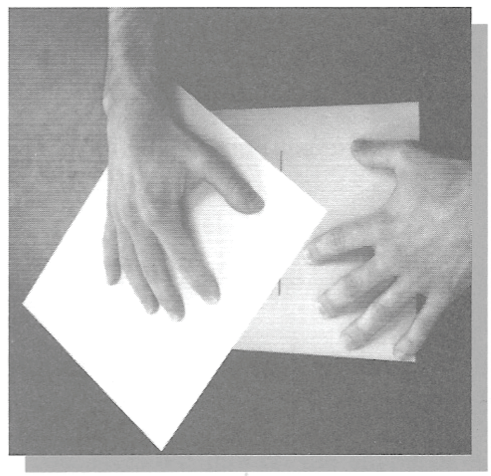


Figure 7. Activity in which students model the diagonal measurement of a television presented in Core-Plus Mathematics Project (CPMP) *Course 1 Part B* (Coxford et al., 1998, p. 362).

1. For this activity, consider a 20-inch TV picture screen.

a. Model the 20-inch diagonal by drawing a 5-inch segment on your paper. (Each member of your group should do this.) In your drawing, each inch represents 4 inches on the picture screen. This is done so that the drawing will fit on your paper. Your drawing has a 1 to 4 (1:4) scale.

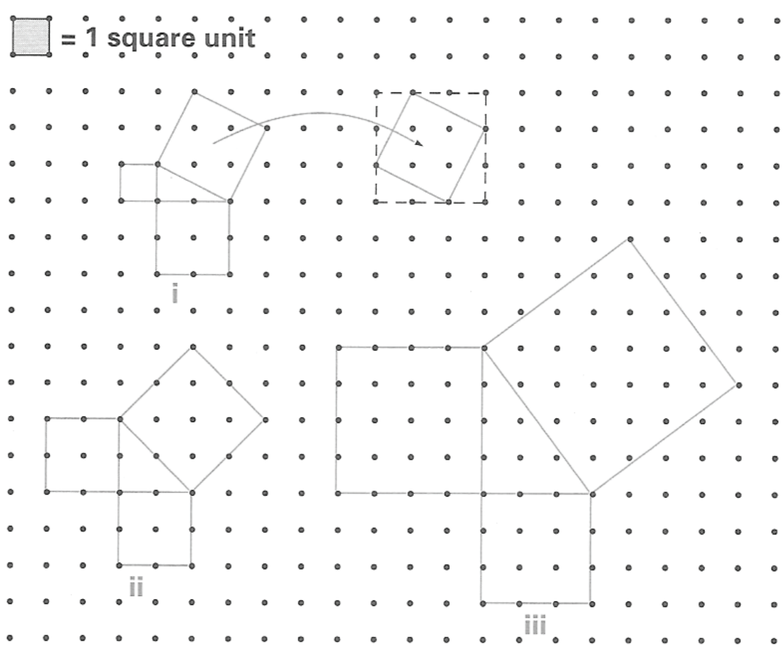
b. Draw a rectangle with the segment you drew as its diagonal. One way to do this is to place a piece of notebook paper with a 90° corner over the segment. Carefully position the paper so that its edges just touch the ends of the segment. Mark the corner. Describe how the entire rectangle can be drawn from this one point and the segment.



c. Compare your rectangular screen with those of others in your group. Are they the same? How do they compare in perimeter? In area?

Figure 8. Construction of squares on the sides of right triangles, demonstrating how to calculate the diagonal lengths of television screens, presented in Core-Plus Mathematics Project (CPMP) *Course 1 Part B* (Coxford et al., 1998, p. 363).

3. You can calculate the diagonal lengths of screens by considering the right triangles formed by the sides. To see how to do this, examine the figures below in which squares have been constructed on the sides of right triangles.



a. For each right triangle, calculate the areas of the squares on the triangle's sides. Use the unit of area measure shown. To calculate areas of squares on the longest side, you may have to be creative as suggested by the first figure. Record your data in a table like the one below.

	Area of Square on Short Side 1	Area of Square on Short Side 2	Area of Square on Longest Side
i.			
ii.			
iii.			

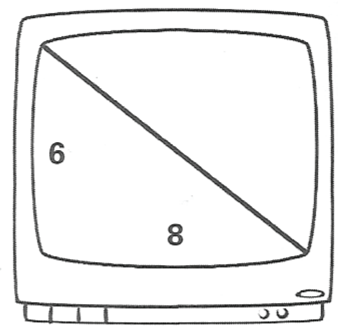
Figure 9. Introduction of the term *Pythagorean Theorem* presented in Core-Plus Mathematics Project (CPMP) *Course 1 Part B* (Coxford et al., 1998, p. 364).

The discovery you made in Activity 3 was based on a careful study of several examples. The Greek philosopher Pythagoras is credited with first demonstrating that this relationship is true for all right triangles. The relationship is called the **Pythagorean Theorem**. Historians believe that special cases of this relationship were discovered earlier and used by the Babylonians, Chinese, and Egyptians.

4. Now investigate how the Pythagorean Theorem can help in sizing television screens.

a. Recall the 6-by-8 inch TV screen.

- Find the square of the diagonal.
- How can you find the length of the diagonal when you know its square? What do you get in this case?
- How do you think the manufacturer advertises the size of the 6-by-8 inch TV set? Compare this answer to what you proposed in Activity 2.

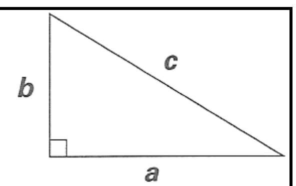


b. Use your calculator or computer to find the length of a diagonal whose square is 56.

Figure 10. Definition of the Pythagorean Theorem presented in Core-Plus Mathematics Project (CPMP) *Course 1 Part B* (Coxford et al., 1998, p. 365).

In a right triangle, the longest side (the one opposite the right angle) is called the **hypotenuse** and the shorter sides are called **legs**. The Pythagorean Theorem can be stated in the following form:

The sum of the squares of the legs of a right triangle equals the square of the hypotenuse.



$a^2 + b^2 = c^2$

3.6. Summary

The example in the previous section demonstrates CPMP's strong commitment to the constructivist principles of teaching and learning outlined in section 2.2.1. Compared to the Glencoe Mathematics textbook, the CPMP textbook presents more problems in real world contexts and engages students in exploring ideas, solving problems, sharing strategies, and building new knowledge based on conceptual understanding. The experiences of students taught using CPMP and Glencoe Mathematics are clearly different.

Field tests conducted by CPMP researchers have generally found that CPMP students perform better than or the same as traditional students on measures of conceptual understanding and problem-solving in applied contexts, while traditional students sometimes perform better than CPMP students on measures of algebraic manipulation and procedural skills. No scientific evidence on the effectiveness of Glencoe Mathematics has been reported in the literature.

The influence of textbooks on mathematics instruction is significant, and more research assessing the impact of reform-oriented versus traditional textbooks is needed. The present study does not resolve the issues described in this chapter; rather, it suggests that future research on the effectiveness of curricula expand the notion of impact by including measures of students' epistemological beliefs of mathematics.

Chapter 4

METHODOLOGY

This chapter explains the methods used in carrying out this study, including information about the participants, specific instruments used, procedures followed, and analyses performed.

4.1. General Methodology

This study compared the epistemological beliefs of mathematics held by high school students after studying three years of an NSF-funded, *Standards*-based curriculum versus a more traditional curriculum. In addition, this study explored the teaching practices used to implement those curricula. The design of the study evolved to include more emphasis on teaching practices after it became clear that some teachers were opposed to the instructional strategies presented by their textbooks.

There were two main components to the study. The first was a questionnaire that was administered to 11^{th}-grade students in four rural Maine high schools to assess their beliefs of mathematics. The questionnaire included all 56 items from the Conceptions of Mathematics Inventory (CMI; Grouws et al., 1996), as well as some additional background items. The second component was a series of classroom observations, teacher questionnaires, and informal interviews used to characterize the level of reform-oriented teaching occurring in the four schools. The primary instrument used for classroom observations was a variation of the Reformed Teaching Observation Protocol (RTOP; Piburn & Sawada, 2000; Sawada & Piburn, 2000).

Implementation of reform-oriented curricula and teaching practices can vary greatly from one school, classroom, or teacher to another (Schoen, Finn, et al., 2003). Most research on students' beliefs of mathematics has been far removed from the learning environment (Hammer, 1994), and several researchers have recommended that future studies of students' beliefs include classroom observations, interviews, and other methods to measure aspects of the instructional context that may affect beliefs (Hirschhorn, 1993; Hofer, 1994; Frykholm, 1995; Hofer & Pintrich, 1997; Kislenko et al., 2005; Star & Hoffmann, 2005; Herbel-Eisenmann et al., 2006). Reform-oriented curricula differ from traditional curricula in their mathematical content and pedagogical focus (Tarr et al., 2006). The National Research Council (2004) recommended that research on the effectiveness of curricula measures the implementation fidelity and the extent of use of the curricular materials. At a minimum, "there should be documentation of the extent of coverage of curricular material (what some investigators referred to as 'opportunity to learn')" (p. 6). By including classroom observations, teacher questionnaires, and informal interviews in this study, this study documented what actually happened in the classrooms rather than making assumptions about the teaching practices used to implement the curricula.

4.2. Research Setting

This study took place in four rural Maine high schools. Data collection activities covered a two-month period, from February 13, 2007 to March 23, 2007. For purposes of confidentiality, the schools are referred to by the textbook used and the teaching characteristics that were identified by classroom observations (e.g., *Glencoe/Reform*), and some specific values have been approximated to prevent the possible identification of individual students, teachers, or schools.

In fall 2006, two curricula were selected for this study based on the results of a state-wide survey of high school mathematics curricula conducted by John E. Donovan II (personal communication, September 2006) at the University of Maine. Although several NSF-funded, *Standards*-based curricula were used in Maine high schools, the survey indicated that CPMP was the most prevalent. Among more traditional curricula, the survey indicated that many Maine high schools used the Glencoe Mathematics textbooks.

After selecting the two curricula, 12 candidate schools were identified that exclusively used either curriculum. Exclusive use of curricula was an important consideration since the survey indicated that many Maine high schools implement multiple curricula, sometimes separating high- and low-achieving students as reported by other researchers (Huntley et al., 2000).

During initial discussions with administrators and teachers at candidate schools, it became clear that some teachers did not implement the curricula as intended by the developers. In one school, teachers using CPMP expressed strong opposition to the curriculum, but had been told to use CPMP by the administration. In another school, administrators indicated that teachers using Glencoe Mathematics often supplemented the curriculum with technology and other reform-oriented materials. Rather than exclude such schools from this study, the design was modified to include them while documenting the teaching practices. Although the initial research questions focused on relationships between curricula and students' beliefs of mathematics, teaching practices became an important variable as well.

Based on the initial discussions described above, as well as consideration of demographic, enrollment, and student achievement data, teachers and students at four schools were invited to participate in the study. The schools are described in the following section.

4.2.1. Schools and Curricula

The four high schools in this study were located in rural Maine, with enrollment ranging from 150 to 450 students. Student/teacher ratios ranged from 10:1 to 12:1. Class scheduling in all four schools was accomplished using 4×4 or A/B plans, with classes typically lasting 75 to 80 minutes. The schools' average scaled scores for the mathematics section of the 2004-2005 Maine Educational Assessment (MEA) were between 520 and 530 on a scale ranging from 200 to 800, close to the state average of 529. Teachers were competent and experienced in all four schools, but very little training in the use of their curricula had been provided. Teachers in all four schools described their school districts as economically depressed, and three of the four schools are Title I schools. Demographic characteristics of the schools are described in the next section.

The first school in the study used the CPMP curriculum for all but a few students who had completed an Algebra 1 course in middle school. Although teachers used CPMP in this school, they made it clear that it was only because administrators insisted they use it, with one teacher even stating, "I am on record as being opposed to this curriculum." When asked why they were opposed to CPMP, teachers cited concerns about students' performance on standardized tests and preparation for college. The perception that using *Standards*-based curricula leads to lower scores on standardized tests despite data indicating the otherwise was also encountered during initial discussions at other schools and has been reported by other researchers (Herbel-Eisenmann et al., 2006). Teachers also expressed the opinion that CPMP students rely too much on calculators without developing number sense.

Despite teachers' expressed opposition to CPMP, classroom observations and Teacher Classroom Description Questionnaire (see section 4.4.4) results for the first school indicated that teachers usually plan and implement lessons as outlined by the curriculum, although supplemental materials are often incorporated. The high frequency of small-group work, whole-class discussions, use of graphing calculators, and extended investigations clearly indicated that CPMP has a strong influence on instruction in this school. However, RTOP (see section 4.4.2) scores indicated a lower level of reform-oriented instruction than observed in the other CPMP school participating in this study. For example, the lessons observed involved less student exploration prior to formal presentation, less reflection about learning, and fewer connections with real world phenomena. Based on a mean overall RTOP score of 2.33, coupled with the teachers' expressed traditional beliefs about teaching mathematics, the first school is referred to as the *CPMP*/*Traditional* school.

The second school in the study also used the CPMP curriculum for all but a few students. Teachers expressed support for the *Standards*-based approach of CPMP, but they also expressed some concerns about implementing CPMP in their school, including a high level of reading required, a need to supplement for practice of procedures, and lack of some content such as permutations and combinations. As in the first school, teachers in the second school expressed concern about standardized test scores; lessons often began with SAT practice questions that teachers used to supplement the lesson.

Classroom observations and Teacher Classroom Description Questionnaire results for the second school indicated that teachers often use the CPMP curriculum to plan and implement lessons, although supplemental materials are usually incorporated as well. Lessons often included small group work, whole-class discussions, exploration of alternative solutions, use of graphing calculators, written reflections, and formal student presentations. Teachers often asked students to explain their reasoning when giving answers, and connections with real world phenomena are emphasized. RTOP scores for this school indicated the highest level of reform-oriented instruction out of all four schools participating in this study, and lessons exhibited reform-oriented practices such as student exploration preceding formal presentation. Based on a mean overall RTOP score of 3.83 and the teachers' expressed support for *Standards*-based instruction, the second school is referred to as the *CPMP/Reform* school.

The third school in the study used the Glencoe Mathematics curriculum for all but a few students. During initial discussions, teachers expressed strong support for traditional mathematics education, with one teacher going as far as saying, "We have known since the fifties what should be taught…" Teachers expressed a belief that students' performance on standardized tests is better with a traditional curriculum, and they described an earlier attempt to implement a *Standards*-based curriculum at a local middle school as a "disaster."

Based on initial discussions, the third school was included in this study as an example of a school that used the Glencoe Mathematics curriculum with traditional teaching practices. In fact, teachers in the school emphasized that they should not be part of the study unless traditional teaching practices were required. Classroom observations and Teacher Classroom Description Questionnaire results indicated a different story. Although teachers used Glencoe Mathematics to plan and implement lessons, the frequency of small group work, whole-class discussions, exploration of alternative solutions, use of graphing calculators, and extended investigations indicated a high level of reform-oriented instruction. Teachers frequently asked students to explain their reasoning when giving answers, and active participation of students was encouraged. RTOP scores generally indicated a high level of reform-oriented instruction, although some specific reform-oriented practices were noticeably absent during classroom observations. For example, student exploration preceding formal presentation was not observed. Similarly, connections with real world phenomena were rarely made. When asked later about the lack of real world connections, teachers agreed that they could improve in this respect, but they were also able to provide examples of lessons that clearly demonstrated such connections. The third school has not implemented inquiry-based instruction, but many other reform-oriented practices were observed and it received a mean overall RTOP score of 3.67. Therefore, the third school is referred to as the *Glencoe/Reform* school.

The fourth school in the study used the Glencoe Mathematics curriculum for most of its students. Teachers expressed strong support for the traditional curriculum, giving high overall quality ratings to the textbook. One teacher did express some concern about students' conceptual understanding, describing students who have learned procedures without knowing why they make sense or when to apply them.

During initial discussions at the fourth school, administrators described the mathematics instruction as being very progressive, with heavy use of computer technology to enhance lessons and very little use of textbooks per se. The fourth school was therefore included in the study as an example of a school using Glencoe Mathematics, and it was anticipated that reform-oriented teaching practices would be observed in the classrooms. Quite the opposite was found. Classroom observations and Teacher Classroom Description Questionnaire results indicated solid traditional teaching practices, with very low frequencies of group work, use of technology, whole-class discussions, or extended investigations. Graphing calculators were not used, and computer technology was only used by one teacher for occasional demonstrations. Student exploration did not precede formal presentation, and connections with real world phenomena were not apparent. Students were not typically asked to explain their reasoning when giving an answer, and alternative solutions were not explored often. The mean overall RTOP score for the fourth school was 2.00, indicating the lowest level of reform-oriented instruction out of all four participating schools. In short, teachers in the fourth school clearly demonstrated traditional teaching practices. Therefore, the fourth school is referred to as the *Glencoe/Traditional* school.

4.2.2. Demographics

For each school participating in this study, the total population in the school district ranged from about 3,000 to 10,000 people, with at least 96% of the population being white and non-Hispanic (National Center for Educational Statistics, 2006).

Throughout this study, teachers and administrators at all four schools expressed concern about the economic situations in their districts. Many of Maine's traditional economic activities have experienced difficulties in recent years, and the populations in the school districts included in this study have suffered as a result. The median household income in 1999 for each school district ranged from about $27,000 to $32,000, and the percentage of households below the poverty level ranged from 13% to 18%. Three of the four schools qualified for Title I assistance. Another measure of the economic situation for a school is the percentage of students eligible for free or reduced price lunch. For each school participating in this study, the percentage of students eligible for free lunch ranged from about 20% to 40%, and the percentage of students eligible for free or reduced price lunch ranged from about 30% to 60%, well above the state average of 32%.

In all four school districts, about 70% of males and females over age 24 were high school graduates or equivalent. In three of the four school districts, about 10% of males and females over age 24 were college graduates. In the Glencoe/Reform school district, however, about 20% of males and females over age 24 were college graduates.

4.3. Participants

During initial visits to each of the schools in this study, teachers were given an overview of the purpose and methodology of the study. All teachers were remarkably receptive to participating in this study. Classroom observations were generally welcomed in all four schools and many teachers went as far as to say that no advance notice was necessary. All teachers expressed strong interest in educational research, particularly research related to curricula and teaching practices.

In both the CPMP/Reform and Glencoe/Reform schools, teachers were observed interacting regularly before, during, and after classes. Group discussions about lesson planning, curriculum issues, and teaching practices appeared to be routine in these schools. In the CPMP/Traditional school, a similar collegial atmosphere was observed during school, but direct observations of teacher interactions before and after school were not possible due to scheduling factors. Interactions between teachers in the Glencoe/Traditional school were clearly hampered by the fact that classrooms were physically separated; going between mathematics classrooms required walking outside to another building.

Students in all four schools appeared comfortable having an observer in the classroom, and observations did not appear to influence their actions or behavior. All students were cooperative when invited to complete a questionnaire and appeared to take it seriously.

4.4. Instruments and Materials Used

Four instruments were used in the data collection process. A Student Mathematics Questionnaire was used to measure students' beliefs about mathematics. Three instruments were used to measure teaching practices: (a) the Teaching Observation Protocol was used to measure the level of reform-oriented instruction in classrooms, (b) the Teacher Background Questionnaire was used to measure teachers' level of preparation to teach various topics and beliefs about student learning, and (c) a Teacher Classroom Description Questionnaire was used to measure frequencies of various classroom activities and textbook usage. This section describes each instrument used.

4.4.1. Student Mathematics Questionnaire

Although many instruments are available for measuring students' epistemological beliefs, few instruments are available that focus on students' epistemological beliefs of mathematics (see section 2.3). There is some evidence that epistemological beliefs may span domains (e.g., Schommer & Walker, 1995), but Hammer (1994) suggested that providing a specific mathematical context is more likely to yield success when addressing certain beliefs. Hammer also illustrated the value of an a priori framework when assessing students' beliefs. The Student Mathematics Questionnaire included all items from the Conceptions of Mathematics Inventory (CMI; Grouws et al., 1994) based on those requirements and the fact that the CMI has already been shown to be a useful, valid, and reliable instrument for assessing students' beliefs of mathematics (Walker, 1999; Star & Hoffmann, 2002, 2005).

The CMI is a Likert scale questionnaire with 56 items based on themes from the Student Conceptions of Mathematics Framework described in section 2.2.3. Questions in the CMI ask students to indicate whether they agree or disagree with statements about four themes: (a) the nature of mathematical knowledge, (b) the nature of mathematical activity, (c) learning mathematics, and (d) the usefulness of mathematics. Those four themes are composed of seven related scales, with each scale considered as a continuum with two poles as shown in Table 3. Eight items from the Fennema-Sherman Usefulness Scale (Fennema & Sherman, 1976) are included, and several items are included from the NAEP and the Indiana Mathematics Belief Scales (Kloosterman & Stage, 1992).

Each scale of the CMI contains eight items, with half of the items phrased positively (e.g., "When learning mathematics, it is helpful to analyze your mistakes") and half of the items phrased negatively (e.g., "One can be quite successful at doing mathematics without understanding it.") Students respond on a six-point, forced-choice Likert scale, with a *6* expressing strong agreement and a *1* expressing strong disagreement.

A student who mostly agrees with positively phrased items and disagrees with negatively phrased items would be considered to have reform-oriented epistemological beliefs. Such a student considers mathematics as a useful, dynamic, and coherent system of important ideas and the relations among them, involving thinking and figuring things out, validating results through personal reflection and individual thought and reasoning, with new mathematical knowledge formed by fitting things with past experiences. Conversely, a student who mostly disagrees with positively phrased items and agrees with negatively phrased items views mathematics as a static collection of independent

Table 3. The seven scales of the Conceptions of Mathematics Inventory (CMI) and their characteristics (Grouws et al., 1996).

I. Nature of Mathematical Knowledge	
1. Composition	
Knowledge as concepts, principles, and generalizations	Mathematical knowledge consists of important ideas and the relations among them.
vs.	
Knowledge as facts, formulas, and algorithms	Mathematical knowledge consists of important procedures and statements.
2. Structure	
Mathematics as a coherent system	As one does mathematics one finds meaningful connections between and among concepts, principles, and skills.
vs.	
Mathematics as a collection of isolated pieces	Mathematics consists of a variety of independent topics and skills; losing or gaining one piece of information has little effect on the development of another.
3. Status	
Mathematics as a dynamic field	Mathematics is growing and changing and this growth affects the entire discipline for both mathematicians and students.
vs.	
Mathematics as a static entity	Mathematics is a compilation of information that remains fixed once developed.
II. Nature of Mathematical Activity	
4. Doing	
Mathematics as sense-making	The process of doing mathematics depends on valuing, exploring, comprehending, and expanding the concepts and principles underlying mathematics.
vs.	
Mathematics as results	The process of doing mathematics is implementing procedures and finding results.
5. Validating	
Logical thought	The validity of mathematical knowledge is established through personal reflection and individual thought and reasoning.
vs.	
Outside authority	One receives valid mathematical knowledge from an authority: a text, a knowledgeable peer, a teacher, or a mathematician.
III. Learning Mathematics	
6. Learning	
Learning as constructing and understanding	One creates new knowledge by fitting things with past experiences.
vs.	
Learning as memorizing intact knowledge	Learning mathematics is a process of mentally storing what one has been taught; that is, the learner is a passive receiver who records existing knowledge.
IV. Usefulness of Mathematics	
7. Usefulness	
Mathematics as a useful endeavor	Mathematics is a worthwhile subject that will be useful to students in many ways as adults.
vs.	
Mathematics as a school subject with little value in everyday life or future work	Mathematics will not be important to students when they get out of school.

procedures that have little value in everyday life or future work, primarily involving the implementation of those procedures and finding results that are validated from an authority, and best learned by mentally storing what one has been taught.

Following the 56 items of the CMI, the Student Mathematics Questionnaire asked each student to indicate gender, year in school, expected grade in the current mathematics course, cumulative high school grade point average, expectation of pursuing an education after high school, expectation of pursuing an education in a mathematics-, science-, or engineering-related field, highest level of formal education attained mother, and highest level of formal education attained by father. To ensure anonymity of the participants, no items related to race or ethnicity were included.

4.4.2. Teaching Observation Protocol

The primary measure of teaching practices was the Teaching Observation Protocol (TOP; see Appendix M), adopted by the Center for Science and Mathematics Education Research at the University of Maine. TOP consists of all sections from the Reformed Teaching Observation Protocol (RTOP; Piburn & Sawada, 2000; Sawada & Piburn, 2000) with the addition of standardized codes for describing events from the Collaboratives for Excellence in Teacher Preparation (CETP) Classroom Observation Protocol (COP; Lawrenz, Huffman, & Appeldoorn, 2002; Collaboratives for Excellence in Teacher Preparation, n.d., 2002).

RTOP was created by the Evaluation Group of the Arizona Collaborative for Excellence in the Preparation of Teachers (ACEPT) as an observational instrument for measuring reformed teaching practices. Based on a framework of *Standards*-based inquiry, RTOP assesses five major pedagogical domains: (a) lesson design and implementation, (b) propositional knowledge, (c) procedural knowledge, (d) communicative interactions, and (e) student-teacher relationships.

Many classroom observation instruments have been developed recently to provide both qualitative and quantitative data to document and describe mathematics and science teaching from a *Standards*-based perspective (see MacIsaac, Sawada, & Falconer, 2001, p. 1, for examples). Unique characteristics of RTOP include: (a) focus on mathematics and science, (b) developed for classrooms from kindergarten to college, (c) focus exclusively on reform rather than general characteristics such as classroom management, lesson closure, etc., (d) brief to administer, (e) very high interrater reliability, (f) factor analyzed for construct validity, (g) proven predictive validity, and (h) training and reference manuals are available. Another benefit of using RTOP is that the language in the instrument provides participants with specific concepts and terms for thinking about and talking about reform-oriented teaching (MacIsaac et al., 2001).

4.4.3. Teacher Background Questionnaire

The Teacher Background Questionnaire (see Appendix K) was developed to measure teachers' attitudes and beliefs about teaching mathematics and perceptions of their preparedness in mathematics content and in using particular pedagogical strategies. Items were selected from a questionnaire developed by the Center for the Study of Mathematics Curriculum (CSMC) for a recent study of curriculum enactment (Chval et al., 2006).

Teachers were asked to indicate how well-prepared they were to teach specific mathematical topics (e.g., "Data collection and analysis") and guide student learning in various domains (e.g., "Connections within mathematics and from mathematics to other disciplines"). The response options were *Not Adequately Prepared*, *Somewhat Prepared*, *Fairly Well Prepared*, and *Very Well Prepared*, which were coded 1, 2, 3, and 4, respectively, for analysis.

Teachers were also asked to indicate their opinions about several statements about student learning (e.g., "At the grades I teach, a lot of things in mathematics must be simply accepted as true and remembered."). The response options ranged from *Strongly Disagree* to *Strongly Agree* and were coded from 1 to 5, respectively, for analysis.

4.4.4. Teacher Classroom Description Questionnaire

The Teacher Classroom Description Questionnaire was developed to supplement the TOP instrument. The questionnaire asked teachers to report teaching practices and textbook usage for each class taught; such a method was shown to be valid in previous research (McCaffrey et al., 2001). In this study, most teachers completed only one questionnaire, while indicating that there was little variation between classes. Most items were selected from the CSMC questionnaire described in the previous section (Chval et al., 2006).

After a short five-item section covering general class characteristics, teachers were asked to indicate what percentage of instructional time was allotted to various instructional activities (e.g., "Small group work"). Teachers were then asked to indicate how often they performed various activities (e.g., "Require students to explain their reasoning when giving and answer") and how often students performed various activities (e.g., "Engage in mathematical activities using concrete materials"). The response options were *Never*, *Rarely* (e.g., a few times a year), *Sometimes* (e.g., once or twice a month), *Often* (e.g., once or twice a week), and *Always* (e.g., done at least once a day), which were coded 1, 2, 3, 4, and 5, respectively, for analysis.

To determine the extent to which the textbook influenced instruction, teachers were asked to indicate how often the textbook was used in a variety of ways (e.g., "Students in this class use their textbook during the mathematics lesson"), with response options ranging from *Never* to *Always* as in the previous sections. Finally, teachers were asked to indicate what percentage of instructional time was based on the textbook, how much of the textbook will be covered during the school year, and the overall quality of the textbook. Teachers were not asked about mathematics content, per se.

4.5. The Procedures Followed

Several specific procedures were used in implementing the research design. This section describes the procedures used for administering the TOP teaching observations, the Teacher Background Questionnaire, and the Teacher Classroom Description Questionnaire.

All teachers were given a copy of the *Informed Consent Form for Teachers* at the beginning of the study (see Appendix I). Prior to each teaching observation, teachers were asked to provide an overview of the lesson and a copy of any materials that would be used. Teachers were asked to explain to the students at the beginning of the lesson that the class was being observed for research purposes, and that the goal of the research was to help improve mathematics education. In general, teaching observations occurred from the back of the classroom and students' behavior did not appear to be influenced by the observations. As Frykholm (1995) and Spradley (1979) suggested, notes taken during the lesson were "cooked" immediately upon completion to retain accurate descriptions for later analysis; most lessons were followed by a break of at least ten minutes, and teachers were usually available to answer questions about the lesson during those times.

Teaching observations were performed at each school over one or two weeks. On the first day of teaching observations, students who would be invited to participate in the study were given a copy of the *Information Form for Parents and Guardians* (see Appendix H). After teaching observations were performed at each school, students in predominately 11th-grade classes were given a copy of the *Informed Consent Form for Students* (see Appendix G) and invited to participate during class. Students were then given the Student Mathematics Questionnaire and told that it generally takes less than 10 minutes to complete. Although participation was voluntary, all students in the participating classes completed the questionnaire.

While students completed the Student Mathematics Questionnaire, teachers were asked to complete the Teacher Background Questionnaire and the Teacher Class Description Questionnaire. Upon completion of the questionnaires, students and teachers were thanked for their participation and most classes were given an opportunity to discuss the content and format of the Student Mathematics Questionnaire.

4.6. Data Analysis Strategies

This section describes the strategies used to analyze the TOP, Teacher Background Questionnaire, Teacher Class Description Questionnaire, and Student Mathematics Questionnaire data. All calculations were performed using Statistical Package for the Social Sciences (SPSS). Schools were labeled as having *Reform* or *Traditional* teaching practices as described in section 4.2.1.

For the TOP data, mean score reports were generated for each scale (see Table 4) and the *Overall Level of Reform Teaching* scores (see Table 5). Due to the low number of teachers participating and teaching observations performed, frequency distribution tables are provided for individual items (see Appendix B). Cronbach's α values were computed for each TOP scale to measure reliability and are reported in Table 6.

Table 4. Mean Teaching Observation Protocol (TOP) scores by scale.

	CPMP		Glencoe		All Schools (*N*=20)
	Trad. (*n*=3)	Reform (*n*=6)	Reform (*n*=6)	Trad. (*n*=5)	
Lesson Design and Implementation	2.33	3.17	3.00	1.60	2.60
Propositional Knowledge	1.33	1.83	1.83	0.80	1.50
Procedural Knowledge	4.00	3.33	3.67	3.80	3.65
Communicative Interactions	2.33	2.17	1.83	0.80	1.75
Student/teacher Relationships	2.00	2.00	1.67	1.00	1.65
Mean	2.40	2.50	2.40	1.60	2.23

(0=*Never Occurred*, 4=*Very Descriptive*).

Table 5. Mean Overall Level of Reform Teaching scores for the Teaching Observation Protocol (TOP).

CPMP		Glencoe		All Schools (*N*=20)
Trad. (*n*=3)	Reform (*n*=6)	Reform (*n*=6)	Trad. (*n*=5)	
2.33	3.83	3.67	2.00	3.10

(1=*Ineffective Instruction*, 4=*Exemplary Instruction*)

Table 6. Cronbach's α reliability for the five scales of the Teaching Observation Protocol (TOP).

	α
Lesson Design and Implementation	.65
Propositional Knowledge	.60
Procedural Knowledge	.85
Communicative Interactions	.71
Student/Teacher Relationships	.76

(*N* = 20)

For both the Teacher Background Questionnaire and Teacher Class Description Questionnaire, mean score reports were generated, but were not useful due to the limited number of participants in each school. Instead, frequency distribution tables are provided for individual items in these instruments (see Appendix C and Appendix D).

Several strategies were used to analyze the CMI data from the Student Mathematics Questionnaire. First, mean scores for each of the seven scales of the CMI were computed and compared to results from previous studies (see Table 7). Cronbach's α values were computed for each scale of the CMI to measure reliability and are reported in Table 8. As Star and Hoffmann (2005) discussed, Cronbach's α values close to or above 0.7 indicate satisfactory internal consistency of constructs. While only the Usefulness scale appears to meet this recommendation, Star and Hoffmann also reported large effect sizes using Cohen’s *d*. In any case, caution should be used when interpreting results for the scales with low Cronbach's α values.

Table 7. Mean scores and standard deviations on Conceptions of Mathematics Inventory (CMI) scales. The higher the number, the more reform-oriented the responses were.

		This Study			Grouws (1996) (N=163)*	Star (2005) (N=134)*	Walker (1999)	
		Male (n=49)	Female (n=53)	All (N=102)			May (N=92)	January (N=92)
Composition	Mean	3.55	3.51	3.53	3.10	3.66	3.89	3.77
	SD	.65	.65	.65	.9	.5	.54	.54
Structure	Mean	4.38	4.51	4.45	3.31	4.24	4.67	4.69
	SD	.78	.72	.75	.8	.7	.54	.50
Status	Mean	3.95	4.01	3.98	3.31	4.25	4.34	4.22
	SD	.63	.76	.70	.9	.7	.55	.64
Doing	Mean	4.41	4.59	4.51	3.11	4.35	4.57	4.61
	SD	.56	.60	.59	.9	.6	.49	.51
Validating	Mean	3.94	4.04	3.99	3.04	3.99	4.26	4.25
	SD	.67	.70	.68	.9	.6	.55	.60
Learning	Mean	3.83	3.97	3.90	3.27	3.99	4.21	4.09
	SD	.50	.54	.52	.8	.5	.50	.55
Usefulness	Mean	4.76	4.39	4.57	3.50	4.80	5.19	4.88
	SD	.99	1.28	1.16	.8	1.1	.69	.90

* Grouws (1996) and Star (2005) originally assigned lower numbers to reform-oriented responses. These mean scores have been adjusted to match this study.

Table 8. Cronbach's α reliability scores for the seven scales of the Conceptions of Mathematics Inventory (CMI).

	This Study		Star (2005)		Walker (1999)			
					May		January	
	N	α	*N*	α	*N*	α	*N*	α
Composition	92	.42	134	.29	92	.45	92	.47
Structure	99	.65	134	.57	92	.63	92	.59
Status	96	.51	134	.52	92	.65	92	.75
Doing	99	.37	134	.43	92	.49	92	.45
Validating	95	.55	134	.36	92	.58	92	.65
Learning	95	.30	134	.26	92	.49	92	.63
Usefulness	96	.91	134	.87	92	.91	92	.90

CMI responses were grouped by textbook (*CPMP* vs. *Glencoe*), teaching practice (*reform* vs. *traditional*), gender (*female* vs. *male*), and intended major (*math* vs. *non-math*), and two-tailed t tests of significance were performed on the mean scores of each CMI scale and individual item. In addition, responses were grouped using combinations of variables, such as gender and textbook, and one-way ANOVA and Tukey's HSD tests of significance were performed on the mean scores. Significant differences are reported in section 5.2.

Pearson *r* values were computed for each scale and individual item of the CMI to measure correlations between CMI responses and other variables, such as parents' level of education. Results for each scale and significant results for individual items are reported in section 5.3.

4.7. Summary of the Methodology

To summarize the previous explanation, this study used the CMI to measure the epistemological beliefs of mathematics for students taught with either a reform-oriented (CPMP) or a traditional (Glencoe Mathematics) curriculum in four rural Maine high schools. Based on lessons learned from previous research, teaching observations, teacher questionnaires, and informal interviews were used to characterize the teaching practices in each of the schools. The next chapter presents the results obtained from those methods.

Chapter 5

RESULTS

As stated in Chapter 1, the study reported here examined whether students' epistemological beliefs of mathematics differ when taught using traditional versus reform-oriented curricula and teaching practices. Other student variables were also considered, including gender, expected grade in current mathematics course, cumulative GPA, parents' level of education, and planned college major. This chapter reports the results as measured by the CMI, and is divided into three sections. The first section provides an overview of the students' beliefs of mathematics in terms of response patterns for the CMI. The second section reports significant differences by each of the seven CMI scales and items described in section 4.4.1. The third section reports significant correlations by each CMI scale and by individual item for each CMI scale. The reader is strongly advised to review the description of the CMI in section 4.4.1 before reading this chapter.

The CMI was completed by 102 11^{th}-grade students in 4 participating schools for this study. After analyzing the data as described in section 4.6, over 700 pages of SPSS reports were generated; obviously, it is impractical to present all results in this report. In general, only statistically significant results are presented in this chapter. An alpha level of .05 was used for all statistical tests.

Before reading this chapter, it is important to be aware of two conventions used to report results. First, responses for each CMI item were scaled so that a score of six indicates strong agreement with the positive pole of the CMI scale; the higher the number, the more reform-oriented the response. Second, schools are identified throughout by the textbook used (*CPMP* or *Glencoe*) and the observed teaching practices (*reform* or *traditional*) as discussed in section 4.2.1. For example, the school using Glencoe Mathematics combined with reform-oriented teaching practices is referred to as *Glencoe/Reform*.

5.1. Overview of Students' Beliefs of Mathematics

Before exploring significant differences and correlations found for the CMI, it is useful to consider the overall response patterns. Mean scores and standard deviations on CMI Scales are presented by gender (see Table 9), textbook (see Table 10), and school (see Table 11). The mean scores for each CMI scale range from 3.53 to 4.57. The strongest responses were in the Usefulness, Doing, and Structure scales, while the weakest responses were in the Composition scale. Other researchers have reported similar results (Walker, 1999; Star & Hoffmann, 2005).

Histograms indicating the proportions of responses for each CMI scale are presented in Figure 11 through Figure 17. In those figures, the proportions were calculated by dividing the number of responses that were assigned each score by the total number of responses. For example, the highest proportion presented in Figure 11 indicates that for the CPMP/Traditional school, 31% of the responses to items in the Composition scale were assigned a score of 4. (Remember that half of the items are

Table 9. Mean scores and standard deviations on Conceptions of Mathematics Inventory (CMI) scales by gender.

		Male (*n*=49)	Female (*n*=53)	All (*N*=102)
Composition	Mean	3.55	3.51	3.53
	SD	.65	.65	.65
Structure	Mean	4.38	4.51	4.45
	SD	.78	.72	.75
Status	Mean	3.95	4.01	3.98
	SD	.63	.76	.70
Doing	Mean	4.41	4.59	4.51
	SD	.56	.60	.59
Validating	Mean	3.94	4.04	3.99
	SD	.67	.70	.68
Learning	Mean	3.83	3.97	3.90
	SD	.50	.54	.52
Usefulness	Mean	4.76	4.39	4.57
	SD	.99	1.28	1.16

Table 10. Mean scores and standard deviations on Conceptions of Mathematics Inventory (CMI) scales by textbook.

		CPMP (*n*=55)	Glencoe (*n*=47)	All (*N*=102)
Composition	Mean	3.54	3.52	3.53
	SD	.70	.59	.65
Structure	Mean	4.31	4.62	4.45
	SD	.70	.77	.75
Status	Mean	3.98	3.98	3.98
	SD	.72	.68	.70
Doing	Mean	4.33	4.71	4.51
	SD	.61	.48	.59
Validating	Mean	3.89	4.11	3.99
	SD	.73	.60	.68
Learning	Mean	3.85	3.97	3.90
	SD	.54	.51	.52
Usefulness	Mean	4.43	4.72	4.57
	SD	1.14	1.17	1.16

Table 11. Mean scores and standard deviations on Conceptions of Mathematics Inventory (CMI) scales by school.

		CPMP/Trad. (*n*=11)	CPMP/Reform (*n*=44)	Glencoe/Reform (*n*=21)	Glencoe/Trad. (*n*=26)	All (*N*=102)
Composition	Mean	3.56	3.54	3.51	3.52	3.53
	SD	.72	.70	.67	.53	.65
Structure	Mean	4.56	4.24	4.97	4.34	4.45
	SD	.63	.71	.65	.75	.75
Status	Mean	3.95	3.98	4.05	3.93	3.98
	SD	.61	.75	.61	.74	.70
Doing	Mean	4.52	4.28	4.79	4.65	4.51
	SD	.57	.62	.50	.47	.59
Validating	Mean	4.11	3.83	4.29	3.97	3.99
	SD	.79	.71	.52	.64	.68
Learning	Mean	4.15	3.77	4.08	3.87	3.90
	SD	.37	.55	.56	.45	.52
Usefulness	Mean	4.86	4.32	5.27	4.27	4.57
	SD	.85	1.19	.67	1.30	1.16

phrased negatively and were scaled accordingly.) The total of all proportions for each school is 1.0. Note that the scales are different for some of the figures.

In general, the distribution shapes are approximately the same for each school and are negatively skewed, indicating high frequencies of strong responses. Some distributions are extremely negatively skewed, such as the distribution representing the Usefulness scale for the Glencoe/Reform school; in that case, over 50% of responses for items in the Usefulness scale were assigned a score of 6. There do not appear to be any bimodal distributions of any concern. Walker (1999) suggested that a strong negative skew for a scale may indicate that the positive beliefs in the scale were held more strongly than those in other scales; this would indicate that the students in this study held stronger beliefs in the Usefulness, Doing, and Structure scales than in the other scales.

Figure 11. Proportions of responses for CMI Composition scale by school.

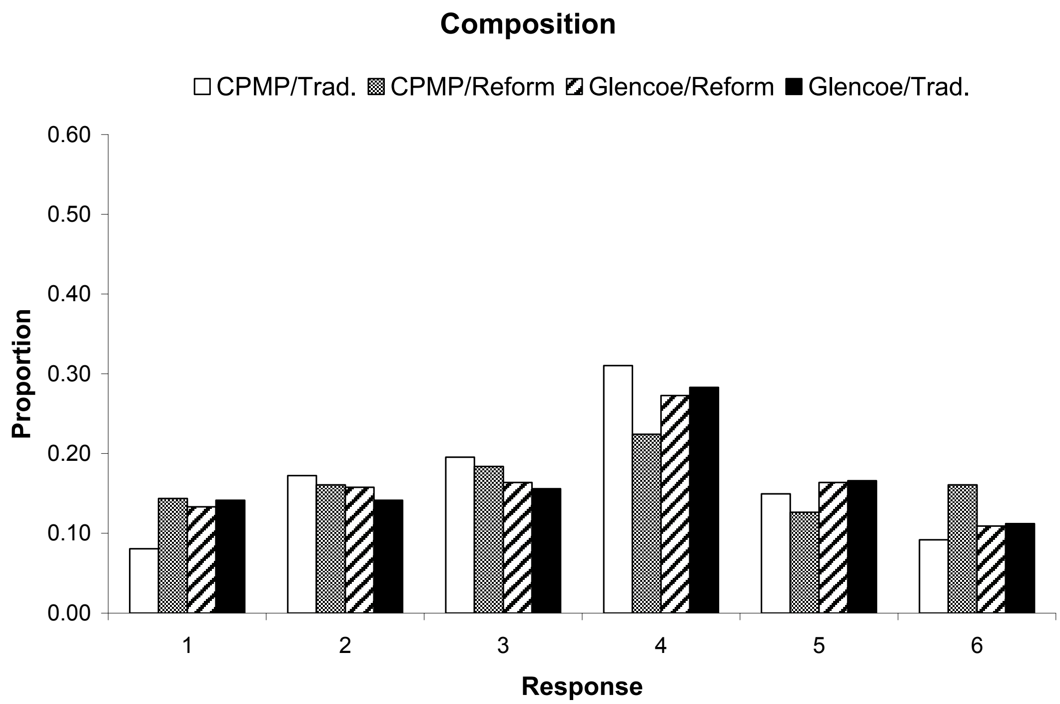


Figure 12. Proportions of responses for CMI Structure scale by school.

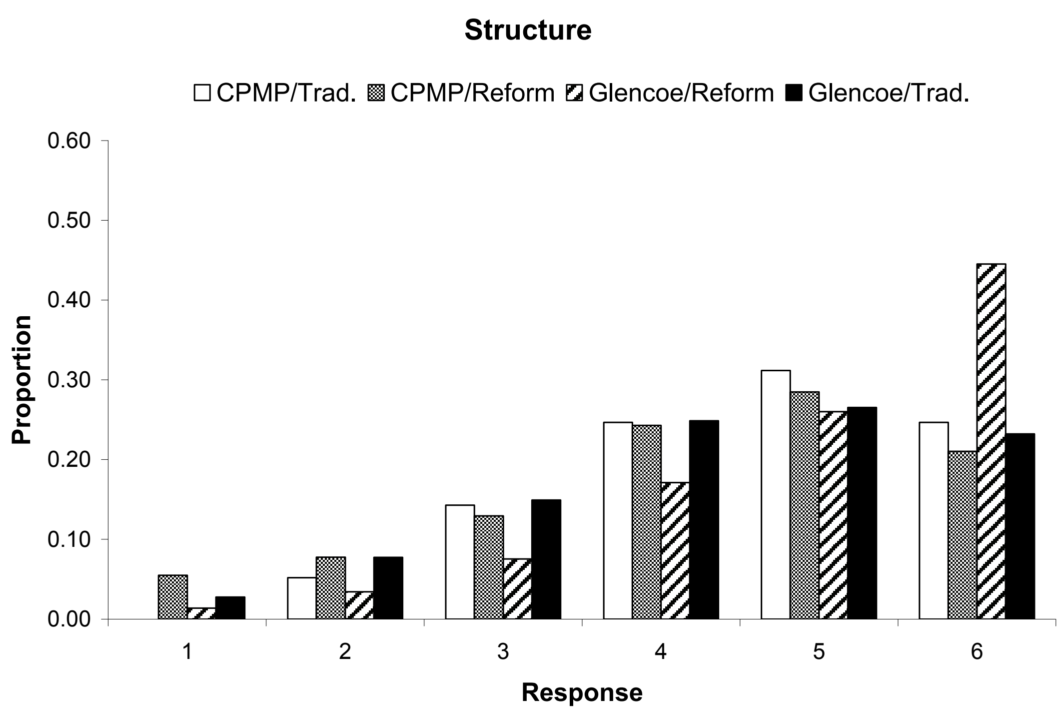


Figure 13. Proportions of responses for CMI Status scale by school.

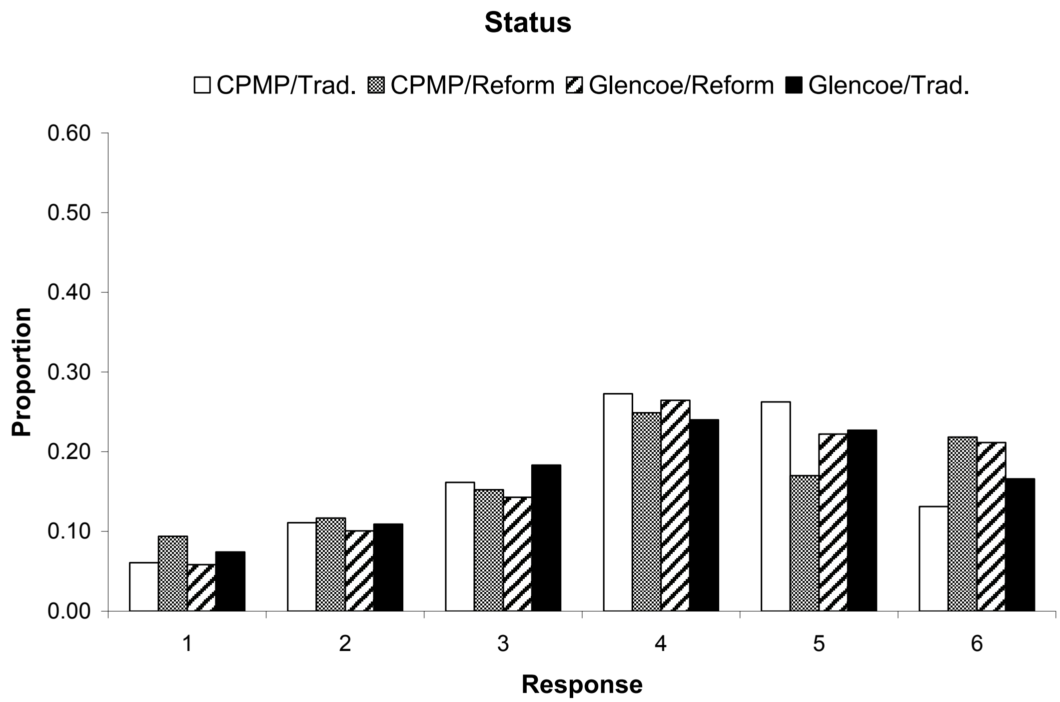


Figure 14. Proportions of responses for CMI Doing scale by school.

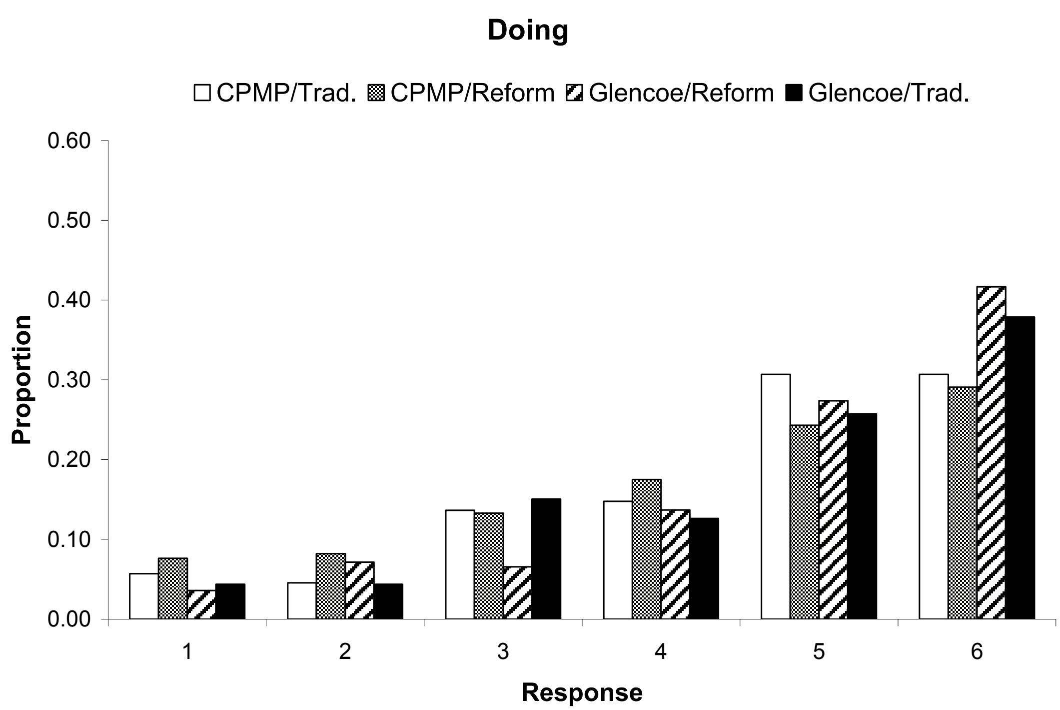


Figure 15. Proportions of responses for CMI Validating scale by school.

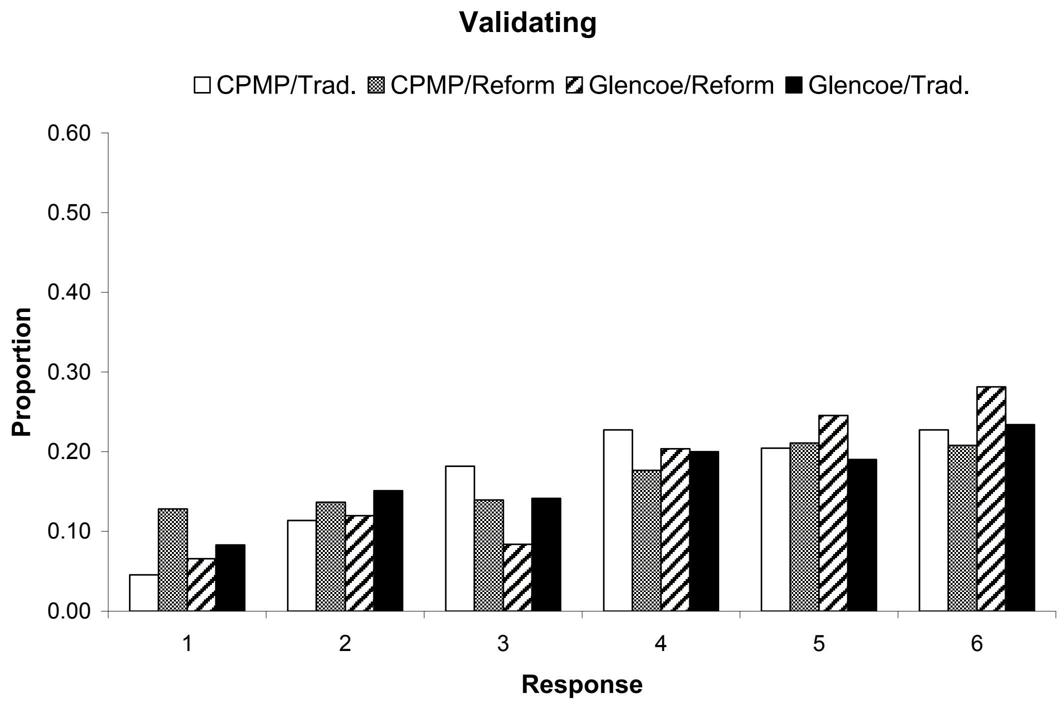


Figure 16. Proportions of responses for CMI Learning scale by school.

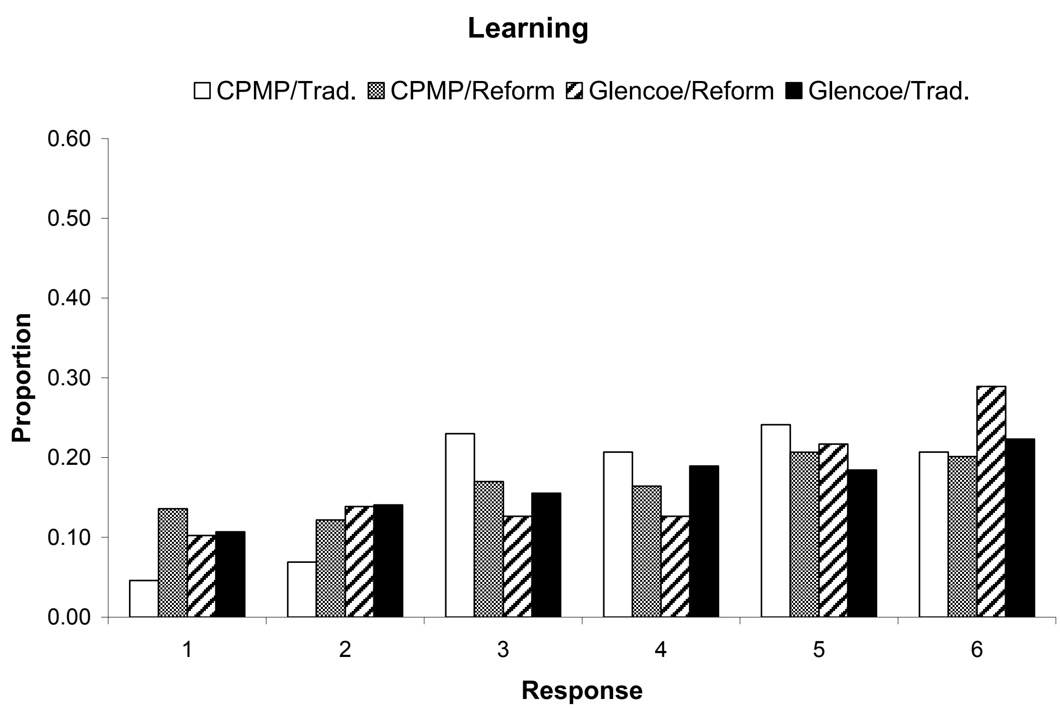
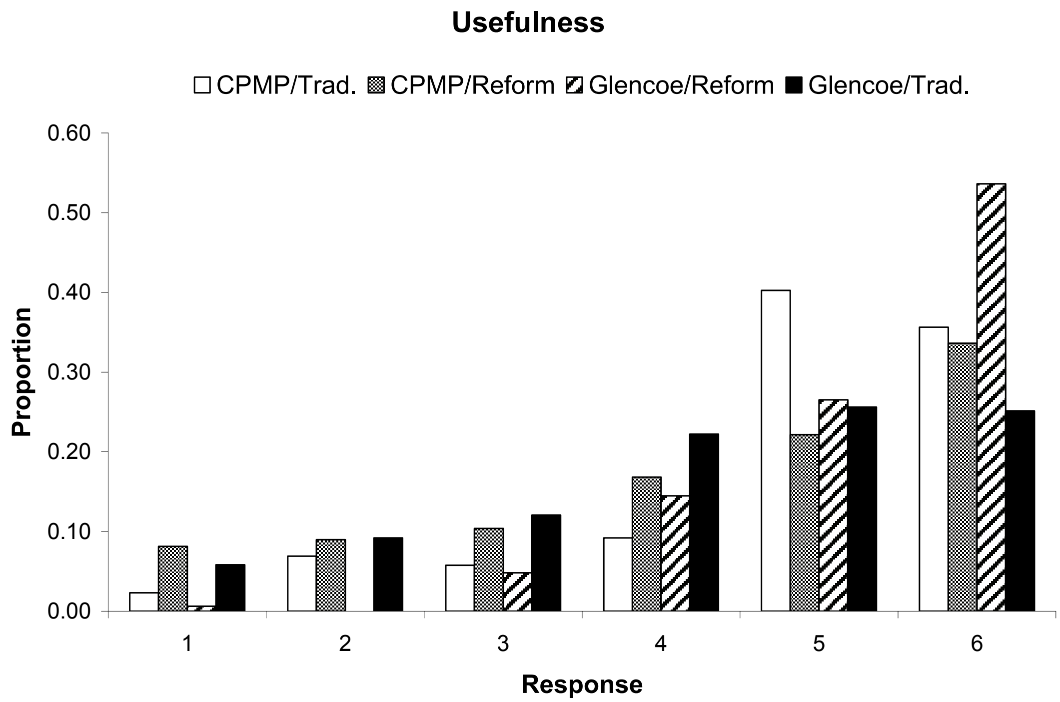


Figure 17. Proportions of responses for CMI Usefulness scale by school.



5.2. Significant Differences for CMI Scales and Items

As discussed in section 4.6, CMI responses were grouped by textbook (*CPMP* vs. *Glencoe*), teaching practice (*reform* vs. *traditional*), gender (*female* vs. *male*), and intended major (*math* vs. *non-math*), and two-tailed t tests of significance were performed on the mean scores of each CMI scale and individual item. In addition, responses were grouped using combinations of variables, such as textbook and gender, and one-way ANOVA and Tukey's HSD tests of significance were performed on those mean scores. This section presents all significant differences found for each CMI scale and individual item.

5.2.1. CMI Scales

Results of two-tailed *t* tests and one-way ANOVA indicate significantly different mean responses for the Structure, Doing, and Usefulness scales of the CMI (see Table 12). There were no significant differences for the Composition, Status, Validating, and Learning scales; differences in mean responses for individual items within those scales are discussed later.

For the Structure, Doing, and Usefulness scales, mean responses for Glencoe students were generally higher than mean responses for CPMP students. The Glencoe/Reform students' mean scores were generally higher, most noticeably for female students, while CPMP/Reform students' mean scores were generally lower. Students who indicated that they plan to major in a mathematics-related field had a high mean response for Usefulness scale.

5.2.2. Composition Items

Although the mean responses for the Composition scale as a whole did not differ, two differences were found for individual items (see Table 13). Male students were more likely than females to agree with the statement, "While formulas are important in mathematics, the ideas they represent are more useful." Glencoe students were more likely than CPMP students to disagree with the negatively-phrased statement, "Learning computational skills, like addition and multiplication, is more important than learning to solve problems."

Table 12. Significant differences for each Conceptions of Mathematics Inventory (CMI) scale.

CMI Scale	Variable(s)	Sig.	Group	*N*	Mean	*SD*
Composition	*No significant differences.*	–	–	–	–	–
Structure	Textbook	.034*	CPMP	55	4.31	.70
			Glencoe	47	4.62	.77
	School	.001**	CPMP/Reform	44	4.24	.71
			Glencoe/Reform	21	4.97	.65
	School	.015*	Glencoe/Reform	21	4.97	.65
			Glencoe/Trad.	26	4.34	.75
	Textbook and Gender	.040*	CPMP Female	27	4.25	.65
			Glencoe Female	26	4.79	.69
	School and Gender	.042*	CPMP/Reform Female	20	4.22	.66
			Glencoe/Reform Female	12	5.02	.66
	School and Gender	.050*	CPMP/Reform Male	24	4.26	.77
			Glencoe/Reform Female	12	5.02	.66
	School and Gender	.019*	Glencoe/Reform Female	12	5.02	.66
			Glencoe/Trad. Male	12	4.05	.76
Status	*No significant differences.*	–	–	–	–	–
Doing	Textbook	.001**	CPMP	55	4.33	.61
			Glencoe	47	4.71	.48
	School	.004**	CPMP/Reform	44	4.28	.62
			Glencoe/Reform	21	4.79	.50
	School	.042*	CPMP/Reform	44	4.28	.62
			Glencoe/Trad.	26	4.65	.47
	Textbook and Gender	.003**	CPMP Male	28	4.31	.61
			Glencoe Female	26	4.83	.48
	Textbook and Gender	.011*	CPMP Female	27	4.36	.63
			Glencoe Female	26	4.83	.48
	School and Gender	.037*	CPMP/Reform Male	24	4.26	.63
			Glencoe/Reform Female	12	4.90	.45
Validating	*No significant differences.*	–	–	–	–	–
Learning	*No significant differences.*	–	–		–	
Usefulness	School	.009**	CPMP/Reform	44	4.33	1.19
			Glencoe/Reform	21	5.27	.67
	School	.014*	Glencoe/Reform	21	5.27	.67
			Glencoe/Trad.	26	4.28	1.30
	School and Gender	.010*	Glencoe/Reform Female	12	5.31	.64
			Glencoe/Trad. Female	14	3.76	1.37
	School and Gender	.042*	Glencoe/Reform Male	9	5.22	.75
			Glencoe/Trad. Female	14	3.76	1.37
	Math-related Major?	.011*	Yes	27	5.07	.72
			No	35	4.35	1.27

**. The mean difference is significant at the 0.01 level (2-tailed).
*. The mean difference is significant at the 0.05 level (2-tailed).

Table 13. Significant differences for Composition scale items.

	CMI Item	Variable(s)	Sig.	Group	*N*	Mean	*SD*
9	While formulas are important in mathematics, the ideas they represent are more useful.	Gender	.029*	Female Male	53 47	4.28 4.81	1.25 1.12
33[N]	Learning computational skills, like addition and multiplication, is more important than learning to solve problems.	Textbook	0.47*	CPMP Glencoe	52 47	3.13 3.72	1.60 1.28

*. The mean difference is significant at the 0.05 level (2-tailed).
[N]. The item is phrased negatively.

5.2.3. Structure Items

While there were general differences in mean responses for the Structure scale, it is also useful to look at the individual item differences (see Table 14). For example, it appears that male students in the Glencoe/Traditional school had lower mean responses than male students in both the Glencoe/Reform and CPMP/Traditional schools for the statement, "Diagrams and graphs have little to do with other things in mathematics like operations and equations." Similar results were found for the statement, "Finding solutions to one type of mathematics problem cannot help you solve other types of problems."

Two items indicate that Glencoe students may be more likely than CPMP students to view mathematical concepts as connected: (a) Glencoe students were more likely than CPMP students to agree with the statement, "Most mathematical ideas are related to one another," and (b) Glencoe students were more likely than CPMP students to disagree with the negatively-phrased statement, "Mathematics consists of many unrelated topics."

Table 14. Significant differences for Structure scale items.

	CMI Item	Variable(s)	Sig.	Group	*N*	Mean	*SD*
7[N]	Diagrams and graphs have little to do with other things in mathematics like operations and equations.	School	.018*	Glencoe/Reform	21	4.90	1.09
				Glencoe/Trad.	26	3.77	1.45
		School and Gender	.006**	Glencoe/Reform Male	9	5.11	1.36
				Glencoe/Trad. Male	12	3.00	1.54
		School and Gender	.020*	Glencoe/Reform Female	12	4.75	.866
				Glencoe/Trad. Male	12	3.00	1.54
		School and Gender	.049*	CPMP/Trad. Male	4	5.25	.957
				Glencoe/Trad. Male	12	3.00	1.54
19[N]	Finding solutions to one type of mathematics problem cannot help you solve other types of problems.	School	.036*	Glencoe/Reform	21	5.10	1.45
				Glencoe/Trad.	26	3.88	1.66
		School and Gender	.024*	Glencoe/Reform Male	9	5.56	1.33
				Glencoe/Trad. Male	12	3.33	1.78
		Math-related Major?	.016*	Yes	27	4.96	1.22
				No	35	4.00	1.70
31[N]	There is little in common between the different mathematical topics you have studied, like measurement and fractions.	Textbook and Gender	.036*	CPMP Female	27	4.00	1.07
				Glencoe Female	26	5.00	1.27
37	Concepts learned in one mathematics class can help you understand material in the next mathematics class.	School	.012*	CPMP/Reform	43	5.05	.98
				Glencoe/Reform	21	5.81	.40
		School	.036*	Glencoe/Reform	21	5.81	.40
				Glencoe/Trad.	26	5.08	1.09
41[N]	Mathematics consists of many unrelated topics.	Textbook	.049*	CPMP	54	3.80	1.63
				Glencoe	47	4.38	1.28
50	Most mathematical ideas are related to one another.	Textbook	.040*	CPMP	54	4.30	1.33
				Glencoe	46	4.80	1.07

*. The mean difference is significant at the 0.05 level (2-tailed).
**. The mean difference is significant at the 0.01 level (2-tailed).
[N]. The item is phrased negatively.

5.2.4. Status Items

The mean responses for the Status scale as a whole did not differ, but there were two items that differed significantly by gender (see Table 15). Male students were more likely than female students to agree with the statement, "New mathematics is always being invented," while female students were more likely than male students to disagree with the negatively-phrased statement, “Mathematics today is the same as it was when your parents were growing up.”

Students who expected to major in a mathematics-related field were more likely to agree with the statement, “Sometimes when you learn new mathematics, you have to change ideas you have previously learned.”

Table 15. Significant differences for Status scale items.

	CMI Item	Variable(s)	Sig.	Group	*N*	Mean	*SD*
11	New mathematics is always being invented	Gender	.003**	Female	51	3.49	1.32
				Male	47	4.28	1.26
42	Sometimes when you learn new mathematics, you have to change ideas you have previously learned.	Math-related Major?	.043*	Yes	27	3.30	1.44
				No	35	4.00	1.24
44[N]	Mathematics today is the same as it was when your parents were growing up.	Gender	.020*	Female	52	5.08	1.27
				Male	48	4.44	1.43

*. The mean difference is significant at the 0.05 level (2-tailed).
**. The mean difference is significant at the 0.01 level (2-tailed).
[N]. The item is phrased negatively.

5.2.5. Doing Items

Although the comparison of mean responses for the Doing scale as a whole indicated that Glencoe/Reform students generally had higher responses than other schools, the differences at the item level were only significant at the textbook level (see Table 16). For four of the eight statements in the Doing scale, Glencoe students were more likely than CPMP students to view mathematics in terms of sense-making. For example, Glencoe students were more likely than CPMP students to disagree with the negatively-phrased statement, “One can be quite successful at doing mathematics without understanding it.”

Table 16. Significant differences for Doing scale items.

	CMI Item	Variable(s)	Sig.	Group	*N*	Mean	*SD*
16	When working mathematics problems, it is important that what you are doing makes sense to you.	Textbook	.039*	CPMP Glencoe	54 47	5.28 5.64	1.07 .53
32	Understanding the statements a person makes is an important part of mathematics.	Textbook	.036*	CPMP Glencoe	54 47	4.50 4.96	1.27 .81
48[N]	One can be quite successful at doing mathematics without understanding it.	Textbook	.018*	CPMP Glencoe	54 47	4.06 4.74	1.49 1.38
56	Solving a problem in mathematics is more a matter of understanding than remembering.	Textbook	.031*	CPMP Glencoe	54 46	4.28 4.85	1.41 1.15

*. The mean difference is significant at the 0.05 level (2-tailed).
[N]. The item is phrased negatively.

5.2.6. Validating Items

Although the mean responses for the Validating scale as a whole did not differ, one item was found to differ by gender: female Glencoe/Reform students were more likely than CPMP/Reform students to agree with the statement, "When one's method of solving a mathematics problem is different from the instructor's method, both methods can be correct" (see Table 17).

Table 17. Significant differences for Validating scale items.

	CMI Item	Variable(s)	Sig.	Group	*N*	Mean	*SD*
52	When one's method of solving a mathematics problem is different from the instructor's method, both methods can be correct.	Textbook	.013*	CPMP Glencoe	55 46	4.75 5.30	1.22 .96
		School	.019*	CPMP/Reform Glencoe/Reform	44 21	4.57 5.43	1.25 .87
		School and Gender	.043*	CPMP/Reform Female Glencoe/Reform Female	20 12	4.25 5.50	1.52 .80

*. The mean difference is significant at the 0.05 level (2-tailed).

5.2.7. Learning Items

Mean responses for the Learning scale as a whole did not differ, but differences were found for two items (see Table 18). First, Glencoe/Reform students were more likely than CPMP/Reform students to agree with the statement, "When learning mathematics, it is helpful to analyze your mistakes." Second, female students were more likely than male students to disagree with the negatively-phrased statement, "Asking questions in mathematics class means you didn't listen to the instructor well enough." Mean responses for male students taught using reform-oriented teaching practices were generally lower than for females, particularly in the CPMP/Reform school.

Table 18. Significant differences for Learning scale items.

	CMI Item	Variable(s)	Sig.	Group	*N*	Mean	*SD*
22	When learning mathematics, it is helpful to analyze your mistakes.	School	.027*	CPMP/Reform	43	5.02	1.08
				Glencoe/Reform	21	5.71	.46
30[N]	Asking questions in mathematics class means you didn't listen to the instructor well enough.	Gender	.001**	Female	53	5.74	.56
				Male	47	4.98	1.48
		Textbook and Gender	.003**	CPMP Male	26	4.73	1.66
				Glencoe Female	26	5.81	.63
		Textbook and Gender	.012*	CPMP Male	26	4.73	1.66
				CPMP Female	27	5.67	.48
		Teaching Practice and Gender	.005**	Reform Male	31	4.68	1.60
				Trad. Female	21	5.71	.72
		Teaching Practice and Gender	.001**	Reform Female	32	5.75	.44
				Reform Male	31	4.68	1.60
		Teaching Practice and Gender	.040*	Reform Male	31	4.68	1.60
				Trad. Male	16	5.56	1.03
		School and Gender	.009**	CPMP/Reform Male	22	4.50	1.71
				Glencoe/Reform Female	12	5.92	.29
		School and Gender	.017*	CPMP/Reform Female	20	5.65	.49
				CPMP/Reform Male	22	4.50	1.71
		School and Gender	.027*	CPMP Reform Male	22	4.50	1.71
				Glencoe/Trad. Female	14	5.71	.83

*. The mean difference is significant at the 0.05 level (2-tailed).
**. The mean difference is significant at the 0.01 level (2-tailed).
[N]. The item is phrased negatively.

5.2.8. Usefulness Items

Of the 18 items with differences in mean responses found for individual CMI items, 7 are included in the Usefulness scale (see Table 19). In general, students in the

Table 19. Significant differences for Usefulness scale items.

	CMI Item	Variable(s)	Sig.	Group	*N*	Mean	*SD*
6	Students need mathematics for their future work.	School	.024*	CPMP/Reform	43	4.28	1.42
				Glencoe/Reform	20	5.30	.92
		School	.044*	Glencoe/Reform	20	5.30	.92
				Glencoe/Trad.	26	4.27	1.34
		Math-related Major?	.001**	Yes	27	5.26	.76
				No	34	4.15	1.42
20	Mathematics is a worthwhile subject for students.	School	.002**	CPMP/Reform	44	4.09	1.72
				Glencoe/Reform	20	5.55	.89
		School	.010*	Glencoe/Reform	20	5.55	.89
				Glencoe/Trad.	26	4.15	1.49
		School and Gender	.033*	Glencoe/Reform Female	11	5.64	.81
				Glencoe/Trad. Female	14	3.71	1.64
		School and Gender	.044*	CPMP/Reform Female	20	3.90	1.80
				Glencoe/Reform Female	11	5.64	.81
23^{N}	Taking mathematics is a waste of time for students.	Textbook	.040*	CPMP	55	4.31	1.86
				Glencoe	47	5.00	1.43
		School	.001**	CPMP/Reform	44	4.00	1.87
				Glencoe/Reform	21	5.62	.81
		School	.023*	CPMP/Reform	44	4.00	1.87
				CPMP/Trad.	11	5.55	1.21
		School and Gender	.049*	CPMP/Reform Male	24	3.92	1.86
				Glencoe/Reform Female	12	5.67	.65
		Math-related Major?	.003**	Yes	27	5.41	1.15
				No	35	4.29	1.60
34	Knowing mathematics will help students earn a living.	Gender	.012*	Female	53	4.28	1.42
				Male	49	4.94	1.14
		Textbook and Gender	.027*	CPMP Female	27	4.07	1.44
				Glencoe Male	21	5.14	.79
36^{N}	Mathematics will not be important to students in their life's work.	School	.031*	CPMP/Reform	44	4.45	1.56
				Glencoe/Reform	21	5.48	.68
		School	.040*	Glencoe/Reform	21	5.48	.68
				Glencoe/Trad.	26	4.38	1.50
		School and Gender	.033*	Glencoe/Reform Female	12	5.58	.67
				Glencoe/Trad. Female	14	3.86	1.70
		Math-related Major?	.004**	Yes	27	5.33	1.11
				No	35	4.29	1.51
46	Students will use mathematics in many ways as adults.	Teaching Practice and Gender	.030*	Reform Male	31	4.84	1.19
				Trad. Female	21	3.81	1.37
		Teaching Practice and Gender	.043*	Reform Female	32	4.78	1.29
				Trad. Female	21	3.81	1.37
		School and Gender	.044*	Glencoe/Reform Female	12	5.17	1.03
				Glencoe/Trad. Female	14	3.57	1.45
53^{N}	Students should expect to have little use for mathematics when they get out of school.	Teaching Practice and Gender	.038*	Trad. Female	20	3.75	1.80
				Trad. Male	16	5.19	.75

*. The mean difference is significant at the 0.05 level (2-tailed).
**. The mean difference is significant at the 0.01 level (2-tailed).
[N]. The item is phrased negatively.

Glencoe/Reform school had the higher mean responses, and female students taught with reform-oriented teaching practices had higher mean responses than traditional female students. For example, female students taught using reform-oriented teaching practices were more likely than traditional female students to agree with the statement, "Students will use mathematics in many ways as adults." Female students in the Glencoe/Reform school were more likely than those in the Glencoe/Traditional school to agree with the statement, "Mathematics is a worthwhile subject for students."

5.3. Significant Correlations for CMI Scales and Items

As discussed in section 4.6, Pearson *r* values were computed for each CMI scale and individual item to find correlations with students' expected grade in current mathematics course, cumulative GPA, and parents' level of education. This section presents results for each CMI scale and individual item within those scales.

Responses for all CMI scales except the Status and Doing scales were positively correlated with students' expected grade in mathematics. Correlation was found for individual items within all seven CMI scales, including the Status and Doing scales. Successful students disagreed with statements such as, "Diagrams and graphs have little to do with other things in mathematics like operations and equations," "Finding solutions to one type of mathematics problem cannot help you solve other types of problems," "In mathematics, the instructor has the answer and it is the student's job to figure it out," and "Learning mathematics involves memorizing information presented to you."

Correlation with students' cumulative GPA was not as strong; however, many students indicated during the administration of the Student Mathematics Questionnaire that they did not know how to compute GPA, and about half of the students responded to the GPA item.

The Structure and Usefulness scales were positively correlated with parents' level of education, and two individual items in other scales were positively correlated with with parents' level of education. On the whole, responses for the Usefulness scale were most correlated with parents' level of education. For example, students whose parents had a high level of education were more likely to disagree with the negatively-phrased statement, "Mathematics has very little to do with students' lives."

Table 20. Significant correlations for each Conceptions of Mathematics Inventory (CMI) scale.

CMI Scale		Expected grade in current math course	Cumulative GPA	Parents' level of education
Composition	Pearson *r*	.282**	.236	-.035
	Sig.	.006	.083	.738
	N	94	55	96
Structure	Pearson *r*	.340**	.235	.213*
	Sig.	.001	.084	.037
	N	94	55	96
Status	Pearson *r*	-.038	-.068	-.088
	Sig.	.713	.624	.391
	N	94	55	96
Doing	Pearson *r*	.192	.130	.063
	Sig.	.064	.342	.544
	N	94	55	96
Validating	Pearson *r*	.268**	.142	.038
	Sig.	.009	.303	.714
	N	94	55	96
Learning	Pearson *r*	.236*	.243	.003
	Sig.	.022	.074	.974
	N	94	55	96
Usefulness	Pearson *r*	.259*	.018	.238*
	Sig.	.012	.898	.020
	N	94	55	96

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Table 21. Significant correlations for Composition items.

			Expected grade in current math course	Cumulative GPA	Parents' level of education
1[N]	There is always a rule to follow when solving a mathematical problem.	Pearson *r*	.229*	–	–
		Sig.	.027		
		N	93		
17[N]	Mathematicians work with symbols rather than ideas.	Pearson *r*	.208*	–	–
		Sig.	.046		
		N	93		
33[N]	Learning computational skills, like addition and multiplication, is more important than learning to solve problems.	Pearson *r*	.217*	–	–
		Sig.	.037		
		N	92		
49[N]	The field of mathematics is for the most part made up of procedures and facts.	Pearson *r*	.256*	–	–
		Sig.	.014		
		N	91		

*. Correlation is significant at the 0.05 level (2-tailed).
[N]. The item is phrased negatively.

Table 22. Significant correlations for Structure items.

			Expected grade in current math course	Cumulative GPA	Parents' level of education
7[N]	Diagrams and graphs have little to do with other things in mathematics like operations and equations.	Pearson *r*	.405**	.284*	–
		Sig.	.000	.036	
		N	94	55	
19[N]	Finding solutions to one type of mathematics problem cannot help you solve other types of problems.	Pearson *r*	.284**	–	–
		Sig.	.006		
		N	94		
31[N]	There is little in common between the different mathematical topes you have studied, like measurement and fractions.	Pearson *r*	.254*	–	–
		Sig.	.014		
		N	93		
37	Concepts learned in one mathematics class can help you understand material in the next mathematics class.	Pearson *r*	.240*	–	–
		Sig.	.020		
		N	94		
41[N]	Mathematics consists of many unrelated topics.	Pearson *r*	–	–	.243*
		Sig.			.018
		N			95

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).
[N]. The item is phrased negatively.

Table 23. Significant correlations for Status items.

			Expected grade in current math course	Cumulative GPA	Parents' level of education
11	New mathematics is always being invented.	Pearson *r*	-.227*	-.323*	–
		Sig.	.030	.017	
		N	91	54	
35[N]	When you do an exploration in mathematics, you can only discover something already known.	Pearson *r*	.372**	.308*	–
		Sig.	.000	.023	
		N	92	54	
42	Sometimes when you learn new mathematics, you have to change ideas you have previously learned.	Pearson *r*	-.209		–
		Sig.	.043		
		N	94		
44[N]	Mathematics today is the same as when your parents were growing up.	Pearson *r*	–	–	-.259*
		Sig.			.011
		N			95

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).
[N]. The item is phrased negatively.

Table 24. Significant correlations for Doing items.

			Expected grade in current math course	Cumulative GPA	Parents' level of education
16	When working mathematics problems, it is important that what you are doing makes sense to you.	Pearson *r*	–	-.295*	–
		Sig.		.030	
		N		54	
56	Solving a problem in mathematics is more a matter of understanding than remembering.	Pearson *r*	.266*	–	–
		Sig.	.010		
		N	92		

*. Correlation is significant at the 0.05 level (2-tailed).

Table 25. Significant correlations for Validating items.

			Expected grade in current math course	Cumulative GPA	Parents' level of education
28[N]	You can only find out that an answer to a mathematics problem is wrong when it is different from the book's answer or when the instructor tells you.	Pearson *r*	.262*	–	–
		Sig.	.011		
		N	94		
45[N]	In mathematics, the instructor has the answer and it is the student's job to figure it out.	Pearson *r*	.322**	–	–
		Sig.	.002		
		N	93		
52	When one's method of solving a mathematics problem is different from the instructor's method, both methods can be correct.	Pearson *r*	.243*	–	–
		Sig.	.019		
		N	93		

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).
N. The item is phrased negatively.

Table 26. Significant correlations for Learning items.

			Expected grade in current math course	Cumulative GPA	Parents' level of education
14	Memorizing formulas and steps is not that helpful for learning how to solve mathematics problems.	Pearson *r*	–	–	-.205*
		Sig.			.046
		N			95
18[N]	Learning mathematics involves memorizing information presented to you.	Pearson *r*	.301**	–	–
		Sig.	.003		
		N	94		

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).
N. The item is phrased negatively.

Table 27. Significant correlations for Usefulness items.

			Expected grade in current math course	Cumulative GPA	Parents' level of education
6	Students need mathematics for their future work.	Pearson *r*	.253*	–	.214*
		Sig.	.015		.039
		N	91		93
12[N]	Mathematics has very little to do with students' lives.	Pearson *r*	.259*	–	.367**
		Sig.	.012		.000
		N	94		96
20	Mathematics is a worthwhile subject for students.	Pearson *r*	.212*	–	–
		Sig.	.041		
		N	93		
23[N]	Taking mathematics is a waste of time for students.	Pearson *r*	.296**	–	.214*
		Sig.	.004		.037
		N	94		96
53[N]	Students should expect to have little use for mathematics when they get out of high school.	Pearson *r*	–	–	.207*
		Sig.			.043
		N			96

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).
[N]. The item is phrased negatively.

5.4. Summary

The results of this study indicated that students' epistemological beliefs of mathematics differed for some CMI scales when different textbooks and teaching practices were used in the four participating schools. In general, students in the Glencoe/Reform school had the highest mean CMI responses, while students in the CPMP/Reform school had the lowest mean CMI responses. In fact, for all items analyzed and all possible ways of grouping students, only one case was found where a CPMP group had a higher mean response than a Glencoe group: male CPMP/Traditional students were more likely than male Glencoe/Traditional students to agree with the statement, "Diagrams and graphs have little to do with other things in mathematics like operations and equations."

Gender was a factor in some cases, and students with more reform-oriented views of mathematics expected higher grades in their mathematics courses. Parents' level of education was most positively correlated with the Usefulness scale.

The next chapter summarizes the results and discusses their implications.

Chapter 6

SUMMARY AND DISCUSSION

To aid the reader, this chapter begins by restating the research problem and the major methods used in the study. The results are then summarized and discussed.

6.1. Statement of the Problem

The general question this study attempted to answer was as follows: "Do high school students' epistemological beliefs of mathematics differ when using traditional versus reform-oriented curricula?" That general question subsumed the following related questions:

1. Are there differences related to teaching practices?
2. Are there differences related to demographic factors such as gender or parents' level of education?
3. Are there differences related to academic achievement?

6.2. Review of the Methodology

As explained in Chapter 4, this study was a cross-sectional correlation study designed to analyze the relationships between two curricula and the epistemological beliefs of mathematics held by students in four schools after studying three years of those curricula. One curriculum in this study was an NSF-funded, reform-oriented curriculum;

the other was a more popular traditional curriculum. Other variables, such as teaching practices and students' gender, were also considered.

The research perspective for this study was quantitative primary, qualitative first. The study began with a qualitative approach, using a series of informal interviews, classroom observations, and questionnaires to characterize the teaching practices occurring in the schools. That qualitative data on teaching practices was then used as a basis for collecting and interpreting the quantitative data (the primary method) on students' epistemological beliefs of mathematics.

The primary method used in this study was a questionnaire including items from the Conceptions of Mathematics Inventory (CMI) that was administered to 11^{th}-grade students in four rural Maine high schools to assess their beliefs of mathematics. Secondary methods used included classroom observations, questionnaires, and informal interviews to describe the level of reform-oriented teaching occurring in the schools. Teachers were observed using a variation of the Reformed Teaching Observation Protocol (RTOP).

6.3. Summary of the Results

The results of this study indicated that high school students who were taught with a traditional textbook, Glencoe Mathematics, expressed more reform-oriented epistemological beliefs of mathematics than students who were taught with a reform-oriented textbook, CPMP, for some scales of the CMI. Student responses on the CMI indicated that Glencoe Mathematics students were more likely than CPMP students to view the structure of mathematics as a coherent system of concepts, principles, and skills rather than as a collection of isolated pieces. Glencoe mathematics students were also more likely than CPMP students to view the process of doing mathematics as valuing, exploring, comprehending, and exploring concepts and principles rather than simply implementing procedures and finding results.

The use of reform-oriented teaching practices to deliver the curricula appeared to magnify the differences between Glencoe Mathematics and CPMP students' responses on the Structure, Doing, and Usefulness scales of the CMI. The mean responses on those scales were higher for Glencoe Mathematics students and lower for CPMP students, especially when the students were taught with reform-oriented teaching practices.

Some of the differences appeared to be gender-related. For example, female students who were taught using Glencoe Mathematics were much more likely to view mathematics as a useful endeavor if reform-oriented teaching practices were used; the difference was not significant for male students who were taught using Glencoe Mathematics. Female students were much more likely than male students to disagree with the negatively-phrased statement, "Asking questions in mathematics class means you didn't listen to the instructor well enough," while male students were more likely than female students to agree with the statement, "Knowing mathematics will help students earn a living."

Parents' level of education was positively correlated with students' mean responses for the Structure and Usefulness scales of the CMI. Although previous research has shown that some epistemological beliefs predict GPA (Schommer, 1993), students' self-reported cumulative GPA was not correlated with students' responses for any of the CMI scales. This may have been due to students' unfamiliarity with GPA (see section 5.3). Expected grade in current mathematics course was positively correlated with responses for all but the Status and Doing scales of the CMI.

Students who planned to major in a mathematics-related field were more likely to view mathematics as a useful endeavor, but did not exhibit different beliefs about mathematics in general.

6.4. Discussion of the Findings

Some researchers have expressed concerns about the reliability of the CMI (e.g., Star & Hoffmann, 2005) and whether it is even possible to assess students' beliefs about mathematics (e.g., Lester, 2002). Those concerns may be valid, but one finding of this study stands out: students who were taught using Glencoe Mathematics, a traditional textbook, consistently indicated more reform-oriented beliefs about mathematics than students who were taught using CPMP, a reform-oriented textbook. This finding contradicts previous research by Star and Hoffmann (2005).

It is not surprising that Glencoe Mathematics students who were taught using more reform-oriented teaching practices expressed more reform-oriented beliefs of mathematics than Glencoe Mathematics students who were taught using traditional teaching practices. However, the finding that CPMP students who were taught using reform-oriented teaching practices expressed the least reform-oriented beliefs of mathematics was unexpected. The goals stated by the CPMP authors are reform-oriented (see section 3.2), yet the expressed beliefs of mathematics for students who completed three years of CPMP appeared to be less reform-oriented, especially if they were taught using reform-oriented teaching practices.

Many factors other than the textbook and teaching practices used may have contributed to the results of this study. Subtle differences in school demographics, students' experiences in earlier mathematics courses, varying levels of administrative support for teachers, and other unknown factors may have influenced students' beliefs of mathematics in addition to the textbook or teaching practices used. For example, CPMP students in this study were clearly aware that they were being taught using a reform-oriented approach; that awareness may have caused some students to be less enthusiastic about the curriculum.

This study extends previous research on the feasibility of using the CMI to assess students' beliefs of mathematics (Grouws et al., 1996; Walker, 1999; Star & Hoffmann, 2005) by demonstrating the importance of determining what is actually happening in the classrooms. Teachers do not always implement curricula as intended by the developers, and teaching practices may actually influence students' beliefs of mathematics as much as the curricular materials used.

Beliefs about the nature of mathematics and learning mathematics influence how students engage in mathematical activity, and further research is needed to determine how reform-oriented curricula and teaching practices impact those beliefs. This research could involve (a) the development of more reliable instruments for assessing students' beliefs, (b) exploring factors outside the classroom, such as the beliefs of family members and society in general, and (c) exploring whether students' achievement is related to their beliefs of mathematics.

It would be a mistake to draw sweeping conclusions about students' epistemological beliefs of mathematics from a single study using a particular instrument or conceptual framework, especially with such a limited number of participants. Theoretical models of epistemological beliefs continue to evolve, and researchers continue to develop methods of assessing beliefs. It is possible that different results would be found if another instrument or framework were used. Some researchers (e.g., Schommer-Aikins & Easter, 2006) have suggested using combinations of frameworks to explore students' epistemological beliefs.

A single instrument cannot provide educators with definitive information about students' epistemological beliefs of mathematics, but this study used the CMI to demonstrate that some students expressed different beliefs about the structure and nature of mathematics in the four participating schools. It is unclear whether the responses on the CMI accurately reflect the students' beliefs about mathematics, but such information can help educators assess the impact of mathematics curricula and teaching practices in ways that standardized achievement tests do not.

A school system has failed if students emerge viewing mathematics as a static collection of isolated facts to be memorized and having little value in life after school. Although this study does not provide conclusive evidence about the impact of different curricula and teaching practices on students' epistemological beliefs of mathematics, the lessons learned from this study may help guide researchers when assessing the impact of reform-oriented curricula in the future.

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APPENDICES

Appendix A. Items in the Conceptions of Mathematics Inventory (CMI)

Composition

9.	While formulas are important in mathematics, the ideas they represent are useful.
25.	Computation and formulas are only a small part of mathematics.
39.	In mathematics there are many problems that can't be solved by following a given set of steps.
51.	Essential mathematical knowledge is primarily composed of ideas and concepts.
1^{N}.	There is always a rule to follow when solving a mathematical problem.
17^{N}.	Mathematicians work with symbols rather than ideas.
33^{N}.	Learning computational skills, like addition and multiplication, is more important than learning how to solve problems.
49^{N}.	The field of mathematics is for the most part made up of procedures and facts.

^{N}. Statement phrased negatively.

Structure

13*.	Often a single mathematical concept will explain the basis for a variety of formulas.
24.	Mathematics involves more thinking about relationships among things such as numbers, points, and lines than working with separate ideas.
37.	Concepts learned in one mathematics class can help you understand material in the next mathematics class.
50.	Most mathematical ideas are related to one another.
7^{N}.	Diagrams and graphs have little to do with other things in mathematics like operations and equations.
19^{N}.	Finding solutions to one type of mathematics problem cannot help you solve other types of problems.
31^{N}.	There is little in common between the different mathematical topics you have studied, like measurement and fractions.
41^{N}.	Mathematics consists of many unrelated topics.

^{N}. Statement phrased negatively.
*. Statement 13 was omitted in this study due to a typographical error.

Status

11.	New mathematics is always being invented.
27.	The field of mathematics is always growing and changing.
42.	Sometimes when you learn new mathematics, you have to change ideas you have previously learned.
54.	Students can make new mathematical discoveries, as well as study mathematicians' discoveries.
3^{N}.	When you learn something in mathematics, you know the mathematics learned will always stay the same.
21^{N}.	New discoveries are seldom made in mathematics.
35^{N}.	When you do and exploration in mathematics, you can only discover something already known.
44^{N}.	Mathematics today is the same as it was when you parents were growing up.

^{N}. Statement phrased negatively.

Doing

2.	Knowing why an answer is correct in mathematics is as important as getting a correct answer.
16.	When working mathematics problems, it is important that what you are doing makes sense to you.
32.	Understanding the statements a person makes is an important part of mathematics.
56.	Solving a problem in mathematics is more a matter of understanding than remembering.
8^N.	If you cannot solve a mathematics problem quickly, then spending more time on it won't help.
29^N.	Being able to use formulas well is enough to understand the mathematical concept behind the formula.
38^N.	If you knew every possible formula, then you could easily solve any mathematical problem.
48^N.	One can be quite successful at doing mathematics without understanding it.

^{N}. Statement phrased negatively.

Validating

10.	Justifying the statements a person makes is an important part of mathematics.
26.	It is important to convince yourself of the truth of a mathematical statement rather than to rely on the word of others.
40.	When two classmates don't agree on an answer, they can usually think through the problem together until they have a reason for what is correct.
52.	When one's method of solving a mathematics problem is different from the instructor's method, both methods can be correct.
5^N.	When two students don't agree on an answer in mathematics, they need to ask the teacher or check the book to see who is correct.
15^N.	You know something is true in mathematics when it is in a book or an instructor tells you.
28^N.	You can only find out that an answer to a mathematics problem is wrong when it is different from the book's answer or when the instructor tells you.
45^N.	In mathematics, the instructor has the answer and it is the student's job to figure it out.

^{N}. Statement phrased negatively.

Learning

14.	Memorizing formulas and steps is not that helpful for learning how to solve mathematical problems.
22.	When learning mathematics, it is helpful to analyze your mistakes.
43.	When you learn mathematics, it is essential to compare new ideas to mathematics you already know.
55.	Learning mathematics involves more thinking than remembering information.
4^N.	Learning to do mathematics problems is mostly a matter of memorizing the steps to follow.
18^N.	Learning mathematics involves memorizing information presented to you.
30^N.	Asking questions in mathematics class means you didn't listen to the instructor well enough.
47^N.	You can only learn mathematics when someone shows you how to work a problem.

^{N}. Statement phrased negatively.

Usefulness

6.	Students need mathematics for their future work.
20.	Mathematics is a worthwhile subject for students.
34.	Knowing mathematics will help students earn a living.
46.	Students will use mathematics in many ways as adults.
12^N.	Mathematics has very little to do with students' lives.
23^N.	Taking mathematics is a waste of time for students.
36^N.	Mathematics will not be important to students in their life's work.
53^N.	Students should expect to have little use for mathematics when they get out of school.

^{N}. Statement phrased negatively.

Appendix B. Teaching Observation Protocol (TOP) Results

Table 28. Teaching Observation Protocol (TOP) Results: Lesson Design and Implementation.

		School				
		CPMP/ Trad. (*n*=3)	CPMP/ Reform (*n*=6)	Glencoe/ Reform (*n*=6)	Glencoe/ Trad. (*n*=5)	Total (*N*=20)
1. The instructional strategies and activities respected students' prior knowledge and the preconceptions inherent therein.	Never Occurred					
	Rarely Occurred					
	Sometimes Occurred				1	1
	Descriptive	3	2	5	3	13
	Very Descriptive		4	1	1	6
2. The lesson was designed to engage students as members of a learning community.	Never Occurred					
	Rarely Occurred				2	2
	Sometimes Occurred	2	2	2	3	9
	Descriptive	1	2	2		5
	Very Descriptive		2	2		4
3. In this lesson, student exploration preceded formal presentation.	Never Occurred	1		2	5	8
	Rarely Occurred	2	2	1		5
	Sometimes Occurred		3	2		5
	Descriptive					
	Very Descriptive		1	1		2
4. This lesson encouraged students to seek and value alternative modes of investigation or of problem solving.	Never Occurred		1	1		2
	Rarely Occurred	2	1		2	5
	Sometimes Occurred	1	2	2	3	8
	Descriptive		1	3		4
	Very Descriptive		1			1
5. The focus and direction of the lesson was often determined by ideas originating with students.	Never Occurred		4	1		5
	Rarely Occurred	3	1	3	4	11
	Sometimes Occurred		1	2	1	4
	Descriptive					
	Very Descriptive					

Table 29. Teaching Observation Protocol (TOP) Results: Propositional Knowledge.

		School				
		CPMP/ Trad. (*n*=3)	CPMP/ Reform (*n*=6)	Glencoe/ Reform (*n*=6)	Glencoe/ Trad. (*n*=5)	Total (*N*=20)
6. The lesson involved fundamental concepts of the subject.	Never Occurred					
	Rarely Occurred					
	Sometimes Occurred	1			2	3
	Descriptive	2	1	2	2	7
	Very Descriptive		5	4	1	10
7. The lesson promoted strongly coherent conceptual understanding.	Never Occurred					
	Rarely Occurred		3		1	4
	Sometimes Occurred	3		2	3	8
	Descriptive		2	2	1	5
	Very Descriptive		1	2		3
8. The teacher had a solid grasp of the subject matter content inherent in the lesson.	Never Occurred					
	Rarely Occurred					
	Sometimes Occurred					
	Descriptive		1	1	1	3
	Very Descriptive	3	5	5	4	17
9. Elements of abstraction (i.e., symbolic representations, theory building) were encouraged when it was important to do so.	Never Occurred		2			2
	Rarely Occurred	1	1		1	3
	Sometimes Occurred	2		4	4	10
	Descriptive		1			1
	Very Descriptive		2	2		4
10. Connections with other content disciplines and/or other real world phenomena were explored and valued.	Never Occurred		1	3	4	8
	Rarely Occurred	1		1	1	3
	Sometimes Occurred	2	2	1		5
	Descriptive		2	1		3
	Very Descriptive		1			1

Table 30. Teaching Observation Protocol (TOP) Results: Procedural Knowledge.

			School				
			CPMP/ Trad. (*n*=3)	CPMP/ Reform (*n*=6)	Glencoe/ Reform (*n*=6)	Glencoe/ Trad. (*n*=5)	Total (*N*=20)
11.	Students used a variety of means (models, drawings, graphs, concrete materials, manipulatives, etc.,) to represent phenomena.	Never Occurred		2	1	1	4
		Rarely Occurred	1		1	2	4
		Sometimes Occurred	2	2	3	2	9
		Descriptive		1	1		2
		Very Descriptive		1			1
12.	Students made predictions, estimations, and/or hypotheses and devised means for testing them.	Never Occurred	1	3	3	4	11
		Rarely Occurred			1		1
		Sometimes Occurred	2	1	1		4
		Descriptive		1	1	1	3
		Very Descriptive		1			1
13.	Students were actively engaged in thought-provoking activity that often involved the critical assessment of procedures.	Never Occurred				1	1
		Rarely Occurred	2	2	2	4	10
		Sometimes Occurred	1	1	2		4
		Descriptive		2	2		4
		Very Descriptive		1			1
14.	Students were reflective about their learning.	Never Occurred				1	1
		Rarely Occurred	2	1	3	4	10
		Sometimes Occurred	1	2	1		4
		Descriptive		2	2		4
		Very Descriptive		1			1
15.	Intellectual rigor, constructive criticism, and the challenging of ideas were valued.	Never Occurred					
		Rarely Occurred	2	1	1	3	7
		Sometimes Occurred	1	2	2	2	7
		Descriptive		1	2		3
		Very Descriptive		2	1		3

Table 31. Teaching Observation Protocol (TOP) Results: Communicative Interactions.

			School				
			CPMP/ Trad. (*n*=3)	CPMP/ Reform (*n*=6)	Glencoe/ Reform (*n*=6)	Glencoe/ Trad. (*n*=5)	Total (*N*=20)
16.	Students were involved in the communication of their ideas to others using a variety of means and media.	Never Occurred			1	1	2
		Rarely Occurred	1	1	2	3	7
		Sometimes Occurred	2	2	3	1	8
		Descriptive		2			2
		Very Descriptive		1			1
17.	The teacher's questions triggered divergent modes of thinking.	Never Occurred					
		Rarely Occurred	2	2		5	9
		Sometimes Occurred	1	3	3		7
		Descriptive		1	3		4
		Very Descriptive					
18.	There was a high proportion of student talk and a significant amount of it occurred between and among students.	Never Occurred				1	1
		Rarely Occurred	1	3	1	3	8
		Sometimes Occurred	1	1	5	1	8
		Descriptive	1	2			3
		Very Descriptive					
19.	Student questions and comments often determined the focus and direction of classroom discourse.	Never Occurred					
		Rarely Occurred	3	2	3	4	12
		Sometimes Occurred		4	2		6
		Descriptive			1	1	2
		Very Descriptive					
20.	There was a climate of respect for what others had to say.	Never Occurred					
		Rarely Occurred					
		Sometimes Occurred					
		Descriptive		1	1	1	3
		Very Descriptive	3	5	5	4	17

Table 32. Teaching Observation Protocol (TOP) Results: Student/Teacher Relationships.

			School				
			CPMP/ Trad. (*n*=3)	CPMP/ Reform (*n*=6)	Glencoe/ Reform (*n*=6)	Glencoe/ Trad. (*n*=5)	Total (*N*=20)
21.	Active participation of students was encouraged and valued.	Never Occurred					
		Rarely Occurred				2	2
		Sometimes Occurred	2	1	1	3	7
		Descriptive	1	3	4		8
		Very Descriptive		2	1		3
7	Students were encouraged to generate conjectures, alternative solution strategies, and ways of interpreting evidence.	Never Occurred		1		2	3
		Rarely Occurred	2	1	2	2	7
		Sometimes Occurred	1	2	3	1	
		Descriptive		2	1		3
		Very Descriptive					
23.	In general the teacher was patient with students.	Never Occurred		1			1
		Rarely Occurred					
		Sometimes Occurred					
		Descriptive		2	2	1	5
		Very Descriptive	3	3	4	4	14
24.	The teacher acted as a resource person, working to support and enhance student investigations.	Never Occurred				1	1
		Rarely Occurred		3	2	4	9
		Sometimes Occurred	2		3		5
		Descriptive	1	2	1		4
		Very Descriptive		1			1
25.	The metaphor of "teacher as listener" was very characteristic of this classroom.	Never Occurred					
		Rarely Occurred		2	2	5	9
		Sometimes Occurred	3	2	4		9
		Descriptive		2			2
		Very Descriptive					

Appendix C. Teacher Background Questionnaire Results

Table 33. Teacher Background Questionnaire Results: Level of Preparedness to Teach Topics (Means).

(1='Not Adequately Prepared', 4='Very Well Prepared')

		School				
		CPMP/ Trad. (*n*=1)	CPMP/ Reform (*n*=2)	Glencoe/ Reform (*n*=3)	Glencoe/ Trad. (*n*=2)	Total (*N*=8)
a.	Estimation	4.0	3.5	4.0	4.0	3.87
b.	Measurement	4.0	4.0	4.0	4.0	4.00
c.	Pre-Algebra	4.0	4.0	4.0	4.0	4.00
d.	Algebra	4.0	4.0	4.0	4.0	4.00
e.	Patterns and relationships	4.0	4.0	4.0	3.5	3.88
f.	Geometry and spatial sense	4.0	3.5	4.0	4.0	3.87
g.	Functions (including trigonometric functions) and precalculus concepts	4.0	3.0	3.7	3.0	3.38
h.	Data collection and analysis	4.0	3.5	3.7	3.0	3.50
i.	Probability	2.0	3.0	3.3	3.0	3.00
j.	Statistics (e.g., hypothesis tests, curve fitting, and regression)	2.0	3.0	4.0	1.5	2.71
k.	Topics from discrete mathematics (e.g., combinatorics, graph theory, recursion)	3.0	3.0	3.3	2.5	3.00
l.	Calculus	4.0	2.5	3.0	2.5	2.88
m.	Technology (calculators, computers) in support of mathematics	4.0	3.0	4.0	2.5	3.38

Table 34. Teacher Background Questionnaire Results: Level of Preparedness to Guide Student Learning (Means).

(1='Not Adequately Prepared', 4='Very Well Prepared')

		School				
		CPMP/ Trad. (*n*=1)	CPMP/ Reform (*n*=2)	Glencoe/ Reform (*n*=3)	Glencoe/ Trad. (*n*=2)	Total (*N*=8)
a.	Problem solving	4.0	3.5	4.0	3.5	3.75
b.	Reasoning and proof	4.0	3.0	3.7	4.0	3.63
c.	Communication (written and oral)	3.0	3.0	3.7	4.0	3.63
d.	Connections within mathematics and from mathematics to other disciplines	–	3.0	3.3	3.0	3.14
e.	Multiple representations (e.g., concrete models, and numeric, graphical, symbolic, and geometric representations)	3.0	3.0	3.7	3.0	3.25

Table 35. Teacher Background Questionnaire Results: Beliefs (Means).
(1='Strongly Disagree', 5='Strongly Agree')

	School				Total (*N*=8)
	CPMP/ Trad. (*n*=1)	CPMP/ Reform (*n*=2)	Glencoe/ Reform (*n*=3)	Glencoe/ Trad. (*n*=2)	
a. Students generally learn mathematics best in classes with students of similar abilities.	4.0	2.5	4.3	3.0	3.50
b. It is just as important for students to learn data analysis and probability as it is to learn multiplication facts.	4.0	3.5	4.0	4.0	3.87
c. Generally, students learn mathematics best through investigative approaches (e.g., hands-on experiences, inquiry).	2.0	4.0	2.7	3.5	3.13
d. Every student in my room should feel that mathematics is something she or he can do.	4.0	4.5	4.3	4.5	4.38
e. Using computers or calculators to solve mathematics problems distracts students from learning basic mathematical skills.	3.0	2.0	2.0	2.5	2.25
f. Students generally learn mathematics best through traditional approaches (e.g., lecture, drill, and practice/memorization).	3.0	3.0	4.0	3.0	3.38
g. At the grades I teach, a lot of things in mathematics must be simply accepted as true and remembered.	2.0	3.0	3.3	3.0	3.00

Appendix D. Teacher Class Description Questionnaire Results

Table 36. Teacher Class Description Questionnaire Results: Instructional Time.

			School				
			CPMP/ Trad. (*n*=1)	CPMP/ Reform (*n*=3)	Glencoe/ Reform (*n*=3)	Glencoe/ Trad. (*n*=3)	Total (*N*=10)
a.	Daily routines, interruptions, and other non-instructional activities.	0-10%		3	2	3	8
		11-20%	1				1
		21-30%			1		1
		31-40%					
		41-50%					
		51-60%					
		61-70%					
		71-80%					
		81-90%					
		91-100%					
b.	Whole class lecture/discussions.	0-10%					
		11-20%					
		21-30%	1	3			4
		31-40%			1		1
		41-50%			1		1
		51-60%				2	2
		61-70%			1		1
		71-80%				1	1
		81-90%					
		91-100%					
c.	Individual students reading textbooks, completing worksheets, etc.	0-10%			1	1	2
		11-20%	1				1
		21-30%		3	2	2	7
		31-40%					
		41-50%					
		51-60%					
		61-70%					
		71-80%					
		81-90%					
		91-100%					
d.	Small group work.	0-10%			1	3	4
		11-20%			1		1
		21-30%	1	1	1		3
		31-40%		2			2
		41-50%					
		51-60%					
		61-70%					
		71-80%					
		81-90%					
		91-100%					

Table 37. Teacher Class Description Questionnaire Results: Teacher Activities.

			School				
			CPMP/ Trad. (*n*=1)	CPMP/ Reform (*n*=3)	Glencoe/ Reform (*n*=3)	Glencoe/ Trad. (*n*=3)	Total (*N*=10)
a.	Introduce content through formal presentations.	Never					
		Rarely					
		Sometimes		2			2
		Often	1	1	2	1	5
		Always			1	2	3
b.	Pose close-ended questions.	Never					
		Rarely	1			1	2
		Sometimes		2		1	3
		Often			1	1	2
		Always			2		2
c.	Engage the whole class in discussions.	Never					
		Rarely				1	1
		Sometimes			1	1	2
		Often	1	2	1	1	5
		Always		1	1		2
d.	Require students to explain their reasoning when giving an answer.	Never					
		Rarely					
		Sometimes	1		1	2	4
		Often				1	1
		Always		3	2		5
e.	Assess student progress by reviewing homework.	Never					
		Rarely					
		Sometimes					
		Often	1	1		1	3
		Always		2	3	2	7
f.	Encourage students to explore alternative methods for solutions.	Never				1	1
		Rarely					
		Sometimes					
		Often	1	1	2	2	6
		Always		2	1		3
g.	Require students to use calculators/computers for learning or practicing skills.	Never					
		Rarely					
		Sometimes			1	1	2
		Often		1		1	2
		Always	1	2	2	1	6
h.	Help students see connections between mathematics and other disciplines.	Never					
		Rarely					
		Sometimes				1	1
		Often	1	3	2	2	8
		Always			1		1
i.	Encourage students to use multiple representations (e.g., numeric, graphic, geometric, etc.).	Never					
		Rarely					
		Sometimes				3	3
		Often	1	1	2		4
		Always		2	1		3

Table 38. Teacher Class Description Questionnaire Results: Student Activities.

		School				
		CPMP/ Trad. (*n*=1)	CPMP/ Reform (*n*=3)	Glencoe/ Reform (*n*=3)	Glencoe/ Trad. (*n*=3)	Total (*N*=10)
a. Listen and take notes during a presentation by the teacher.	Never					
	Rarely	1				1
	Sometimes		3			3
	Often			2	1	3
	Always			1	2	3
b. Work in groups.	Never					
	Rarely					
	Sometimes			2	3	5
	Often	1	1	1		3
	Always			1	2	3
c. Read from a mathematics textbook in class.	Never				1	1
	Rarely		1		2	3
	Sometimes		1	2		3
	Often	1	1	1		3
	Always					
d. Read other (non-textbook) mathematics-related materials in class.	Never			1	3	4
	Rarely	1	2	1		4
	Sometimes		1	1		2
	Often					
	Always					
e. Engage in mathematical activities using concrete materials.	Never					
	Rarely					
	Sometimes	1	3	1	3	8
	Often			1		1
	Always			1		1
f. Practice routine computations/algorithms.	Never					
	Rarely	1				1
	Sometimes					
	Often		3	1	3	7
	Always			2		2
g. Review homework/worksheet assignments.	Never					
	Rarely					
	Sometimes	1				1
	Often		1		1	2
	Always		2	3	2	7
h. Use mathematical concepts to interpret and solve applied problems.	Never					
	Rarely					
	Sometimes	1				1
	Often		1	1	2	4
	Always		2	2		4
i. Answer textbook or worksheet problems.	Never					
	Rarely					
	Sometimes	1				1
	Often				1	1
	Always		3	3	2	8

			School				
			CPMP/ Trad. (*n*=1)	CPMP/ Reform (*n*=3)	Glencoe/ Reform (*n*=3)	Glencoe/ Trad. (*n*=3)	Total (*N*=10)
j.	Write reflections (e.g., in a journal).	Never	1		1	3	5
		Rarely		1	2		3
		Sometimes		2			2
		Often					
		Always					
k.	Make formal presentations to the rest of the class.	Never	1			1	2
		Rarely				2	2
		Sometimes		3	3		6
		Often					
		Always					
l.	Keep notes in an organized notebook that is periodically reviewed by teacher.	Never					
		Rarely		1	1	1	3
		Sometimes					
		Often	1	2	1		4
		Always			1	2	3
m.	Work on extended mathematics investigations or projects (a week or more in duration).	Never			1		1
		Rarely		2		3	5
		Sometimes	1		2		3
		Often		1			1
		Always					
n.	Record, represent, and/or analyze data.	Never					
		Rarely				1	1
		Sometimes	1	2	3	2	8
		Often		1			1
		Always					
o.	Use calculators or computers to develop conceptual understanding.	Never					
		Rarely					
		Sometimes				1	1
		Often	1	1	2	2	6
		Always		2	1		3
p.	Take a test or quiz.	Never					
		Rarely					
		Sometimes	1	3		2	6
		Often			2	1	3
		Always			1		1

Table 39. Teacher Class Description Questionnaire Results: Textbook Use.

		School				
		CPMP/ Trad. (*n*=1)	CPMP/ Reform (*n*=3)	Glencoe/ Reform (*n*=3)	Glencoe/ Trad. (*n*=3)	Total (*N*=10)
a. The textbook guides the structure (content emphasis) of this class.	Never					
	Rarely					
	Sometimes	1			1	2
	Often		3	3	1	7
	Always				1	1
b. I follow the textbook page by page.	Never					
	Rarely			1		1
	Sometimes	1		2	1	4
	Often		3			3
	Always				2	2
c. I pick what I consider important from the textbook and skip the rest.	Never					
	Rarely				1	1
	Sometimes		1		2	3
	Often		2	2		4
	Always	1		1		2
d. I follow my district's curriculum recommendation regardless of what is in the textbook.	Never	1				1
	Rarely			1		1
	Sometimes				1	1
	Often		3		1	4
	Always		2	1		3
e. I incorporate activities from other sources to supplement the textbook.	Never					
	Rarely				1	1
	Sometimes				1	1
	Often	1	1	2	1	5
	Always		2	1		3
f. I use the student textbook to plan lessons for this class.	Never			1		1
	Rarely					
	Sometimes					
	Often	1	3	1	1	6
	Always			1	2	3
g. I read and review suggestions in the textbook's teacher guide to plan lessons for this class.	Never					
	Rarely					
	Sometimes		1	1		2
	Often		2	1	3	6
	Always	1		1		2
h. I assign homework from the textbook.	Never					
	Rarely					
	Sometimes	1				1
	Often					
	Always		3	3	2	8
i. Students in this class use their textbook during the mathematics lesson.	Never					
	Rarely				1	1
	Sometimes					
	Often		1	1		2
	Always	1	2	2	2	7

Table 40. Teacher Class Description Questionnaire Results: Textbook Coverage.

			School				
			CPMP/ Trad. (*n*=1)	CPMP/ Reform (*n*=3)	Glencoe/ Reform (*n*=3)	Glencoe/ Trad. (*n*=3)	Total (*N*=10)
11.	Over the course of the school year, approximately what percentage of mathematics instruction time for this target class will be based on that mathematics textbook?	< 25%					
		25-49%					
		50-74%		2	1		3
		75-90%	1	1	2	2	6
		> 90%				1	1
12.	Estimate the percentage of that mathematics textbook you will cover during the school year with this target class.	< 25%					
		25-49%					
		50-74%			2	3	5
		75-90%		2	1		3
		> 90%	1	1			2

Table 41. Teacher Class Description Questionnaire Results: Textbook Quality.

			School				
			CPMP/ Trad. (*n*=1)	CPMP/ Reform (*n*=3)	Glencoe/ Reform (*n*=3)	Glencoe/ Trad. (*n*=3)	Total (*N*=10)
13.	How would you rate the overall quality of that mathematics textbook for this target class?	Very Poor					
		Poor					
		Fair	1	2			3
		Good		1			1
		Very Good			3	1	4
		Excellent				2	2

Appendix E. Application for Approval of Research with Human Subjects

(This page will be replaced by application form, filled out by hand.)

Principal Investigator: Glenn T. Colby

Email: glenn.colby@umit.maine.edu

Faculty Sponsor (if any): John E. Donovan II, Ph.D.

Title of Project: The Effects of an Integrated Mathematics Curriculum on Students' Epistemological Beliefs of Mathematics in Maine High Schools

Project Starting Date: February 6, 2007

PI Department: MST

Mailing Address: 5752 Neville Hall

Telephone: 207-288-4124

Funding Agency: n/a

Status of PI: GRADUATE

1. **If PI is a student, is this research to be performed:**

   for a master's thesis

2. **Does this application modify a previously approved project?**

   No

3. **Do you believe this project is exempt from further review requirements?**

   Yes

4. **Is an expedited review requested?**

   Yes

5. **Has everyone named in this application completed the mandatory training on the Protection of Human Subjects of Research?**

   Yes

1. **Summary of the proposal.**

This research project explores the relationships between mathematics curricula (textbooks), classroom practices, and students' epistemological beliefs of mathematics in four Maine high schools. The investigator hypothesizes that the use of an NSF-funded textbook (Core-Plus Mathematics Project) may lead to different classroom practices and, ultimately, different students' epistemological beliefs of mathematics than if a more traditional textbook (Glencoe Mathematics) were used.

Although there have been countless studies that compare outcomes for students who have been taught using different curricula, such studies almost always focus on achievement as determined by standardized tests or other measures of performance. Very few curriculum comparisons have considered students' epistemological beliefs of mathematics. The few researchers who have performed studies of relationships between curricula and students' epistemological beliefs have consistently recommended that any future studies also consider classroom practices. This research project attempts to address that problem by including a teacher survey of classroom practices along with formal classroom observations.

Four area high schools were identified as candidate participants for this research and have expressed interest in participating in the study. Two of the high schools use exclusively the Core-Plus Mathematics Project textbook series and two of the high schools use exclusively the Glencoe Mathematics textbook series. All four schools are similar in size and have comparable scores on recent Maine Educational Assessment (MEA) mathematics exams.

Research Questions

The following research questions will be addressed in this study:

- In what ways do the Core-Plus Mathematics Project and Glencoe Mathematics textbooks differ?
- In what ways do classroom practices differ when those textbooks are used?
- Do Core-Plus Mathematics Project students have different beliefs of mathematics than Glencoe Mathematics?
- Do male and female students have different beliefs of mathematics? If so, does it depend on the textbook used and/or classroom practices?
- What other factors may affect students' beliefs of mathematics? Variables considered may include teachers' preparation to teach various topics, teachers' preparation to develop student learning in various domains, teachers' beliefs about learning mathematics,
- Is there a correlation between students' beliefs and performance?

What Are Epistemological Beliefs?

There are many theoretical models of epistemological beliefs. The model used in this research, known as the *Student Conceptions of Mathematics Framework* (D. A. Grouws, et al., 1996) focuses on beliefs of mathematics, proposing six domains as follows:

- *Composition of Mathematical Knowledge* – Mathematical knowledge is composed of EITHER concepts, principles, and generalizations OR facts, formulas, and algorithms.
- *Structure of Mathematical Knowledge* – Mathematics is structured EITHER as a coherent system OR a collection of isolated pieces.
- *Status of Mathematical Knowledge* – mathematics as EITHER a dynamic field OR a static entity.
- *Doing Mathematics* – Doing mathematics is EITHER a process of sense-making OR a process of obtaining results.
- *Validating Ideas in Mathematics* – Validating ideas in mathematics occurs EITHER through logical thought OR via mandate from and outside authority.
- *Learning Mathematics* – Learning mathematics is EITHER a process of constructing and understanding OR a process of memorizing intact knowledge.

Student Conceptions of Mathematics Questionnaire

The main instrument used in this study, the *Student Conceptions of Mathematics Questionnaire* (see **Figures 1a, 1b, 1c, and 1d**), is based on the *Conceptions of Mathematics Inventory* (D.A.Grouws et al., 1996), which was developed from the Student Conceptions of Mathematics Framework described above along with an additional domain described as follows:

- *Usefulness of mathematics* – Mathematics is viewed as EITHER a useful endeavor OR as a school subject with little value in everyday life or future work.

Additional questions regarding classroom activities have been included in the Student Conceptions of Mathematics Questionnaire based on the Center for the Study of Mathematics Curriculum's (CSMC) *Teacher Questionnaire* (K. Chval, et al., 2006). The Student Conceptions of Mathematics Questionnaire will be offered to all 11^{th}-grade mathematics students at the four participating high schools during their normal mathematics class time. The questionnaire takes less than 15 minutes to administer. Student participation will be optional.

Other Instruments

Other instruments used in this study include the following:

- The *Teacher Background Questionnaire* (see **Figures 2a and 2b**), based on the CSMC's *Teacher Questionnaire*, will be offered to all mathematics teachers at the four participating high schools. The questionnaire takes less than 10 minutes to complete.
- The *Teacher Class Description Questionnaire* (see **Figures 3a, 3b, 3c, and 3d**), based on the CSMC's *Teacher Questionnaire*, will be offered to all mathematics teachers at the four participating high schools. Teachers will be asked to complete one copy of the questionnaire for each mathematics course they teach at the high school. The questionnaire takes less than 10 minutes to complete.
- The University of Maine's Center for Science and Mathematics Education Research *Teaching Observation Protocol* (see **Figures 4a, 4b, 4c, and 4d**.), based on the *Reformed Teaching Observation Protocol* (D. Sawada & M. Piburn, 2002), will be used for a series of 4-6 classroom observations at each participating high school. This instrument was selected mostly because of the following characteristics: (1) focus on mathematics and science, (2) developed for classrooms from K to 20, (3) focus exclusively on reform rather than general characteristics such as classroom management, lesson closure, etc., (4) brief to administer, (5) very high interrater reliability, (6) factor analyzed for construct validity, (7) proven predictive validity, and (8) training and reference manuals are available.

2. Personnel.

The investigator, Mr. Colby, is a second-year graduate student in the University of Maine's Master of Science in Teaching (M.S.T.) program. Mr. Colby holds 7-12 Mathematics and K-12 Technology teaching certificates in the state of Maine and has worked formerly as the K-8 Technology Coordinator for School Union #98.

The faculty sponsor, Dr. John E. Donovan II, is an Assistant Professor of Mathematics Education in the Department of Mathematics and Statistics and the College of Education and Human Development at the University of Maine.

Only Mr. Colby and Dr. Donovan will have access to identifiable data. Mr. Colby will be the only contact with the subjects.

Both Mr. Colby and Dr. Donovan have received formal training in the use of the Teaching Observation Protocol instrument, including workshops and training materials.

3. Subject recruitment.

Four schools will be invited to participate in the study, two of which use the Contemporary Mathematics in Context (Core-Plus) series of textbooks and two of which use the Glencoe series of textbooks.

In each school, all 11th-grade mathematics students will be invited to complete the Student Conceptions of Mathematics Questionnaire and all teachers will be invited to complete the Teacher Background Questionnaire and one copy of the Teacher Class Description Questionnaire for each class taught. It is anticipated that between 50 and 100 students and four to six teachers per school will participate, assuming close to a 100% response rate.

In each school, Mr. Colby will work with administration and faculty to identify a representative sample of 9th, 10th, and 11th grade classes to observe using the Teaching Observation Protocol.

4. Informed consent.

This research project involves both teachers and 11th-grade students at four Maine high schools. Informed consent forms are provided for students, parents or guardians, and teachers as follows:

- The *Informed Consent Form for Students* (see **Figure 5a and 5b**) is provided for students who are at least 18 years old.
- The *Information Form for Parents or Guardians* (see **Figure 6a and 6b**) is provided for students who are under 18 years old.
- The *Informed Consent Form for Teachers* (see **Figures 7a and 7b**) is provided for teachers.

5. Confidentiality.

Student questionnaires will be completed anonymously and will be identified only with an identification number representing the school. It will not be possible to link the data to individual students or teachers. A lookup table of numbers and schools will be kept in a password-protected file on Mr. Colby's computer for a period of two years.

Teacher questionnaires and classroom observation data will be kept confidential and stored in electronic form in password-protected files on Mr. Colby's computer. Questionnaire and classroom observation data will be identified only with an identification number representing the teacher and school. A lookup table of numbers, teachers, and schools will be kept in a password-protected file on Mr. Colby's computer for a period of two years.

6. Risks to subjects.

There are no risks to the subjects other than the time and inconvenience associated with completing the questionnaires.

7. Benefits

There are no direct benefits to the students.

Teachers may find the reflective nature of the questionnaires and the classroom observation procedures to be informative.

This study may provide valuable information to educators in Maine as they struggle to make informed decisions about high school mathematics curricula and teaching practices. Currently, teachers, administrators, and other educational policy-makers have very little information about the outcomes associated with curricula other than students' performance on standardized tests. In the worst case, decisions are often made on assumptions that have not been confirmed by research. This study may address some of those assumptions and may also help encourage educational policy-makers to consider students' beliefs of mathematics when selecting mathematics curricula.

Appendix F. Approval of Research with Human Subjects

UNIVERSITY OF MAINE -- APPLICATION FOR APPROVAL OF RESEARCH WITH HUMAN SUBJECTS
(See instructions on reverse for completing application)

PRINCIPAL INVESTIGATOR: Glenn T. Colby email: glenn.colby@umit.maine.edu
CO-INVESTIGATOR(S):
FACULTY SPONSOR (if any): John E. Donovan II, Ph.D.
TITLE OF PROJECT: The Effects of Integrated Mathematics Curricula on Student's Epistemological Conceptions of Mathematics in Maine High Schools
PROJECT START DATE: Upon approval PI DEPARTMENT: MST
MAILING ADDRESS: 5709 Bennett Hall TELEPHONE: 207-288-4124
FUNDING AGENCY (if any): n/a CONTRACT/GRANT #:
STATUS OF PI (circle one):

FACULTY/STAFF/GRADUATE/UNDERGRADUATE/OTHER

1. If PI is a student, is this research to be performed:

____ for an honors thesis? X for a master's thesis?
____ for a doctoral dissertation? ____ for a course project?
____ other (specify)

2. Does this application modify a previously approved project? No. If yes, please give assigned number (if known) of previously approved project:

3. Do you believe this project is exempt from further review requirements? Y (Y/N, unsure). Information regarding exemption categories may be found on pages 4-5 of the Policies and Procedures (http://orspdocs.umesp.maine.edu/Ethical/humanpolicy.pdf).

4. Is an expedited review requested? Y (Y/N). Information regarding expedited review procedures may be found on pages 8-11 of the Policies and Procedures (http://orspdocs.umesp.maine.edu/Ethical/humanpolicy.pdf).

5. Has everyone named in this application completed the mandatory training on the Protection of Human Subjects of Research? Y (Y/N). Approval will not be granted until training has been completed. The tutorial is found at www.umaine.edu/irb.

SIGNATURES: All procedures performed under the project will be conducted by individuals qualified and legally entitled to do so. No deviation from the approved protocol will be undertaken without prior approval of the Board.

Faculty Sponsors are responsible for oversight of research conducted by their students. By signing this application page, the Faculty Sponsor ensures that the conduct of such research will be in accordance with the University of Maine's *Policies and Procedures for the Protection of Human Subjects of Research*.

22-Jan-2007 Glenn T. Colby John E. Donovan
Date Principal Investigator Faculty Sponsor

Co-Investigator Co-Investigator

****

FOR BOARD USE ONLY Application # 2007-02-05 Date received 1/22/07 Review (F/E): E
ACTION TAKEN:

✓ Judged Exempt; category 1. Modifications required? Y (Y/N) Accepted (date) 2/7/07
____ Approved as submitted. Date of next review: by ____.
____ Approved pending modifications. Date of next review: by ____.
Modifications accepted (date): ____.
____ Not approved. (See attached statement.)

Date: 2/4/07 Chair's Signature: Adrienne A White 12/03

Appendix G. Informed Consent Form for Students

Center for Science and Mathematics Education Research

1865 THE UNIVERSITY OF MAINE

5709 Bennett Hall
Orono, ME 04469
Tel: 207-581-1016
www.umaine.edu/center/

February 11, 2007

INFORMED CONSENT FORM FOR STUDENTS

You are invited to participate in a research project being conducted by Glenn Colby, a graduate student in the Department of Physics and Astronomy at the University of Maine. The purpose of this research is to determine if there are relationships between high school mathematics textbook usage, classroom practices, and students' beliefs of mathematics. This research may be valuable in the future as Maine educators make decisions about textbook purchases and teaching practices.

What Will You Be Asked to Do?

If you decide to participate, you will be asked to complete a two-page questionnaire about beliefs of mathematics. You will be asked to provide your opinion about statements such as "Knowing why an answer is correct in mathematics is as important as getting a correct answer" and "The field of mathematics is for the most part made up of procedures and facts."

The questionnaire takes approximately 10 minutes to complete and would be completed during a class.

Risks

Except for your time and inconvenience, there are no foreseeable risks to you participating in this study.

Benefits

There are no direct benefits to students. However, this study may provide valuable information to educators in Maine as they struggle to make informed decisions about high school mathematics curricula and teaching practices.

Confidentiality

Your name will not appear on any of the documents. Student questionnaires will be completed anonymously and will be identified only with an identification number representing the school. Please do not write your name on the questionnaire. It will not be possible to link the data to individual students or teachers. A lookup table of numbers and schools will be kept in a password-protected file on Mr. Colby's computer for a period of two years.

The data that you provide may be used to produce scholarly works. This may include, but is not limited to, journal articles and conference presentations. Scholarly works produced will neither identify specific schools nor individuals in any way. Research collaborators, including mathematics education professionals and other graduate students in the Department of Physics

Page 1 of 2

and Astronomy at the University of Maine, may also study the data, but will not have access to the file containing the lookup table of numbers and schools.

Voluntary

Participation is voluntary. If you choose to take part in this study, you may stop at any time during the study. You may skip any questions you do not wish to answer on the questionnaires.

Contact Information

If you have any questions about this study, please contact Mr. Colby at (207) 581-3951 (or email glenn.colby@umit.maine.edu). You may also reach Dr. John Donovan, the faculty advisor on this study, at (207) 581-3910 (or email john.donovan@umaine.edu). If you have any questions about your rights as a research participant, please contact Gayle Anderson, Assistant to the University of Maine's Protection of Human Subjects Review Board, at (207) 581-1498 (or email gayle.anderson@umit.maine.edu).

Thank you very much for your consideration.

Sincerely,

Glenn T. Colby

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Appendix H. Information Form for Parents and Guardians

Center for Science and Mathematics Education Research

1865 THE UNIVERSITY OF MAINE

5709 Bennett Hall
Orono, ME 04469
Tel: 207-581-1016
www.umaine.edu/center/

February 11, 2007

INFORMATION FORM FOR PARENTS AND GUARDIANS

Your child is invited to participate in a research project being conducted by Glenn Colby, a graduate student in the Department of Physics and Astronomy at the University of Maine. The purpose of this research is to determine if there are relationships between high school mathematics textbook usage, classroom practices, and students' beliefs of mathematics. This research may be valuable in the future as Maine educators make decisions about textbook purchases and teaching practices.

What Will Your Child Be Asked to Do?

If your child decides to participate, she or he will be asked to complete a two-page questionnaire about beliefs of mathematics. Students will be asked to provide their opinions about statements such as "Knowing why an answer is correct in mathematics is as important as getting a correct answer" and "The field of mathematics is for the most part made up of procedures and facts."

The questionnaire takes approximately 10 minutes to complete and may be completed during a class.

Risks

Except for your child's time and inconvenience, there are no foreseeable risks to participating in this study.

Benefits

There are no direct benefits to students. However, this study may provide valuable information to educators in Maine as they struggle to make informed decisions about high school mathematics curricula and teaching practices.

Confidentiality

Your child's name will not appear on any of the documents. Student questionnaires will be completed anonymously and will be identified only with an identification number representing the school. Students will be instructed not to write their names on the questionnaires. It will not be possible to link the data to individual students or teachers. A lookup table of numbers and schools will be kept in a password-protected file on Mr. Colby's computer for a period of two years.

The data that your child provides may be used to produce scholarly works. This may include, but is not limited to, journal articles, and conference presentations. Scholarly works produced will neither identify specific schools nor individuals in any way. Research collaborators,

Page 1 of 2

including mathematics education professionals and other graduate students in the Department of Physics and Astronomy at the University of Maine, may also study the data, but will not have access to the file containing the lookup table of numbers and schools.

Voluntary

Participation is voluntary. If your child chooses to take part in this study, she or he may stop at any time during the study. Students may skip any questions they do not wish to answer on the questionnaire.

Contact Information

If you or your child have any questions about this study, please contact Mr. Colby at (207) 581-3951 (or email glenn.colby@umit.maine.edu). You may also reach Dr. John Donovan, the faculty advisor on this study, at (207) 581-3910 (or email john.donovan@umaine.edu). If you or your child have any questions about your child's rights as a research participant, please contact Gayle Anderson, Assistant to the University of Maine's Protection of Human Subjects Review Board, at (207) 581-1498 (or email gayle.anderson@umit.maine.edu).

Thank you very much for your cooperation.

Sincerely,

Glenn T. Colby

Appendix I. Informed Consent Form for Teachers

Center for Science and Mathematics Education Research

1865 THE UNIVERSITY OF MAINE

5709 Bennett Hall
Orono, ME 04469
Tel: 207-581-1016
www.umaine.edu/center/

February 11, 2007

INFORMED CONSENT FORM FOR TEACHERS

You are invited to participate in a research project being conducted by Glenn Colby, a graduate student in the Department of Physics and Astronomy at the University of Maine. The purpose of this research is to determine if there are relationships between high school mathematics textbook usage, classroom practices, and students' beliefs of mathematics. This research may be valuable in the future as Maine educators make decisions about textbook purchases and teaching practices.

What Will You Be Asked to Do?

If you decide to participate, you will be asked to complete a two-page questionnaire about your teaching background, including questions about how well-prepared you feel to teach various topics, how well-prepared you feel to develop student learning in various domains, and your beliefs about student learning of mathematics. It may take approximately 5-10 minutes to complete the questionnaire.

In addition, you will be asked to complete a two-page questionnaire for each mathematics class that you teach. This questionnaire asks about frequency of various teacher and student activities, textbook usage, and textbook quality. It may take approximately 10 minutes to complete the questionnaire for each of your classes.

Your students will be invited to participate in the research project as well. If they decide to participate, they will be asked to complete a two-page questionnaire about their beliefs of mathematics. The student questionnaire takes approximately 10 minutes to administer and may be completed during a class at your convenience.

Finally, you may be asked to allow Mr. Colby to observe a few of your classes using the University of Maine's Center for Science and Mathematics Education Research *Teaching Observation Protocol* (TOP). Mr. Colby has received training and is experienced in using the TOP, and these observations would be as unobtrusive as possible. In addition to your normal classroom time, you may be asked to spend a few minutes before class describing the lesson to be observed and to provide copies of supplemental materials. A copy of the TOP is provided with this form.

Risks

Except for your time and inconvenience, there are no foreseeable risks to you participating in this study.

Benefits

You may find the reflective nature of the questionnaires and the classroom observation procedures to be informative. This study may also provide valuable information to other educators in Maine as they struggle to make informed decisions about high school mathematics curricula and teaching practices.

Confidentiality

Neither your name nor your students' names will appear on any of the documents. Student questionnaires will be completed anonymously and will be identified only with an identification number representing the school. It will not be possible to link the data to individual students or teachers. A lookup table of numbers and schools will be kept in a password-protected file on Mr. Colby's computer for a period of two years. Teacher questionnaires and classroom observation data will be kept confidential and stored in electronic form in password-protected files on Mr. Colby's computer. Questionnaire and classroom observation data will be identified only with an identification number representing the teacher and school. A lookup table of numbers, teachers, and schools will be kept in a password-protected file on Mr. Colby's computer for a period of two years.

The data that you provide may be used to produce scholarly works. This may include, but is not limited to, journal articles and conference presentations. Scholarly works produced will neither identify specific schools nor individuals in any way. Research collaborators, including mathematics education professionals and other graduate students in the Department of Physics and Astronomy at the University of Maine, may also study the data, but will not have access to the file containing the lookup table of numbers, teachers, and schools.

Voluntary

Participation is voluntary. If you choose to take part in this study, you may stop at any time during the study. You may skip any questions you do not wish to answer on the questionnaires.

Contact Information

If you have any questions about this study, please contact Mr. Colby at (207) 581-3951 (or email glenn.colby@umit.maine.edu). You may also reach Dr. John Donovan, the faculty advisor on this study, at (207) 581-3910 (or email john.donovan@umaine.edu). If you have any questions about your rights as a research participant, please contact Gayle Anderson, Assistant to the University of Maine's Protection of Human Subjects Review Board, at (207) 581-1498 (or email gayle.anderson@umit.maine.edu).

Thank you very much for your cooperation.

Sincerely,

Glenn T. Colby

Page 2 of 2

Appendix J. Student Mathematics Questionnaire

UNIVERSITY OF MAINE – STUDENT MATHEMATICS QUESTIONNAIRE

Instructions: Thank you for volunteering to participate in this research project. In order to protect your identity, **PLEASE DO NOT WRITE YOUR NAME ON THIS QUESTIONNAIRE.** You may use a pen or pencil. Thank you!

SCHOOL NO. ______________

CLASS NO. ______________

PART A – MATHEMATICAL BELIEFS

Please provide your opinion about each of the following statements. (Darken one circle for each question.)

AGREE ○ ○ ○ ○ ○ ○ DISAGREE		AGREE ○ ○ ○ ○ ○ ○ DISAGREE	
○ ○ ○ ○ ○ ○	**1. There is always a rule to follow when solving a mathematical problem.**	○ ○ ○ ○ ○ ○	**17. Mathematicians work with symbols rather than ideas.**
○ ○ ○ ○ ○ ○	**2. Knowing why an answer is correct in mathematics is as important as getting a correct answer.**	○ ○ ○ ○ ○ ○	**18. Learning mathematics involves memorizing information presented to you.**
○ ○ ○ ○ ○ ○	**3. When you learn something in mathematics, you know the mathematics learned will always stay the same.**	○ ○ ○ ○ ○ ○	**19. Finding solutions to one type of mathematics problem cannot help you solve other types of problems.**
○ ○ ○ ○ ○ ○	**4. Learning to do mathematics problems is mostly a matter of memorizing the steps to follow.**	○ ○ ○ ○ ○ ○	**20. Mathematics is a worthwhile subject for students.**
○ ○ ○ ○ ○ ○	**5. When two students don't agree on an answer in mathematics, they need to ask the teacher or check the book to see who is correct.**	○ ○ ○ ○ ○ ○	**21. New discoveries are seldom made in mathematics.**
○ ○ ○ ○ ○ ○	**6. Students need mathematics for their future work.**	○ ○ ○ ○ ○ ○	**22. When learning mathematics, it is helpful to analyze your mistakes.**
○ ○ ○ ○ ○ ○	**7. Diagrams and graphs have little to do with other things in mathematics like operations and equations.**	○ ○ ○ ○ ○ ○	**23. Taking mathematics is a waste of time for students.**
○ ○ ○ ○ ○ ○	**8. If you cannot solve a mathematics problem quickly, then spending more time on it won't help.**	○ ○ ○ ○ ○ ○	**24. Mathematics involves more thinking about relationships among things such as numbers, points, and lines than working with separate ideas.**
○ ○ ○ ○ ○ ○	**9. While formulas are important in mathematics, the ideas they represent are useful.**	○ ○ ○ ○ ○ ○	**25. Computation and formulas are only a small part of mathematics.**
○ ○ ○ ○ ○ ○	**10. Justifying the statements a person makes is an important part of mathematics.**	○ ○ ○ ○ ○ ○	**26. It is important to convince yourself of the truth of a mathematical statement rather than to rely on the word of others.**
○ ○ ○ ○ ○ ○	**11. New mathematics is always being invented.**	○ ○ ○ ○ ○ ○	**27. The field of mathematics is growing and changing.**
○ ○ ○ ○ ○ ○	**12. Mathematics has very little to do with students' lives.**	○ ○ ○ ○ ○ ○	**28. You can only find out that an answer to a mathematics problem is wrong when it is different from the book's answer or when the instructor tells you.**
○ ○ ○ ○ ○ ○	**13. Mathematics has very little to do with students' lives.**	○ ○ ○ ○ ○ ○	**29. Being able to use formulas well is enough to understand the mathematical concept behind the formula.**
○ ○ ○ ○ ○ ○	**14. Memorizing formulas and steps is not that helpful for learning how to solve mathematical problems.**	○ ○ ○ ○ ○ ○	**30. Asking questions in mathematics class means you didn't listen to the instructor well enough.**
○ ○ ○ ○ ○ ○	**15. You know something is true in mathematics when it is in a book or an instructor tells you.**	○ ○ ○ ○ ○ ○	**31. There is little in common between the different mathematical topics you have studied, like measurement and fractions.**
○ ○ ○ ○ ○ ○	**16. When working mathematics problems, it is important that what you are doing makes sense to you.**	○ ○ ○ ○ ○ ○	**32. Understanding the statements a person makes is an important part of mathematics.**

Glenn T. Colby **Please continue on the other side.** 11-Feb-2007

PART A (Continued)

AGREE ○ ○ ○ ○ ○ ○ DISAGREE	33.	Learning computational skills, like addition and multiplication, is more important than learning how to solve problems.
AGREE ○ ○ ○ ○ ○ ○ DISAGREE	34.	Knowing mathematics will help students earn a living.
AGREE ○ ○ ○ ○ ○ ○ DISAGREE	35.	When you do an exploration in mathematics, you can only discover something already known.
AGREE ○ ○ ○ ○ ○ ○ DISAGREE	36.	Mathematics will not be important to students in their life's work.
AGREE ○ ○ ○ ○ ○ ○ DISAGREE	37.	Concepts learned in one mathematics class can help you understand material in the next mathematics class.
AGREE ○ ○ ○ ○ ○ ○ DISAGREE	38.	If you know every possible formula, then you could easily solve any mathematical problem.
AGREE ○ ○ ○ ○ ○ ○ DISAGREE	39.	In mathematics there are many problems that can't be solved by following a given set of steps.
AGREE ○ ○ ○ ○ ○ ○ DISAGREE	40.	When two classmates don't agree on an answer, they can usually think through the problem together until they have a reason for what is correct.
AGREE ○ ○ ○ ○ ○ ○ DISAGREE	41.	Mathematics consists of many unrelated topics.
AGREE ○ ○ ○ ○ ○ ○ DISAGREE	42.	Sometimes when you learn new mathematics, you have to change ideas that you have previously learned.
AGREE ○ ○ ○ ○ ○ ○ DISAGREE	43.	When you learn mathematics, it is essential to compare new ideas to mathematics you already know.
AGREE ○ ○ ○ ○ ○ ○ DISAGREE	44.	Mathematics today is the same as it was when your parents were growing up.
AGREE ○ ○ ○ ○ ○ ○ DISAGREE	45.	In mathematics, the instructor has the answer and it is the student's job to figure it out.
AGREE ○ ○ ○ ○ ○ ○ DISAGREE	46.	Students will use mathematics in many ways as adults.
AGREE ○ ○ ○ ○ ○ ○ DISAGREE	47.	You can only learn mathematics when someone shows you how to work a problem.
AGREE ○ ○ ○ ○ ○ ○ DISAGREE	48.	One can be quite successful at doing mathematics without understanding it.
AGREE ○ ○ ○ ○ ○ ○ DISAGREE	49.	The field of mathematics is for the most part made up of procedures and facts.
AGREE ○ ○ ○ ○ ○ ○ DISAGREE	50.	Most mathematical ideas are related to one another.
AGREE ○ ○ ○ ○ ○ ○ DISAGREE	51.	Essential mathematical knowledge is primarily composed of ideas and concepts.
AGREE ○ ○ ○ ○ ○ ○ DISAGREE	52.	When one's method of solving a mathematics problem is different from the instructor's method, both methods can be correct.
AGREE ○ ○ ○ ○ ○ ○ DISAGREE	53.	Students should expect to have little use for mathematics when they get out of school.
AGREE ○ ○ ○ ○ ○ ○ DISAGREE	54.	Students can make new mathematical discoveries, as well as study mathematicians' discoveries.
AGREE ○ ○ ○ ○ ○ ○ DISAGREE	55.	Learning mathematics involves more thinking than remembering information.
AGREE ○ ○ ○ ○ ○ ○ DISAGREE	56.	Solving a problem in mathematics is more a matter of understanding than remembering.

PART B – ADDITIONAL INFORMATION

Please provide the following information. (Darken one circle for each question. Leave blank if you are not sure.)

56. WHAT IS YOUR SEX? M ○ F ○

57. YEAR IN SCHOOL 9TH ○ 10TH ○ 11TH ○ 12TH ○ OTHER ○

58. EXPECTED GRADE IN CURRENT MATH COURSE A ○ B ○ C ○ D ○ E/F ○ N/A ○

59. CUMULATIVE HIGH SCHOOL GPA 0.00–1.99 ○ 2.00–2.49 ○ 2.50–2.99 ○ 3.00–3.49 ○ 3.50–4.00 ○

60. DO YOU EXPECT TO PURSUE AN EDUCATION AFTER HIGH SCHOOL? Y ○ N ○

61. IF YOU PURSUE AN EDUCATION AFTER HIGH SCHOOL, WILL IT BE IN A MATHEMATICS, SCIENCE, OR ENGINEERING-RELATED FIELD? Y ○ N ○ N/A ○

62. WHAT IS THE HIGHEST LEVEL OF FORMAL EDUCATION OBTAINED BY YOUR FATHER?

- ○ Grammar school or less
- ○ Some high school
- ○ High school graduate
- ○ Postsecondary school other than college
- ○ Some college
- ○ College degree
- ○ Some graduate school
- ○ Graduate degree
- ○ Professional degree (e.g., law, medicine)

63. WHAT IS THE HIGHEST LEVEL OF FORMAL EDUCATION OBTAINED BY YOUR MOTHER?

- ○ Grammar school or less
- ○ Some high school
- ○ High school graduate
- ○ Postsecondary school other than college
- ○ Some college
- ○ College degree
- ○ Some graduate school
- ○ Graduate degree
- ○ Professional degree (e.g., law, medicine)

Glenn T. Colby **Thank You!** 11-Feb-2007

Appendix K. Teacher Background Questionnaire

Teacher Background Questionnaire

Glenn T. Colby – Spring 2007

Instructions: Thank you for volunteering to participate in this research project. . In order to protect your identity, **PLEASE DO NOT WRITE YOUR NAME ON THIS QUESTIONNAIRE**. You may use a pen or pencil.

TEACHER NO. _______________

1. How many mathematics classes are you teaching? (Darken one circle.)

1	2	3	4	5	6 or more
O	O	O	O	O	O

2. Including this year, how many years have you: (Darken one circle on each line.)

	Number of Years									
	1	2	3	4	5	6-10	11-15	16-20	21-25	26 or more
a. Taught at the high school level?	O	O	O	O	O	O	O	O	O	O
b. Taught in this high school?	O	O	O	O	O	O	O	O	O	O
c. Taught mathematics in this high school or elsewhere?	O	O	O	O	O	O	O	O	O	O

3. Within mathematics, many teachers feel better prepared to teach some topics than others. How well prepared do you feel to teach each of the following topics **at the grade level(s) you teach**, whether or not they are currently included in your curriculum? (Darken one circle on each line.)

	Not Adequately Prepared	Somewhat Prepared	Fairly Well Prepared	Very Well Prepared
a. Estimation	O	O	O	O
b. Measurement	O	O	O	O
c. Pre-Algebra	O	O	O	O
d. Algebra	O	O	O	O
e. Patterns and relationships	O	O	O	O
f. Geometry and spatial sense	O	O	O	O
g. Functions (including trigonometric functions) and pre-calculus concepts	O	O	O	O
h. Data collection and analysis	O	O	O	O
i. Probability	O	O	O	O
j. Statistics (e.g., hypothesis tests, curve fitting, and regression)	O	O	O	O
k. Topics from discrete mathematics (e.g., combinatorics, graph theory, recursion)	O	O	O	O
l. Calculus	O	O	O	O
m. Technology (calculators, computers) in support of mathematics	O	O	O	O

University of Maine

Please continue on the other side.

11-Feb-2007

4. When teaching mathematics, many teachers feel better prepared to guide and help develop student learning in some domains than others. How well prepared do you feel to teach each of the following **at the grade level(s) you teach**, whether or not they are currently included in your curriculum? (Darken one circle on each line.)

	Not Adequately Prepared	Somewhat Prepared	Fairly Well Prepared	Very Well Prepared
a. Problem solving	○	○	○	○
b. Reasoning and proof	○	○	○	○
c. Communication (written and oral)	○	○	○	○
d. Connections within mathematics and from mathematics to other disciplines	○	○	○	○
e. Multiple representations (e.g., concrete models, and numeric, graphical, symbolic, and geometric representations)	○	○	○	○

5. Please provide your opinion about each of the following statements. (Darken one circle on each line.)

	Strongly Disagree	Disagree	No Opinion	Agree	Strongly Agree
a. Students generally learn mathematics best in classes with students of similar abilities	○	○	○	○	○
b. It is just as important for students to learn data analysis and probability, as it is to learn multiplication facts.	○	○	○	○	○
c. Generally, students learn mathematics best through investigative approaches (e.g., hands-on experiences, inquiry).	○	○	○	○	○
d. Every student in my room should feel that mathematics is something she or he can do.	○	○	○	○	○
e. Using computers or calculators to solve mathematics problems distracts students from learning basic mathematics skills.	○	○	○	○	○
f. Students generally lean mathematics best through traditional approaches (e.g., lecture, drill, and practice/memorization.	○	○	○	○	○
g. At the grades I teach, a lot of things in mathematics must be simply accepted as true and remembered.	○	○	○	○	○
h. Every student in my room should feel that mathematics is something she or he can do.	○	○	○	○	○

6. Please provide any comments that may be relevant to this study.

University of Maine **Thank You!** 11-Feb-2007

Appendix L. Teacher Class Description Questionnaire

Appendix M. Teaching Observation Protocol (TOP)

Teaching Observation Protocol
Center for Science and Mathematics Education Research
Fall 2005

Note: Sections I, II, IV, V, and VI in this protocol are taken from the Reformed Teaching Observation Protocol (RTOP) by Daiyo Sawada, Michael Piburn, Kathleen Falconer, Jeff Turley, Russell Benford, and Irene Bloom, then with the Arizona Collaborative for Excellence in the Preparation of Teachers, Arizona State University. Other portions are adapted from the Classroom Observation Handbook by Frances Lawrenz, Douglas Huffman, Karen Appeldoorn, and Tao Sun from the College of Education and Human Development at the University of Minnesota and were developed with funding from the National Science Foundation.

BACKGROUND INFORMATION

Name of Teacher ____

Announced Observation?__________________________________
(yes, no or explain)

Location of class____
(district, school, room)

Years of Teaching _________ Teaching Certification _________________
(K-8 or 7-12)

Subject Observed ____________________ Grade Level _______________

Observer ______________________ Date of Observation ______________

Start time ______________________ End time ______________________

CONTEXTUAL BACKGROUND AND ACTIVITIES

In the space provided below, please give a brief description of the lesson observed, the classroom setting in which the lesson took place (space, seating arrangements, etc.), and any relevant details about the students (number, gender, ethnicity) and teacher that you think are important. Use diagrams if they seem appropriate.

LESSON DESIGN AND IMPLEMENTATION

	Never Occurred				Very Descriptive
1) The instructional strategies and activities respected students' prior knowledge and the preconceptions inherent therein.	0	1	2	3	4
2) The lesson was designed to engage students as members of a learning community.	0	1	2	3	4
3) In this lesson, student exploration preceded formal presentation.	0	1	2	3	4
4) This lesson encouraged students to seek and value alternative modes of investigation or of problem solving.	0	1	2	3	4
5) The focus and direction of the lesson was often determined by ideas originating with students.	0	1	2	3	4

DESCRIPTION OF EVENTS

Time	Description of Events

Codes for Description of Events

Please fill in the instructional strategies (*not* the instructor's actual activities, in case they are correcting papers or something non-instructional), student engagement, and cognitive activity used in each segment of this class. There may be one or more strategies used in each category during each segment. For example, SGD, HOA, and TIS often occur together, but SGD and L do not.

Type of Instruction:

L	lecture/presentation	CL	cooperative learning (roles)
PM	problem modeling	LC	learning center/station
SP	student presentation (formal)	TIS	teacher/faculty interacting w/ student
LWD	lecture with discussion	UT	utilizing digital educational media and/or technology
D	demonstration	A	assessment
CD	class discussion	AD	administrative tasks
WW	writing work (if in groups, add SGD)	OOC	out-of-class experience
RSW	reading seat work (if in groups, add SGD)	I	interruption
HOA	hands-on activity/materials	OTH	Other: please describe
SGD	small group discussion (pairs count)		

Student Engagement:

HE	high engagement, 80% or more of the students engaged
ME	mixed engagement
LE	low engagement, 80% or more of the students off-task

Cognitive Activity:

1	**Receipt of Knowledge** (lectures, worksheets, questions, observing, homework)
2	**Application of Procedural Knowledge** (skill building, performance)
3	**Knowledge Representation** (organizing, describing, categorizing)
4	**Knowledge Construction** (higher order thinking, generating, inventing, solving problems, revising, etc.
0	**Other** (e.g., classroom disruption

CONTENT

Propositional knowledge

	Never Occurred				Very Descriptive
6) The lesson involved fundamental concepts of the subject.	0	1	2	3	4
7) The lesson promoted strongly coherent conceptual understanding.	0	1	2	3	4
8) The teacher had a solid grasp of the subject matter content inherent in the lesson.	0	1	2	3	4
9) Elements of abstraction (i.e., symbolic representations, theory building) were encouraged when it was important to do so.	0	1	2	3	4
10) Connections with other content disciplines and/or real world phenomena were explored and valued.	0	1	2	3	4

Procedural Knowledge

11) Students used a variety of means (models, drawings, graphs, concrete materials, manipulatives, etc.,) to represent phenomena.	0	1	2	3	4
12) Students made predictions, estimations and/or hypotheses and devised means for testing them.	0	1	2	3	4
13) Students were actively engaged in thought-provoking activity that often involved the critical assessment of procedures.	0	1	2	3	4
14) Students were reflective about their learning.	0	1	2	3	4
15) Intellectual rigor, constructive criticism, and the challenging of ideas were valued.	0	1	2	3	4

CLASSROOM CULTURE

Communicative Interactions

	Never Occurred				Very Descriptive
16) Students were involved in the communication of their ideas to others using a variety of means and media.	0	1	2	3	4
17) The teacher's questions triggered divergent modes of thinking.	0	1	2	3	4
18) There was a high proportion of student talk and a significant amount of it occurred between and among students.	0	1	2	3	4
19) Student questions and comments often determined the focus and direction of classroom discourse.	0	1	2	3	4
20) There was a climate of respect for what others had to say.	0	1	2	3	4

Student/Teacher Relationships

21) Active participation of students was encouraged and valued.	0	1	2	3	4
22) Students were encouraged to generate conjectures, alternative solution strategies, and ways of interpreting evidence.	0	1	2	3	4
23) In general the teacher was patient with students.	0	1	2	3	4
24) The teacher acted as a resource person, working to support and enhance student investigations.	0	1	2	3	4
25) The metaphor "teacher as listener" was very characteristic of this classroom.	0	1	2	3	4

CAPSULE DESCRIPTION OF THE QUALITY OF THE LESSON AND ADDITIONAL COMMENTS

- Level 1: Ineffective Instruction
  - Passive "Learning
  - Activity for Activity's Sake
- Level 2: Elements of Effective Instruction
- Level 3: Beginning stages of Effective Instruction (Select one below.)

  ¤ Low 3 ¤ Solid 3 ¤ High 3
- Level 4: Accomplished, Effective Instruction
- Level 5: Exemplary Instruction

Please provide your rationale for the capsule rating.

Any other comments:

BIOGRAPHY OF THE AUTHOR

Glenn T. Colby was born in West Palm Beach, Florida in 1966. He and his family moved to Columbus, Georgia in 1983, and he graduated high school from Brookstone School in 1985. He attended Georgia Institute of Technology in Atlanta, Georgia and graduated in 1990 with a Bachelor of Science degree in Information and Computer Science. He subsequently attended Georgia State University in Atlanta, Georgia and graduated in 1992 with a Bachelor of Science degree in Mathematics.

Glenn moved to Bar Harbor, Maine in the summer of 1992 and began working in a variety of education-related positions, including K-8 Technology Coordinator for School Union #98. In 1995, he began working as a Scientific Software Engineer for the Mouse Genome Informatics project at The Jackson Laboratory in Bar Harbor, Maine. In 2000, he began working as the Information Systems Specialist for the Comparative Toxicogenomics Database project at The Mount Desert Island Biological Laboratory in Salsbury Cove, Maine. He entered the Master of Science in Teaching program at The University of Maine in Orono, Maine in the fall of 2005.

After receiving his degree from The University of Maine in the summer of 2007, Glenn will enter the doctoral program (Ph.D.) in Learning, Teaching, and Diversity at Vanderbilt University in Nashville, Tennessee, specializing in mathematics and science education. He is a candidate for the Master of Science in Teaching degree from The University of Maine in August, 2007.