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ABSTRACT

This paper presents a conceptual model that casts teachers' thinking and their practice at the heart of mathematics education reform. Data were collected about each of the interrelated parts of the conceptual model and concerned four teachers from two high schools and their principals. The four teachers' case stories with descriptions of a class that the researcher observed extensively for each teacher are described. Findings indicate that the teachers in this study had a strong sense of autonomy about their work--they were teaching in unique ways that they each considered to be the best for their students. (Contains 66 references.) (ASK)

A MODEL OF THE INFLUENCE OF TEACHER THINKING AND CONTEXTS ON TEACHER CHANGE AS CONCEPTUAL CHANGE IN MATHEMATICS EDUCATION REFORM

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INTRODUCTION

Despite a long history of attempts to reform what students learn and how teachers teach, activity in classrooms has remained fairly constant over time (Cuban, 1988a, 1988b, 1993; Fullan, 1991; Goodman, 1995; Romberg & Price, 1983; Sarason, 1982; Sirotnik, 1983; Tyack & Tobin, 1994). Also intriguing is that this phenomenon is particularly true for high schools (Cuban, 1993) and for mathematics education (Gregg, 1995). There appear to be broadly accepted and highly resilient cultural beliefs about the nature of teaching and learning mathematics, and about the organization, purpose, and practice of formal schooling in mathematics that inhibit fundamental change.

A flurry of recent reform efforts in mathematics education that focus on pedagogy along with curriculum have cast teachers as the root of this problem with educational reform because of their entrenched classroom practices and sometimes inadequate mathematical knowledge. Simultaneously, teachers are portrayed as the "key agents of improvement" because it is their actions that must change in order to improve teaching (Cohen & Ball, 1990a, p. 233). Teacher thinking research has provided strong evidence of the robust link between teachers' actions in the classroom, and their knowledge and beliefs (Ball, 1994; Clark & Peterson, 1986; Cohen & Ball, 1990b; Cooney & Shealy, 1997; Czerniak & Lumpe, 1995, 1999; Ernest, 1989; Franke, Fennema, Carpenter, 1997; Gess-Newsome, 1999; Lloyd, 1999; Thompson, 1984, 1992; Wilson & Goldenberg, 1998). Evidence from this body of research suggests that teachers' ability to teach differently may depend on their ability to think differently about their work.

Current reform documents that have attempted to provide guidance and vision for mathematics education reform (NCTM, 1989, 1991, 1995, 1998), call for a shift from the traditional mathematics curriculum to a curriculum that integrates mathematical ideas and emphasizes broad conceptual understandings and applications. Those documents also indicate that "instructional patterns and...the roles of both teachers and students" will need to change (NCTM, 1989, p.125). Entrenched ideas about the inherent nature of mathematics or the required nature of mathematics instruction often inhibit teachers from making just those types of pedagogical and curricular changes. Yet, little is known about the ways in which teachers who have currently chosen to engage in mathematics education reform are changing their thinking and/or their practice. Many questions remain about the types of information, materials, and/or experiences that are likely to prompt and sustain teacher change.

Similarly, it is not well understood what contextual factors are likely to support reform oriented changes in secondary teachers' practice. Many structural and cultural factors have been empirically identified as contributing to educational reform such as faculty collegiality and meaningful collaboration (Fullan, 1991; Hargreaves, 1994); the availability of reform oriented texts, assessments, and materials along with aligned professional development opportunities (Ball, 1994; Little, 1993); daily scheduling that allows teachers time to develop new curricula and to teach in new ways (Hargreaves, 1994); administrative support, particularly from the principal, for the process of reform (Leithwood, 1992; Sergiovanni, 1984), and students, the context that "teachers agree...matters most to what they do in the classroom" (McLaughlin & Talbert, 1993). Yet, the link between these contextual factors, and fundamental and sustainable changes

in practice remains tenuous. It is not clear which factors and in what configuration will incline teachers toward increased learning in their subject area(s), and toward altering their practice of teaching.

Also empirically identified as affecting the ability and inclination of secondary teachers to make fundamental change is the context of subject-matter departments (Hargreaves, 1994; McLaughlin & Talbert, 1993). The departmental organization of high schools has produced boundaries around subject areas that have shaped pedagogical and curricular reform. Teachers tend to view their work as existing within a particular discipline of knowledge as well as within certain physical boundaries within the school building (Siskin, 1994). Their work as teachers and their thinking about their work are shaped by the norms and structures of their department. However, again it is unclear which cultural and/or structural factors encourage and support teachers in coming to think about, understand, and practice teaching in fundamentally different and sustainable ways.

A CONCEPTUAL MODEL

Based on the above outlined review of teacher thinking literature, the conceptual model for this research casts teachers' thinking and their practice at the heart of mathematics education reform (see Figure 1). The demonstrated (a) influence of teachers' subject-matter knowledge on the content they teach (Ball, 1991; Ernest, 1989; Fennema & Franke, 1992; Gess-Newsome, 1999; Gess-Newsome & Lederman, 1995; Grossman, Wilson, & Shulman, 1989; Shulman, 1987); (b) impact of teachers' knowledge of student thinking on their instruction (Fennema et al., 1996; Schultz & Thomas, 1998); (c) supportive role of teacher efficacy in teachers making change (Guskey, 1988; Smith, 1996; Smylie, 1988; Stein & Wang, 1988) and (d) mediating role

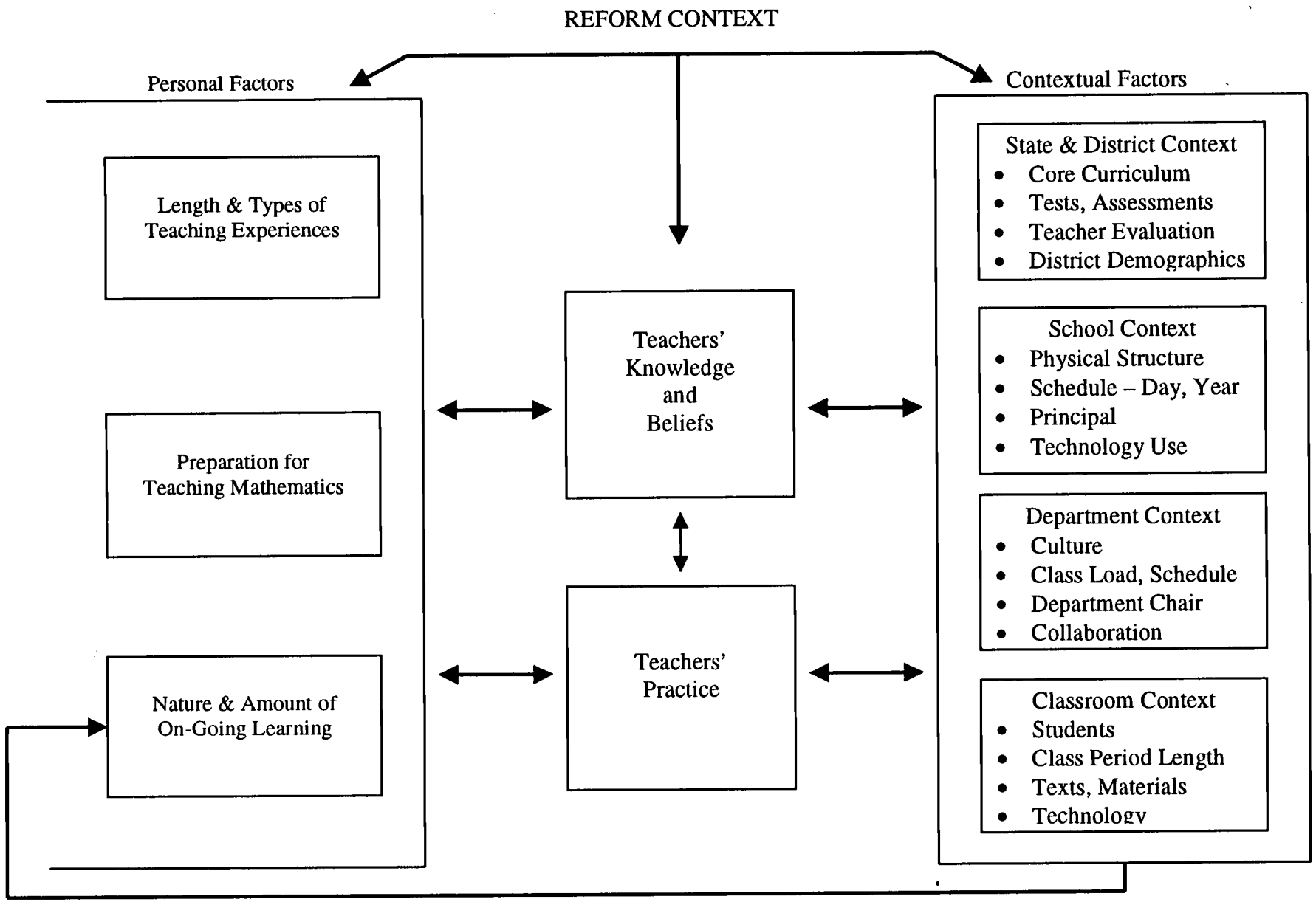

Figure 1
Conceptual Model:
Factors That Influence Teacher Change in the Context of Reform

of teachers' beliefs in shaping their instructional choices and behavior (Cooney & Shealy, 1997; Franke, et al., 1997; Thompson, 1984, 1992) suggest that a teachers' knowledge and beliefs should be considered a central part of their personal profile in terms of potential effects on their willingness and ability to make changes in their practice.

Saying something is at the center implies a great deal around it (c.f. Sirotnik, 1987, p.2 in Fullan, 1990, p.250). In the conceptual model for this research depicted in Figure 1, teachers' knowledge and beliefs and their practice are then conceptualized to be influenced by other interrelated personal and contextual factors based on the above outlined review of school reform literature (see Woodbury, 2000). Personal factors such as duration and types of teaching experiences, preparation for teaching mathematics, and the nature and amount of their continued learning and development each shape teachers' thinking and their work.

However, both a teacher's inclination and their ability to engage in on-going meaningful learning experiences are, in turn, influenced by many contextual factors. The educational reform context within which mathematics teachers currently find themselves is predicated on teacher learning (Ball, 1994) and thus has the potential to create a strong influence. There is also empirical evidence of state, district, school, department, and classroom level structural and cultural factors that shape teachers' opportunities for professional growth, as well as directly influencing their thinking and their practice as delineated in Figure 1.

RESEARCH QUESTIONS

Some high school mathematics teachers and their mathematics departments have recently involved themselves in reform. Based on what is known about the strong link

between teacher thinking and teacher practice, the fact that these teachers have, of their own initiative, become active agents of reform suggests that some of their thinking about mathematics education may have changed. The purpose of the research reported in this paper was to uncover (a) the types of changes in thought or action these teachers and departments have made, (b) the antecedent factors that prompted these mathematics teachers to pursue change, and (c) the factors that influenced these mathematics teachers to remain actively involved in sustaining reform efforts. Specifically, what were the personal, structural, and cultural factors that influenced curricular and pedagogical change for these teachers? Also, how do the types of changes these teachers made compare with their personal goals and with reformed practice as currently promoted by many concerned national organizations?

RESEARCH METHOD

Design and Data Collection

In order to learn from what theoretically should be a best case scenario, mathematics departments and participating teachers for this study were purposefully chosen to represent teachers who were engaged in reforming their practice and who were working in a supportive setting based on personal and contextual factors identified through the literature review (see Figure 1). Mathematics departments were selected based on information gathered in telephone interviews with district math specialists, principals, and department chairs from a total pool of 24 high schools in 4 districts. Selected teachers reported feeling efficacious about their work, and were self-described, as well as identified by colleagues and administrators, to be actively engaged in "trying

some new things" with mathematics education in the direction of reform oriented teaching.

This research was designed to collect data about each of the interrelated parts of the conceptual model described in Figure 1. Therefore, the four teachers who were the key teacher participants in this research, two from each of two selected high schools, were purposefully chosen to include the department chairs. Also, each principal became a key participant in the study.

The six key participants, four teachers and two principals, completed surveys and were interviewed and observed extensively in three rounds of data collection in the spring of one school year and the fall and spring of the next. During the fall, I selected a particular one of each teacher's classes to watch and audio-record every day for the duration of one unit of study. I simultaneously made lengthy field notes noting the structure of the class, classroom discourse, what was written on the board, materials used during class, the physical layout of the classroom, and my sense of the classroom activity. My conversations with teachers about their goals for the day, students' work, and/or an issue that had come up for me in reflections on data collected previously were also recorded in field notes as I waited for class to begin, or after class.

In this research I used a method of participant observation to gather from teachers "their definitions of reality and the organizing constructs of their world" (LeCompte & Preissle, 1993, p. 196). Teacher's textbooks, assignments, lesson plans, and other classroom artifacts were also collected and included in data analysis. These types of data were used to triangulate with field notes and transcripts of interviews and observations. For example, when a teacher described her belief that students should be doing more

practical application or critical thinking type problems, I checked her assignment sheets and textbook to see what types of problems and how many she had actually assigned.

In order to enhance and triangulate the data gathered about key participants, these data were combined with survey, interview, and observational data for each mathematics teacher in both schools, and for the mathematics departments and other contexts within which the teachers worked. The intent was to produce thick description for each case and use these rich descriptions to generate theoretical insights into how and why teachers were interacting with reform agenda ideas.

Data Analysis

Informal analysis of the data began with the first interviews and occurred daily during my time in the schools (Merriam, 1988). I used a constant comparative method of analysis (Strauss & Corbin, 1990) to review, annotate, and summarize field notes, interview transcripts, observation notes, memos, participant survey responses, and other documents. Following a grounded theory approach as outlined by Strauss and Corbin (1990), more formal interpretations of the data were undertaken at the end of each round of data collection which took the form of written memos about possible story lines in the data. As an intermediate step I drew concept maps to test the explanatory power of identified core categories and the validity of identified relationships between categories of data prior to writing case stories (see Appendix A).

The development of individual analytic stories for each teacher and department, and then the similar development of a cross case-story analysis was an important part of the analysis process as well as a presentation of the data. The findings from this research were then compared and contrasted with the findings of related research and with the

goals of current mathematics education reform initiatives to produce a final level of interpretation and the basis for implications.

RESULTS

Structurally and culturally the two mathematics departments that provided the contexts for this research were quite different. However, there was a culture of sharing materials and ideas that pervaded both departments. In the next section I will describe the structural and cultural contexts that the two high schools created for teachers.

The teachers in this study had a strong sense of autonomy about their work. They were teaching in unique ways that they each considered to be the best for students. In following sections I present the four teachers' case stories with descriptions of the one class that I observed extensively for each teacher. Also presented in those sections are issues raised by each teacher's story.

The Two High Schools

McKenzie High School

Tucked away in an older middle class neighborhood of a mid-size metropolitan area, McKenzie High School blended with its surroundings. It was a brick, two-story building built in 1961 that housed 2100 students in grades 10-12, 90 teachers, and around 15 administrators, counselors, and office personnel. The demographics of the McKenzie student body were similar to, though slightly more diverse than, those for the other seven high schools in the district – 88.9% White, 7.3% Hispanic/Latino, 2.0% Asian/Pacific, 0.9% Native American/American Indian, and 0.9% Black/Afro American. Statistics provided by the school district indicated that at McKenzie 89% of students entering twelfth grade graduated, and 76% of the seniors planned on attending a two-year or four-

year college after high school. Twenty-seven percent of the seniors took at least four years of mathematics during grades nine through twelve.

The McKenzie mathematics department of four women and six men had nine full time teachers and Keith, who taught three periods of mathematics each morning and coached basketball in the afternoon (see Appendix B). Robin and Andrea were mathematics department co-chairs and thus became the key teacher participants from McKenzie in this study.

Ackerton High School

Ackerton, built in 1975, was a large high school in the same district with a student body of around 3,000 and a faculty of 115 teachers. The school building was located about seven miles across town from McKenzie in a neighborhood that was transitioning from homes on farming and horse properties, to a middle class residential area. The demographics of the Ackerton student body were less diverse than most of the district with 96.7% listed as "White." Statistics provided by the school district indicated that at Ackerton 91% of students entering twelfth grade graduated, and 78% of the seniors planned on attending a two-year or four-year college after high school. Thirty-six percent of the seniors took at least four years of mathematics during grades nine through twelve.

There were 14 mathematics teachers including the key participant teachers from Ackerton in this study - Paul, the department chair, and Karen. The composition of the mathematics faculty was seven men and seven women, with nine teachers having six or fewer years of teaching experience (see Appendix C). This stood in sharp contrast to the collective teaching experience of the McKenzie mathematics department.

A Culture of Sharing

There was a strong culture of sharing in the mathematics departments at both high schools that many teachers described as a "tradition." Every teacher in each department noted, and felt they personally had benefited from, sharing with the other teachers in their department. However, teachers' daily schedules, the physical organization of the mathematics departments in the school buildings, and the influence of the department chairs affected the nature of sharing in the two departments as described below.

McKenzie was on a seven-periods-a-day schedule, and only 5 of the 10 math teachers had a daily 50-minute preparation period. McKenzie teachers were spread across three different hallways in their building. They described talking with another teacher for five minutes between classes whenever possible, or catching each other before or after school and occasionally during lunch. Robin and Andrea, as department co-chairs, readily disseminated materials and new teaching ideas, and encouraged their colleagues to do so as well. Teachers typically shared and gathered materials and ideas but did not discuss, analyze, or evaluate them. Much of the sharing at McKenzie was in the form of having one teacher write a worksheet, syllabus, disclosure statement, or test that was utilized by many of the rest of the teachers who were teaching that subject. It helped to reduce teachers' workload and the stress of preparing for and teaching six to seven classes each day.

Ackerton mathematics teachers reported a different kind of sharing that usually took place in their large department office space during their daily 87-minute preparation periods. They too shared successes and failures of assignments, teaching strategies, and tests. However, Ackerton teachers also shared ideas about developing their teaching

around the state core curriculum, about ways to help students engage with the mathematics using calculators or manipulatives, and some even reported discussing how to help students learn certain mathematical ideas. The department chair, Paul, organized work groups of teachers according to courses they taught, and explicitly orchestrated mentoring in mathematics and in teaching mathematics for the less experienced teachers. At Ackerton, the time, place, and motivation for discussion were formally structured into the workplace context. This led to the more regular and educative collaboration of Ackerton teachers.

In both mathematics departments, teachers' collaborative tendencies allowed innovative ideas and materials to spread more quickly through the department. Teachers perceived themselves to be part of a cohort that supported them in trying new things. The culture of sharing that pervaded both departments created a positive environment for teacher learning and innovation to take place. However, the nature of the sharing, and therefore the nature of teacher learning and of innovations attempted, was noticeably different between the two schools. This will be further discussed in the cross case analysis.

The Four Teachers

Teachers' Sense of Autonomy

During interviews, teachers in both schools expressed feelings that they had, for example, "all I need," "a lot of," and "enough" control over decisions about textbooks, teaching materials, and how they were going to teach. They described the state core curriculum as guiding what they were supposed to teach, and the new district teacher evaluation program, that encouraged more cooperative learning and hands-on learning

experiences, as influencing how they taught. The new state end-of-level tests, and in Paul's case the AP test, influenced teachers' choices of topics to teach. Beyond that, the teachers in this study felt an appreciated sense of autonomy about their work.

Department chairs and principals in this study also each believed that teachers were responsible for making decisions about curriculum and pedagogy, and they delegated that responsibility to them. Teachers used their autonomy to teach in ways that they felt were important for their students. For example, when Mike, a teacher at McKenzie, wanted to develop a mathematics course for students who were struggling within the system, he was encouraged to do so and had been running that program for several years. Teachers' observed and personally described sense of autonomy is significant to this study. Given their autonomy, teachers' actions can more readily be thought of as reflections of their own knowledge and beliefs.

Robin's Story – Learning Math Should Feel Comfortable

All of Robin's fifteen years of teaching experience had been at McKenzie High School. During that time she had also earned her M.Ed. plus more than 45 hours of credit in continuing education. She regularly attended workshops and conferences that were available through the district or from national organizations such as the NCTM or Texas Instruments. Robin was very aware that there were reforms going on in mathematics education. She had heard a reform message of more mathematics for more students.

> The standards are getting higher...the requirements to get into the university are higher. Most kids are going through Algebra 2 or College Algebra/Trigonometry where before they just went Algebra 1 and Geometry and stopped....I think the [new] core curriculum elevated those standards [too]. We were one of the pilot schools for the state [core curriculum aligned] test last year and there was a ton of stuff in Algebra 2 that our old book did not cover. (Interview, 5/13/97)

Robin knew that the NCTM had published standards documents. She had not read the documents but she felt she understood their intent through professional development experiences, conversations with other math teachers, and by paying attention to the content of new textbooks and the new state tests.

In Robin's mind, her teaching exemplified ideas from the reforms. She had refocused the content of her courses through the use of new textbooks to represent the content on the new state end-of-level tests, she had students do more collaborative work, she used some practical application problems and project-based learning, she made more of an effort to help students see the ways new material connected to their previous understandings, and she tried to have students answer their peers' questions by doing and explaining problems at the board for each other more often.

Robin's Algebra 2 Class: Active Passive Learning

Robin's interpretation of reform messages was guided by her beliefs that her job was to help students feel comfortable with learning, and that students learned best if she showed them how to do it. The result was an updated version of the familiar mathematics classroom. Traditional mathematics instruction is often characterized by students who passively sit and listen while a teacher explains or demonstrates. Conversely, students were very active during Robin's math class as she interspersed her lecturing with problems for students to try at their desks.

> Write an equation of a line that goes through (-5, 8) and is parallel to this line [an equation they had been working with]. Try it. If you're clueless turn around and see what someone else is doing. Ask them. If you get an equation, check with your neighbor or check it on your calculator. Did you get it? No? Ask your neighbor what they did. (9/23/97, 6)

She regularly encouraged this type of collaborative learning. However, it was usually in pursuit of learning a rule or procedure, or of coming up with a correct answer rather than being used to develop deeper understandings about a topic through listening to others' ideas. Students were actively engaged taking notes and working through her guided practice problems. They were giving her short responses to her questions of, "What do I do next?" or "How do I find the slope?" However, from my perspective sitting in the back of the classroom, it was cognitively passive activity.

What was taking place in Robin's classroom could be described as "active passive learning" in that it required only lower-level thinking by students. Using Bloom's (1956) taxonomy of thinking skill levels as a template, Robin's students were being asked to work at the lower three levels, i.e. at the knowledge level of recalling facts, formulas, and definitions; at the comprehension level of describing what they knew in their own words; and at the application level of applying learned techniques and using previous knowledge in new, but closely related, situations. They were not challenged to analyze, synthesize, or evaluate what they or Robin were doing. Robin avoided pressing students that far. Her goal was to help them feel comfortable that they knew what to do to solve problems.

Robin's classes had overtones of reform ideas but followed a familiar pattern. In each class Robin went over homework problems by guiding students through how to work problems they had questioned. Robin encouraged conversation and collaboration, but did not orchestrate learning situations where students needed to carefully discuss mathematical ideas. Her instruction, which was a large portion of class time, remained didactic and was usually oriented toward mathematical rules and procedures. She wanted to increase students' comfort with mathematics through helping them connect what they

were learning to their intuitive understandings, to what they had previously studied, and to their lives. However, she attempted to accomplish that objective by pointing out those connections to students rather than by providing learning opportunities that would help students make those connections themselves.

Robin believed that practical application problems were exciting to students and helped to show how mathematics was used, but she found very little time to include them in her curriculum. Her curriculum was textbook based and focused on routine problem solving with non-contextual exercises from the text. Robin had modified her curriculum and pedagogy but had not made any fundamental shifts in the types of problems students engaged with, nor in her role or students' roles in the educational experience.

Issues Raised by Robin's Story

This story could be read as another case of a teacher assimilating reform ideas to fit her existing beliefs and practice of teaching. However, a slightly different interpretation emerges as useful. Robin did not view *herself* as a reformer nor as an integral part of the reform movement. Robin often referred to an anonymous "they" who wanted her and her students to consider problems in a certain way. Robin set herself apart from the textbook authors and other reformers by referring to what "they" wanted everyone to do.

Not viewing herself as part of the reform movement allowed Robin to think of change efforts in an isolated way. She saw, heard, and read about reform oriented teaching and then adjusted her curricula by, for example, de-emphasizing formal proofs in geometry, and adding more work with statistics in algebra classes. She infused more technology into her curricula. She changed the scope and sequence of what she taught.

However, she had not modified her basic ideas about teaching and learning. The majority of time in her classroom still consisted of teacher-directed activity. Her new textbook, purchased to better cover topics found in the new state mandated end-of-level test, provided many possible reform-oriented learning experiences for each mathematical topic presented, but Robin only assigned the beginning routine practice problems that were more familiar to her and, she believed, more comfortable for her students.

From her vantage point outside of the reform movement, Robin was gathering ideas about changes in mathematics education, but she was not actively engaged in a consideration of the significance or effects of those changes. Viewing herself as an outsider, Robin was not moved to think critically about reform intentions nor about the results of changes she was making. Because she did not consider herself to be a "key agent of improvement" (Cohen & Ball, 1990) within a broader reform initiative, she was content to do those things that seemed to make improvements in her own classroom.

Andrea's Story - Variety is Important for Students and Teachers

The influence of 13 years of middle school experience was apparent in Andrea's teaching. She had shelves full of various mathematics manipulatives that she used regularly. The desks in Andrea's room were arranged quite often in groups of four. This classroom arrangement was unusual for the mathematics department at McKenzie, but Andrea said she encouraged other teachers to try it. Andrea explained that during the six years since she had moved to the high school level she had been experimenting with collaborative learning to find what worked best for her high school students and herself.

There were many catalysts for change influencing Andrea's teaching as this research project began in the early spring of 1997. At workshops and conferences she

learned about NCTM standards, the new state core curriculum, School-to-Careers issues, and integrating technology into her curriculum. Andrea's interpretation of these reform messages was that variety was important. She believed students should now be able to use a variety of methods to solve a given problem, and students should be working on problems emerging from a variety of contexts.

Another strong pressure for Andrea to add variety to her curriculum was that she and some of her close colleagues were getting bored with what they were teaching.

> I go over and talk to Robin and Leslie all the time about geometry. We're sick of this [the curriculum in their old textbooks]. [We ask ourselves] *What can we do? How can we...?* We finally have new books, so that ought to make a significant difference in our enjoyment of it. Yeah, that will be good. (Interview, 3/31/97)

As a teacher Andrea felt the need to vary to her curriculum to make her work more enjoyable.

Andrea's Advanced Algebra and Trigonometry Class

Andrea had attended a two week workshop to learn about teaching precalculus given by authors of her textbook Precalculus Mathematics: A Graphing Approach, Third Edition (Demana, Waits, & Clemens, 1994). She also used this short workshop experience as a means of reviewing her advanced mathematics in preparation for teaching at the high school level. Following the workshop she was convinced that the authors' curricular approach was the best way to teach the course. She described the approach as "inductive," "looking for patterns and generalizations," and "visual," "a lot of experimentation, try this, see what you see, try this, comment on what you see visually, what's going on?" (Interview, 10/20/97). In general, the textbook curriculum made sense to Andrea, "It is a logical process for me, the way they develop things" (Interview,

10/20/97), and she was comfortable following the textbook page by page, chapter by chapter.

Andrea also found that the textbook curriculum provided students important opportunities to analyze problem situations and consider both the algebraic representation of the problem and its graphical representation as was suggested in reform messages. Accordingly, each of Andrea's students was working through problems with a graphing calculator in their hands, and drawing other representations of their problems as well. However, Andrea's understanding of the mathematics involved in the textbook problems was limited to her experience at the textbook related two-week workshop. She was only able to guide students' understandings about the work they were doing to the extent that information was presented in the problem examples in the textbook.

Andrea was committed to her new ideas about variety, and an inductive approach to teaching and learning. However, her commitment was mediated by her guiding belief that her job as a teacher was to model, demonstrate, and otherwise provide students with enough information to circumvent their potential confusion when working their homework problems. In anticipation of students' confusion, Andrea would often explain how to solve problems before students asked questions or had even tried the problems. For example, after assigning a set of problems one day she said,

> Let's look at number 32. [She writes on the board: $2x - 10 < -\frac{1}{2}x - 1 < x - 4$] I've answered so many questions about this all day that I'm just going to tell you. *Shame on me.* (10/1/97, 4)

She then told students to solve the inequality by breaking it apart into two problems. Her comment, "Shame on me," indicated that she realized she was taking something away

from her students by telling them how to do this before they had tried it, but in the interest of eliminating confusion she told them anyway.

Issues Raised by Andrea's Story

Andrea defined traditional mathematics instruction as "lecture, see, and do." She felt her class probably resembled the traditional "lecture, see, do" structure, but that it was different and improved in several ways. The "lecture" and "see" parts of class were more process oriented, utilized technology, and contained greater variety than in traditional instruction. The "do" part of class included more student collaboration, and consideration of more contextual real-life problems with both algebraic and geometric representations. Andrea believed she was implementing reform-oriented teaching. However, the educational experience in her classroom fell short of reform intentions in that she was showing and telling students how to work typical types of problems without engaging them in developing a broad, connected, conceptual understanding of the mathematics they were learning. The result was an educational experience that focused on solving problems rather than on helping students learn to become problem solvers.

A likely explanation for the lack of reform oriented teaching in Andrea's classroom despite her reform efforts was Andrea's narrow subject matter understanding and her adherence to belief in the efficiency and effectiveness of didactic instruction. She believed that it was her job to eliminate confusion for her students so they could efficiently negotiate the variety of mathematics they needed to learn. However, Andrea's less than reform oriented teaching was also linked to her perceptions of reform messages. It was Andrea's understanding that providing students a variety of experiences with contextualized problems and with the use of calculators would be the best way to prepare

them for their diverse future educational and career needs. She understood those to be goals of reform efforts, and therefore she considered herself to be implementing the reforms. Similar to Robin, however, Andrea did not envision herself as actively engaged in the reform movement. Therefore, while her intent was to shift her practice toward reform oriented teaching, she was not thinking critically about reform intentions or about how her teaching compared with that rhetoric.

Karen's Story - Teaching is Empowering Students

Karen was one of the young teachers at Ackerton High School. She spent time regularly with her mentor, Aaron, receiving help with calculus and some of the precalculus mathematics she was teaching. She had studied the NCTM Standards in college, and she described them as providing her with overarching goals.

> The NCTM standards have more basic things: reasoning, is your answer realistic, connections, can you communicate the math when you talk about it, and problem solving, can you say, "this is my answer, my answer means that I used this much kool aid" [laughs]. So, I think those four things are more what I concentrate on. (Interview, 5/98)

Karen felt that the first four curriculum standards (NCTM, 1989) were powerful and "all encompassing," but that the rest of the multitude of individual standards in the document were not as useful to her in thinking about teaching.

Karen's teaching was influenced by her intention to make her teaching better than that which she had experienced as a student, and by her on-going study of psychology. She wanted mathematics to feel accessible to students rather than feeling like something they had to struggle to understand as she had. "I think my role is to empower kids to have their lives, and believe in themselves" (Interview, 5/98). However, in Karen's thinking, empowering students fell short of expecting them to take responsibility for

grappling with hard ideas or for synthesizing their own learning. Karen may have been helping them to be self-reliant students, but they were not learning from her instruction to be self-reliant mathematicians.

Karen's Precalculus Class

In spite of Karen's convictions about the importance of helping students to understand and be empowered to use mathematics, her teaching was centered around conveying information to students. Karen taught in very methodical ways.

> I show all the steps on the board. I define terms. That's boring for some of the quick learners... I feel like I have to show them how to do the new material. Sometimes I'm just standing up here talking and I know they're bored. Ten are listening and twenty aren't, *but I don't know how else to get through the material* [emphasis added]. (Interview, 12/2/97)

Whatever else Karen believed about teaching and learning, she did not feel students could "get through the material" effectively without being shown what to do.

During her lecture/discussions Karen would often answer students' questions with questions. For example, one day the following exchange took place,

Student A:	What's a discriminant?
Karen:	What is it?
Student A:	I don't know.
Karen:	It is part of what formula that we already know?
Student B:	The quadratic formula.

This classroom conversation was similar to many others. Karen later explained that she responded to students' questions in that manner to encourage them to reason and think for themselves so that they would better understand the material. To Karen, *understanding* meant knowing certain rules, like the quadratic formula, and knowing how to use them to solve the basic practice problems from the textbook. She knew that if students knew those two things they could pass the tests. As a result there was noticeably little math

phobia in Karen's classroom, but also noticeably little student inquisitiveness or conversation about the ideas of mathematics to which they were being exposed.

Ultimately, Karen's teaching was bounded by her knowledge of mathematics. One day she was reviewing the quadratic formula and completing-the-square as methods of finding, respectively, roots and vertices of quadratic equations. After she had gone over completing-the-square the following exchange took place in the classroom,

Student:	Why do we need to know this?
Karen:	Why do you do it? So you can find the vertex of a parabola. Why else do you do it? I don't know.
Student:	To find roots?
Karen:	To find roots? Could you find roots this way?
Student:	Yeah, off of the graph.
Karen:	Ok, so after you graphed it, did you look at it?
Student:	Yeah. (11/26/97, 7)

In follow-up conversations about this teaching incident it became apparent that Karen did not have the mathematical understanding necessary to talk with students about how the quadratic equation and the completing-the-square form of an equation related.

Karen was not aware of any significance to teaching about completing the square other than how it was used in the textbook to put an equation into the form $(y-k)=a(x-h)^2$ where the vertex of the parabola was apparent as the point (h,k). In her mind, factoring, using the quadratic formula, and completing-the-square were not connected except in that they were all ways of algebraically manipulating quadratic equations for different purposes. Karen's reflections about teaching completing-the-square centered around when students might need to use that form of the equation to solve problems, rather than around helping students gain a connected understanding of the various theorems and formulas pertaining to quadratic equations. Thus, her ability to be reflective about her practice was also bounded by her knowledge of mathematics.

In certain ways Karen was aware of how her own knowledge had affected her teaching of content over the years.

> Paul, our department head, he always says, "Don't just teach from the book." My first year I didn't know anything but the book. Now I say, "This is the topic I'm teaching today. Let me find from three or four different books, good worksheets and stuff. That's more of how I teach now. I think it's a lot better, it's more applicable than just going by one book and one normal worksheet. The more I get to know about it the more I can say, "Ok, this can help us out with this concept." (Interview, 5/97, 3)

Karen was also aware that she was more knowledgeable about high school mathematics topics than when she had begun teaching.

> My first year teaching I think I was pretty much winging it. I planned lessons for hours every night and it was just crazy. Now I know the material well enough that, to just, I kind of, I know what they have to know. (Interview, 5/97, 1)

She described how the state core curriculum dictated what topics she taught, but she did not feel the need to follow the core in some linear or particular fashion. She decided how long to spend on certain topics and what projects would be useful for students to pursue based on what she then knew about those subjects.

Issues Raised by Karen's Story

The extent to which Karen was able to develop her teaching practice in reform oriented ways was bounded by her self-admitted inadequate knowledge of mathematics and her belief that ultimately teaching involved showing and telling students what they needed to know. Karen was aware of some of the ways that her narrow subject-matter knowledge affected her teaching, but she was not aware of the ways it limited her ability to be reflective about the content she was teaching. She described herself as constantly working to improve her teaching by searching for new ideas from colleagues and through

reading reform oriented materials and professional development experiences. However, the questions that guided her search were queries like "how could I better explain this?" or "how is this skill or topic used in real life?" During the year that I observed and talked with her, she never expressed thinking carefully about the problems she was assigning students in terms of what students may or may not be learning mathematically from that work.

For Karen, the search for personal understanding revolved around learning about the rules and procedures that were useful for solving textbook exercises. Similarly, her definitions of *teaching for understanding* and *empowering students* revolved around helping students come to know the necessary rules and procedures of mathematics. That view of learning mathematics coupled with her belief in the necessity of didactic instruction led her to focus her efforts to improve teaching on ways to improve her delivery, i.e. more ways to explain a particular idea or procedure, better questioning techniques, and other organizational issues. She did not describe having thoughts about finding ways to help students build and organize their own understandings.

Reformers encourage teachers to "reason about pedagogy in professionally defensible ways within the particular contexts of their own work" (NCTM, 1991, p.22). Karen was doing that. However, she was not reasoning about nor pondering ideas that were outside the context of her own work or knowledge. This seems understandable, but does not help to further the reform of mathematics education. Possibly, in order to nudge teaching toward becoming something "very different from much of current practice" (NCTM, 1991, p.1), reformers will need to find ways to more explicitly encourage and support teachers in thinking beyond their own contexts. In Karen's case, her engagement

with reform messages did not stimulate her to reconsider the basic structures of her pedagogy, and it did not motivate her improve her understandings of mathematics beyond being better able to explain procedures for solving textbook problems.

Paul's Story - Finding Relevance

Paul had a long-term perspective on mathematics education reform. He had been aware of the reform movement and had been attempting to implement ideas from the NCTM during his 18 years of teaching at various high schools. During that time he had also completed an M.S. in mathematics education. He was personally invested in the evolution of mathematics teaching and he attended conferences to "find out what the most current ideas and thoughts [were] about the standards" (Interview, 5/98). Paul felt himself to be a part of a broader network of mathematics educators who were all working to improve mathematics education.

Paul's story provides a glimpse of the work of a knowledgeable, experienced teacher who viewed himself as an active agent of change. Paul saw the current reform initiatives as directing him toward providing a more "relevant" mathematics education for his students, a view that meshed well with his guiding belief that teaching should whet students' appetites for learning. Paul's conceptions of teaching closely matched pedagogical reform messages about guiding students to engage meaningfully with contextualized problems using multiple representations and technology in their work.

Paul's AP Calculus Class

Paul felt his job as a teacher was to whet students' appetites for mathematics, in other words, to pique their interest, arouse their curiosity, and engage them in the pursuit of mathematical understanding. In accordance with this belief, Paul spent some time on

most days telling stories; relaying pertinent historical tidbits; providing examples of real-life applications of topics being studied; indicating connections between new, old, and future material; and making calculus come to life. While this part of class was different from lecturing, it was still teacher directed in that it was not interactive. Paul and his words had center stage during that time. There were also more interactive but teacher-guided portions of class time when Paul, through asking purposeful questions, was leading his students toward a particular understanding.

Every day student's were also engaged about half the time in working together on a variety of routine practice, as well as practical application and critical thinking problems from their textbook or from an old AP test. Students often led their own discussions of problems. "This is what you're given," Jake began, and as he continued explaining his work he wrote more things on the board for clarity. "Where did you get the 100?," a student asked. Jake explained and then asked, "Okay?" "No," she answered. Another seated student, Jeff, provided an explanation to the girl who had been confused about the 100. Following that, a third student asked Jeff a question about something else and a short discussion ensued. Finally students were satisfied with the problem Jake had demonstrated. During that student discussion Paul was watching and only occasionally asked questions such as, "Is everybody okay so far?," or " Penny, did that answer your question?" (Observation, 11/4/97).

Issues Raised by Paul's Story

Paul perceived ideas about content *and* pedagogy in reform messages. He envisioned his work to be more than incorporating various reform agenda items into his teaching. Paul felt he was part of a larger reform movement that was working to create a

more coherent, relevant mathematics learning experience for students. However, while he encouraged other teachers in his department to collaborate on improving their teaching, he was not working with them in systematic ways to share a larger vision of reform. Paul also was not regularly collaborating with other mathematics department chairs or colleagues that could further his professional growth. He sensed his place in a larger reform movement, but was not motivated to engage collaboratively with his colleagues in the development and enactment of reform intentions.

ANALYSIS ACROSS CASE STORIES

The findings of this study reaffirm those of a great deal of prior research indicating that contextual settings shape but do not steer teachers' practice (Cuban, 1993; Feiman-Nemser & Floden, 1986; Fennema & Nelson, 1997; McLaughlin & Talbert, 1990). Particular elements of the structural contexts in this study – such as tests, reform oriented curriculum materials, district teacher evaluation procedures, physical placement of the mathematics department in the building, and daily schedules – shaped teachers' disposition and ability to engage in making changes. Also, a strong department culture of sharing gave teachers an appreciated sense of support in their work and proliferated the spread of new ideas. Within that collaborative culture, the types of ideas and information teachers sought out and shared, and the nature of learning experienced by these teachers were influenced by structural and cultural factors such as available time and space, encouragement of principals and department chairs, and accepted patterns for interactions, as well as by teachers' professional development opportunities.

While there were contextual and also personal factors (see Figure 1) that affected teachers' work, there was no clear pattern to their influence. Three of the teachers in this

study, Robin, Andrea, and Karen, orchestrated a more teacher-centered classroom experience for students. Three teachers, Robin, Andrea, and Paul, had fifteen or more years of teaching experience in secondary mathematics as compared to Karen's 4 years. A different three teachers, Andrea, Karen, and Paul, had recent learning experiences specifically focused on ideas from the NCTM Standards that they reported had affected their teaching. Karen and Paul taught within a school and department context that was supportive in many ways of teacher collaboration and attempted reform, Robin and Andrea did not. Overall, there was not a direct relationship between teachers' experience, professional development, and teaching context, and their enactment of reform oriented teaching.

The results of this research indicate that the ways in which teachers change their practice were

1. enabled by teachers' sense of autonomy,
2. supported by specific structural and cultural features of teaching contexts, but
3. ultimately driven by teachers' knowledge and guiding beliefs about mathematics and about teaching and learning mathematics.

In particular, the following elements of teachers' knowledge and beliefs directed their enactment of reform ideas:

- teachers' knowledge of mathematics,
- teachers' guiding pedagogical beliefs, and
- teachers' perceptions of what needed to change in mathematics education and schooling.

Each of these facets of teacher thinking were salient mediators of the changes these

teachers were making and will be discussed further in the following sections.

Teachers' Knowledge of Mathematics

As would be expected, teachers' knowledge of mathematics affected the content they were able to teach as well as the pedagogical choices they made (Ball, 1991; Gess-Newsome, 1999). In this study, subject matter knowledge was also found to affect not only teachers' understandings of content-related reform messages, but also their response to those messages. For example, Andrea heard the message urging that algebra instruction should feature algebraic, graphical, and geometric representations of the same mathematical situation. Accordingly, Andrea assigned students to solve problems by using equations and by drawing pictures and graphs. Her interpretation of the reform message, though, was that this would be a means of offering students a variety of ways to work on a particular problem. Through later conversations it became apparent that due to her narrow understanding of the advanced mathematics, she did not prompt students to think about or discuss how these different representations provided connected pieces of information about the same problem situation.

In general, however, reform messages about content did have an impact on teachers' practice. Teachers did not express strongly held convictions about the content they were teaching. When they received reform messages indicating the need for new topics such as statistics, more practical application problems, or less emphasis on formal proof in geometry, they typically attempted to make those changes. Those changes were made, however, within the parameters of a teacher's knowledge of those mathematical topics.

Teachers' Guiding Pedagogical Beliefs

Teachers in this study, even those with minimal classroom experience, had strong guiding beliefs about pedagogy in which their teaching efficacy was rooted. Teachers described these beliefs as coming from what they *knew* about the mathematics and about typical student difficulties in learning mathematics. Teachers also held guiding beliefs about how to best teach mathematics based on their personal learning and teaching experiences. These guiding beliefs were held strongly enough that they tempered and sometimes overrode other newly formed beliefs teachers expressed about moving their practice in a reform oriented direction. For example, Robin asserted many times through the duration of this research project that she believed it was important for students to be doing practical application problems, but she never assigned any. Andrea and Karen each described a belief in the importance of reformers' urgings that students reason, problem solve, and make connections. However, their guiding belief in the necessity of didactic instruction led them to tell students about the connections and show them how to reason and problem solve, rather than providing experiences where students would engage in those activities themselves. Karen expressed a conviction that discovery situations improved student learning, but she did not provide those types of experiences for her students.

Each of the four teachers had a teaching style that was a clear manifestation of their knowledge and beliefs about teaching mathematics. Karen and Robin framed their teaching with the intent of creating safe, comfortable, risk-free environments so that learning math would not be too difficult for students. This security blanket approach to teaching pervaded everything they thought about or did in relation to reform oriented

teaching. It is possible to think of security blanket teaching as a defensive teaching strategy (McNeil, 1988) where teachers were controlling knowledge in the classroom in order to control students. However, it is important to look underneath these teachers' actions to their intentions. McNeil (1988) reports from her research that in teachers' own statements they indicated that their teaching patterns of knowledge control were "rooted in desire for classroom control" (p.159). The expressed beliefs of the mathematics teachers in this study were that students learned best when teachers explained and carefully structured learning experiences. Karen also indicated that her lack of ability to let go of knowledge control in the classroom was influenced by her sketchy knowledge of mathematics.

Andrea's teaching reflected her intent to eliminate confusion for her students. In this case, a teachers' ability to anticipate students' confusion about a particular math topic was a barrier to reform oriented teaching. This stands in contrast to literature suggesting that being able to predict student reasoning and being able to predict students' problem solving performance may be a positive influence on reform oriented teaching (Fennema, et al., 1996). A possible explanation for this discrepancy is that Andrea, and in a similar manner Robin and Karen, coupled their knowledge about student problem solving with a belief that good teaching involves showing, telling, modeling, and otherwise helping students feel comfortable, or at least not confused, with the mathematics. Their ability to anticipate student confusion, then, led these teachers to particularly show, tell about, and model typically confusing topics and problems.

Paul's guiding belief was that teachers should whet students' appetites for learning and doing mathematics. This whet students' appetites approach to teaching was

different in many ways from the security blanket approach or Andrea's attempts to eliminate confusion. In particular it was different in that the goal of instruction was to give students' a taste of something they would explore further, but it was not intended to make students feel like they knew everything about it.

Each of the teachers in this study reported the significant influence of NCTM standards based reforms on their work. Yet, their teaching was more accurately characterized by each teacher's guiding pedagogical beliefs. In this study, as has also been reported in previous research, teachers' reform efforts were perceived differently by the teachers and the researcher sitting in the back (Cohen, 1990). Teachers like Robin, Andrea, Karen, and Cohen's Mrs. Oublier thought they had embraced reform ideas and were teaching in new, more meaningful ways. To the researcher, their practices were really a weaving of some new ideas into what continued to be a traditional practice. Results of this study shed new light on why the practice of these teachers continued to be unaffected by their own stated reform intentions. These results are described and analyzed in the following sections.

Teachers' Perceptions of Needed Change

Current reform efforts being led by the NCTM (1989, 1991, 1995, 1998) suggest that the reform of mathematics education will require fundamental changes in the mathematics classroom learning environment, as well as in teachers thinking about students, learning, mathematics, the teaching of mathematics, and the purpose of schooling. Noticeably missing from that agenda is the issue of teachers' thinking about change or reform, a factor that is also known to influence the outcomes of reform efforts

(Berman & McLaughlin, 1978; Sarason, 1982) and that emerged as a central factor in this research.

Teachers in this study were aware of and conversant about ideas from the reform movement, they were following a state core curriculum that had been rewritten in alignment with the NCTM (1989) curriculum standards, they had participated in reform-oriented professional development experiences, they were teaching from newly published reform-oriented textbooks, and they each referred to a new district teacher evaluation program that influenced them to teach in reform oriented ways. However, teachers' who could have found inducement from those sources to fundamentally transform their practice of teaching did not perceive reform messages in that light, and were not acting upon them as intended by reformers. Teachers gained an awareness of new ideas, but their existing beliefs about the need for change directed how they interpreted and acted upon the information.

Each of the key participants in this research described themselves as changing their practice in order to implement the NCTM reforms. However, the observed practice of three of the four teachers was not what could be labeled reform oriented teaching. Teachers in this study had different perceptions of what needed to be changed based on their different knowledge and beliefs about teaching and learning mathematics, and about what was working and what was not working in their practice and why. Teachers only sought ways to change the parts of their practice with which they were dissatisfied, and they explicitly paid attention to information from reform messages that would help them fulfill their perceived need for change. Teachers then followed those incomplete versions

of the reform messages creating a discrepancy between reform messages and their enactment by the teachers.

Teacher Change and Conceptual Change

The conceptual change model (CCM) (Posner et al., 1982; Strike & Posner, 1992) provides a template for change that fits the data from this research. Conceptual change research on learning in science indicates that a learners' conceptual context for learning, which includes an individual's prior knowledge, beliefs, and motivation, play an important role in the process of conceptual change (Demastes, et al., 1995, 1996; Pintrich, et al., 1993; Posner, et al., 1982). Similarly the existing conceptions of mathematics and of teaching mathematics held by the teachers in this study, and their motivation in to change particular aspects of their practice each influenced the way these teachers perceived and acted upon reform messages.

The CCM goes on to suggest that the process of conceptual change begins with a dissatisfaction with existing conceptions, in fact "people resist making such [conceptual] changes, unless they are dissatisfied with their current concepts and find an intelligible and plausible alternative" (Posner et al., 1982, p. 223). Pintrich et al., (1993) explain that for an individual to become "dissatisfied with their original ideas, they would have to attend to the discrepant information" (p. 174). There are, for example, messages in the reform agenda about reducing the amount of "telling" in teaching and replacing it with more exploration and exchange of ideas. In this study, neither Andrea, Robin, nor Karen was dissatisfied with their didactic pedagogy. Because they were not dissatisfied with their pedagogy, they did not attend to those pedagogical reform messages.

Further, the more interactive teaching philosophy in the reform messages did not coexist well with Robin, Andrea, and Karen's strong beliefs in didactic instruction. It could be, as some conceptual change researchers have suggested, that accommodation of radical new ideas may be a "gradual piecemeal affair" (Posner et al., 1982, p. 223), or a pattern of "incremental changes" (Demastes et al., 1996, p. 425). However, based on these teachers' descriptions of the pedagogical messages they heard, they did not find the messages intelligible or plausible for their practice. For example, Andrea had participated in a workshop where she described hearing about "a more inductive approach to teaching. Having students looking for patterns and generalizations. A lot of experimentation." However, Andrea did not view her existing didactic teaching as problematic, and she attended to this pedagogical reform message as something interesting, but not as something that should challenge her existing practice. Therefore, there was not a situation that would have initiated a gradual accommodation of new ideas.

Since these teachers engaged with reform ideas from their own perspectives, what they perceived was a version of the reform messages that also could not challenge their existing beliefs. The conceptions these teachers held about what constituted effective pedagogy, and perceptions they held about what needed to change in mathematics education, prevented them from attending to the reform messages that stood in contrast to their own thinking. Since they did not perceive the relevance of those messages to their teaching, there was nothing to create dissonance or dissatisfaction with their existing conceptions of mathematics instruction. Findings of this research indicate that messages

from the reform movement, as experienced by these teachers, did not motivate a conceptual shift, or a replacement of old ideas with new ones.

The interrelated nature of teachers' knowledge and beliefs, and their actions suggests that a sustainable reform of practice occurs along side teachers coming to believe in the necessity and viability of reform oriented ideas. The types of changes envisioned by reformers (AAAS, 1989; NCTM, 1989, 1991, 1995; NRC, 1989) and cited as goals by these teachers, will require teachers like Karen, for example, to do more than broaden their knowledge of mathematics. An expanded knowledge of mathematics will need to be coupled with new beliefs about teaching and learning that drive teachers to teach in fundamentally different ways (Putnam, Heaton, Prawat, & Remillard, 1992). Findings from this research indicate that, for the types of changes required of teachers in order to enact pedagogical ideas from the NCTM Standards, the process of teacher change will often involve the process of *conceptual change*.

IMPLICATIONS

In this paper I argue that teachers changing from belief in a transmission model of teaching and learning, to the belief that students actively build their own knowledge over time is a radical change of fundamental conceptions similar to grappling with ideas about creationism versus evolution, or Newtonian physics versus Einstein's theories of relativity. Studies have shown that in those cases, conceptual change, or a reorganization of central concepts, depends upon unfruitful attempts to hold dual conceptions and upon the motivation to continue in the process of conceptual change (Demastes, et al., 1996; Posner, et al., 1982).

Characterizing teacher change as conceptual change has implications for

messages of reform, for teacher education and staff development, and for further research. I will discuss each of these in the sections that follow.

Implications for Reform Messages

Many of the teachers in this study found reform messages to be answers to questions that they did not have, or solutions to problems that they did not perceive. This was the case in particular for Robin, Andrea, and Karen. They added topics to their curricula. They tried to squeeze in a day here and there for a group project between their regular teacher-directed lessons. They purchased new textbooks and tried to make time for some of the extra calculator activities or history lessons they found in those books. In general, they perceived a need to implement what they understood was being requested of them, but they viewed much of what was being asked as an addition to their existing efforts rather than a modification or a change. These teachers found some reform ideas to be of value, and they added a subset of those to what they already did. However, I argue that "what they did" did not change because their fundamental conceptions of their pedagogy had not changed.

Conceptual change theory suggests that the process of fundamental conceptual change is initiated by a dissatisfaction with existing ways of thinking about and understanding a particular phenomenon (Posner, et al., 1982). In the presence of dissatisfaction with their existing norms of pedagogy, teachers might then consider reform messages for their plausibility as solutions to that teaching dilemma. For most of the teachers in this study, mathematics education reform messages did not serve to initiate fundamental change. On the contrary, the messages were solutions to teaching

dilemmas that these teachers did not recognize as their own, and the teachers did not attend closely to the messages.

When reform messages are circulated, it can not be assumed that they are answers to questions that teachers have, or solutions to problems teachers perceive. On the contrary, in light of the prevailing context of reform for mathematics education that exists nationally and within this state, the difficulty in finding high school mathematics departments for this research project that reported to be engaged in mathematics education reform suggests that it would be more useful to assume that teachers may not be wondering about or dissatisfied with the status quo of the targeted areas of reform messages. The findings of this research indicate that if teachers are not thinking about changing the aspects of their practice that are targets of the reform messages, then they will not engage with those reform messages in ways that promote fundamental change in those target areas.

Recognizing the limiting effect of teachers' thinking on their level of engagement with reform ideas, if the intent of the reform messages is to initiate fundamental change in the status quo, then reform messages must also initiate fundamental change in teachers' conceptions of the status quo. When teachers have cognitive dissonance about the nature of their teaching they would be more likely to engage with new pedagogical ideas at the level of looking to resolve that dilemma, i.e., at a level of looking to actually change their practice.

Contexts, Reform Messages, and Conceptual Change

Findings from this study suggest that reform messages should more explicitly challenge teachers to examine their pedagogy and their beliefs in relation to reform

images of teaching and learning mathematics. Teachers' engagement in that examination process will take *time*. Time is a structural feature of teachers' work that often "compounds the problem of innovation and confounds the implementation of change (Hargreaves, 1994, p.95). Daily schedules that are conducive to engaging with reform messages and to creating change, then, become an important contextual factor that could influence the effects of reform messages on teachers' thinking and their practice.

Teachers' engagement in the process of examining and problematizing their own teaching would also benefit from *collaboration* as it provides moral support; encourages risk-taking, diversity in teaching strategies, and improved senses of efficacy among teachers; increases the capacity for reflection as some become mirrors for another's practice; and promotes the continuous pooling of collected expertise (Hargreaves, 1994, pp. 245-247). However, the department cultures of sharing found in this study are more accurately described by Hargreaves (1994) account of collaboration that is unproductive.

> Collaboration can be confined to safer, less controversial areas of teachers' work – ones which avoid collaboration in classroom practice, or collaboration through systematic shared reflection, in favor of moral support and sharing of resources and ideas. Such safer forms of collaboration can consolidate rather than challenge existing practice. (p. 247)

For promoting conceptual change, collaboration about reform messages that can challenge existing practice and create questions in teachers' minds will be necessary because to begin the process of conceptual change a teacher "must have collected a store of unsolved puzzles or anomalies and lost faith in the capacity of his current concepts to solve these problems (Posner, et al., 1982, p. 214).

The process of conceptual change is supported when, following initial dissatisfactions, teachers are presented with new ideas or new evidence that they

understand and believe to be plausible and fruitful (Posner, et al., 1982). These generative opportunities could be found in groups of teachers who collaborate regularly in a professional development setting with teacher educators or other external critical friends toward the goal of enacting a reform oriented practice. The development of electronic communication and collaboration networks could support broad sharing of ideas and information, and encourage teachers to view themselves as active agents of change in partnership with colleagues across the nation, and world.

Implications for Teacher Education and Staff Development

The results of this research indicate that teachers' improved knowledge of mathematics will be *necessary but not sufficient* for supporting a changed pedagogy. Teacher learning situations become sites for initiating change when they also include opportunities for teachers to study and analyze their conceptions about teaching and learning mathematics. The following sections discuss implications for each of these facets of teacher education and staff development in the context of supporting change.

Teachers' Knowledge of Mathematics

> Philosophical arguments (e.g. Buchmann, 1984), as well as common sense, have persuaded us that teachers' knowledge of mathematics influences their teaching of mathematics. In the most extreme case, teachers cannot help children learn things they themselves do not understand. More subtle and less well understood, are the ways in which teachers' understandings shape their students' opportunities to learn. (Ball, 1991, p.6).

The findings from this study indicate several ways in which teachers' understandings of mathematics shaped the learning opportunities they provided for students. Karen described her own lack of mathematical knowledge and realized that she was more inclined to provide open-ended, inquiry-based learning opportunities for her

students when she felt more comfortable with the mathematics. Andrea had a narrow understanding of the advanced mathematics she was teaching that was directly connected to the textbook she was using. As a result, the learning opportunities she provided for students strictly followed the material presented in her textbook and she was often reluctant to incorporate students' ideas into her instruction because it would draw discussion away from her understanding of the material. Students in these classrooms experienced teacher-directed, and rules-and-procedures-oriented learning opportunities because the narrow knowledge structures of these teachers inclined them to be less willing to let go of knowledge control in the classroom.

However, it was not the case that teachers' better subject matter knowledge led them to teach in reform oriented ways. For example, even though she understood the mathematics of functions in ways that related algebraic equations to empirical data, graphs, everyday life situations, and other topics of mathematics, Robin did not structure learning opportunities for her students that allowed them to explore and build their own understandings about functions and function relationships in those ways. The didactic teaching method she employed was based on her beliefs about teaching mathematics. Similarly, Paul's knowledge of mathematics supported him in changing the content he taught, but it was his inclination to seek out and utilize new mathematical knowledge and pedagogical ideas that eventually supported his changing practice.

Never the less, research indicates that teachers' broad and connected subject matter structures can have a positive affect on teaching practice (Gess-Newsome, 1999; Fennema & Franke, 1992). In this study knowledge of mathematics was an enabling factor for teachers trying to teach in more interactive and connected ways. A confidence

in their own knowledge of mathematics provided them with security for using an inquiry approach to teaching. A broad knowledge of mathematics also prompted teachers to ask questions that helped students spiral through the curriculum connecting their existing ideas to new ones, as Robin did when she tied her class discussion of slope to skiing and to some previous work they had done with functions.

Contextual Support for Teacher Learning

Providing structural support and building cultural support for teacher learning in mathematics will be important. It stands to reason that as teachers build their knowledge of the concepts and connected structures of mathematics they will be better able to engage with students in the types of non-routine, open-ended, problem solving learning opportunities for students that are described in reform literature. Increased teacher learning for practicing teachers requires support and encouragement from within many different contexts – designated time in daily and yearly schedules, guidance and recognition from principals and department chairs, educative textbooks and teaching materials, teachers' active participation in professional organizations, and an emphasis in teacher evaluation procedures.

Research also indicates that the structure and culture of teacher education settings should provide teachers opportunities to strengthen their subject matter *and* pedagogical content knowledge (Borko, Eisenhart, et al., 1992), and to learn mathematics as the student is to learn it (Schultz & Thomas, 1998; Stoddart, 1993). Even though teachers in Stoddart's (1993) study had become convinced that an inquiry approach to teaching mathematics was better for their students, their own teaching changed only after they were able to experience constructing mathematical concepts as learners themselves.

From a conceptual change perspective, it was necessary for those teachers to develop understanding about the viability and fruitfulness of the alternative approach to teaching.

Facilitating Conceptual Change

Beyond strengthening teachers' knowledge of mathematics, teacher educators and staff developers working to encourage teacher development within the current context of mathematics education reform will need to envision much of their work as facilitating the process of pedagogical conceptual change. What would it mean to facilitate the process of conceptual change? Within the conceptual change model it would begin by challenging teachers to hold up their own pedagogy against descriptions in reform documents and attend to the comparisons. While this would not necessarily be a comfortable undertaking, it could provide teachers with the requisite cognitive dissonance that would begin them on their own process of conceptual change.

If teachers then have concerns, questions, and/or dissatisfaction with their existing pedagogy relative to the vision of reform, facilitating conceptual change would involve helping teachers understand some of the alternatives to their existing practice. This would provide an important step in helping them gain the pedagogical content knowledge (Shulman, 1987) that would enable them to teach in new ways.

Contexts That Support Teacher Learning and Change

McLaughlin (1990) reminds us that, "Reform is steady work....Reform needs to be systemic and on-going" (p.15). This on-going, steady work would of course involve teachers, but also teacher educators and staff developers, principals, department chairs, and those setting teacher evaluation policies in encouraging and supporting teachers as

they continue to develop their practice and in occasionally re-focusing their efforts toward a shared vision of an improved educational experience for all.

Teachers' motivation to engage in and continue with a process of conceptual change would also be important (Pintrich et al., 1993). Findings from this study indicate that even though teachers were aware of a reform movement and believed themselves to be following its tenants, they did not consider themselves to be reformers. Teachers like Robin, Andrea, and Karen were content to incorporate as much of what "they," or others who *were* reformers, were asking for as possible. Another role for teacher educators and staff developers, professional organizations, and others wishing to affect and support change would be to encourage teachers' expanded involvement in educational reform. Helping teachers develop as active agents of change could stimulate their intrinsic motivation to do the steady work of achieving the reform vision.

Implications for Further Research

An important focus for further empirical work will be to explore the interaction of contexts and teachers' thinking as they combine to influence teacher change and educational reform. The primary role of teachers' knowledge and beliefs in steering their practice within contextual settings that shape what they are willing and able to accomplish is corroborated by the findings of much previous research (Cuban, 1993; Feiman-Nemser & Floden, 1986; Fennema & Nelson, 1997; McLaughlin & Talbert, 1990). These works help us understand how teachers make sense of their work, and how teachers change through participation in socio-cultural contexts. However, an important question still remains: What structural, cultural, and personal features encourage and support teachers in examining their practice and in pursuing new learning in ways that

move them *beyond* their existing knowledge and beliefs? In other words, what contextual features facilitate and support conceptual change in teachers?

One important research strand to pursue will be to explore what it means for teacher education and staff development to "facilitate conceptual change." It must be recognized that conceptual change is a unique and personal process for every individual. Never-the-less, changing conceptions of teaching appears to be a critical factor in determining teachers' initial involvement with the envisioned reform of mathematics education, as well as their eventual enactment of a reform oriented pedagogy. In that case, teacher educators, staff developers, and others in the role of "facilitators of conceptual change" will need to look systematically at whether and in what ways various experiences nudge pre-service and in-service teachers down a path of conceptual change, and then sustain their efforts in that direction. What mathematical and pedagogical development experiences and what contexts, such as

- studying current research on teaching and learning and attempting to put it into practice, individually and/or in collaborative settings,
- studying the tenants of primary reform documents as compared to existing mathematics curriculum and pedagogy, individually and/or in collaborative settings,
- observing other teachers in person and/or through videotape or written case studies and analyzing their work, individually and/or in collaborative settings,
- participation in curriculum development experiences,
- on-going teacher study groups,
- educative textbooks and teaching materials, or
- teacher evaluation programs

are influential to teachers and in what ways? To what extent and in what ways do high school departments, collaborative efforts between university professors and high school teachers, or an electronically connected conversation among a broad group of teachers affect teachers' conceptions of their work and of mathematics and then move and support them to fundamentally change what they do?

Another important research avenue has to do with students, admittedly a facet not focused on in this study. First, as educators begin to move instruction in a reform oriented direction, students will play a role in the process. What are high school students' perceptions of their mathematics education? High school students who have been enculturated into passive learning roles in schools will need to change their conceptions of what it means to learn and do mathematics in order to participate with teachers in a different classroom experience. How should students (and possibly their parents) be explicitly involved in the reform of mathematics education?

Second, to initiate dissatisfaction with the status quo empirical evidence is needed that specifically links the types of interactive, connected, student-centered teaching envisioned in the reform documents to improved learning and achievement for all students. This would involve longitudinal research that documents links between the contexts and types of reform oriented instruction students experience and their learning outcomes.

The Reform of Practice or the Practice of Reforms?

I have conceptualized teachers as the center of change (see Figure 1). Through that model I have described the influence of contextual factors on teachers' willingness and ability to make change. At the same time, the central role teachers play in thinking

about and enacting change in their classrooms is also acknowledged. Findings from this study indicate that it also matters whether teachers perceive themselves in that central role of *change agent.* If they view their work as the daily and on-going task of working toward a new vision of mathematics education, they might find more reason for undertaking the learning necessary to support a changed practice. Viewing themselves as reformers, teachers might feel more ownership of a shared vision and therefore more intrinsically motivated to do the personally and professionally hard work of bringing it to life.

This picture of teachers explicitly working together toward *the reform of the practice* of teaching mathematics, as Paul felt he was, is very different from the experience of most of the teachers interviewed for this research. Their picture was more aptly described as teachers attempting the *practice of reform ideas.* As images of reform, those two pictures lead teachers toward very different patterns of behavior, and ultimately to fundamental change or change without difference. At this time it seems important to focus the efforts of mathematics educators down the path of fundamental change in order that there might be a recognizable difference in the future.

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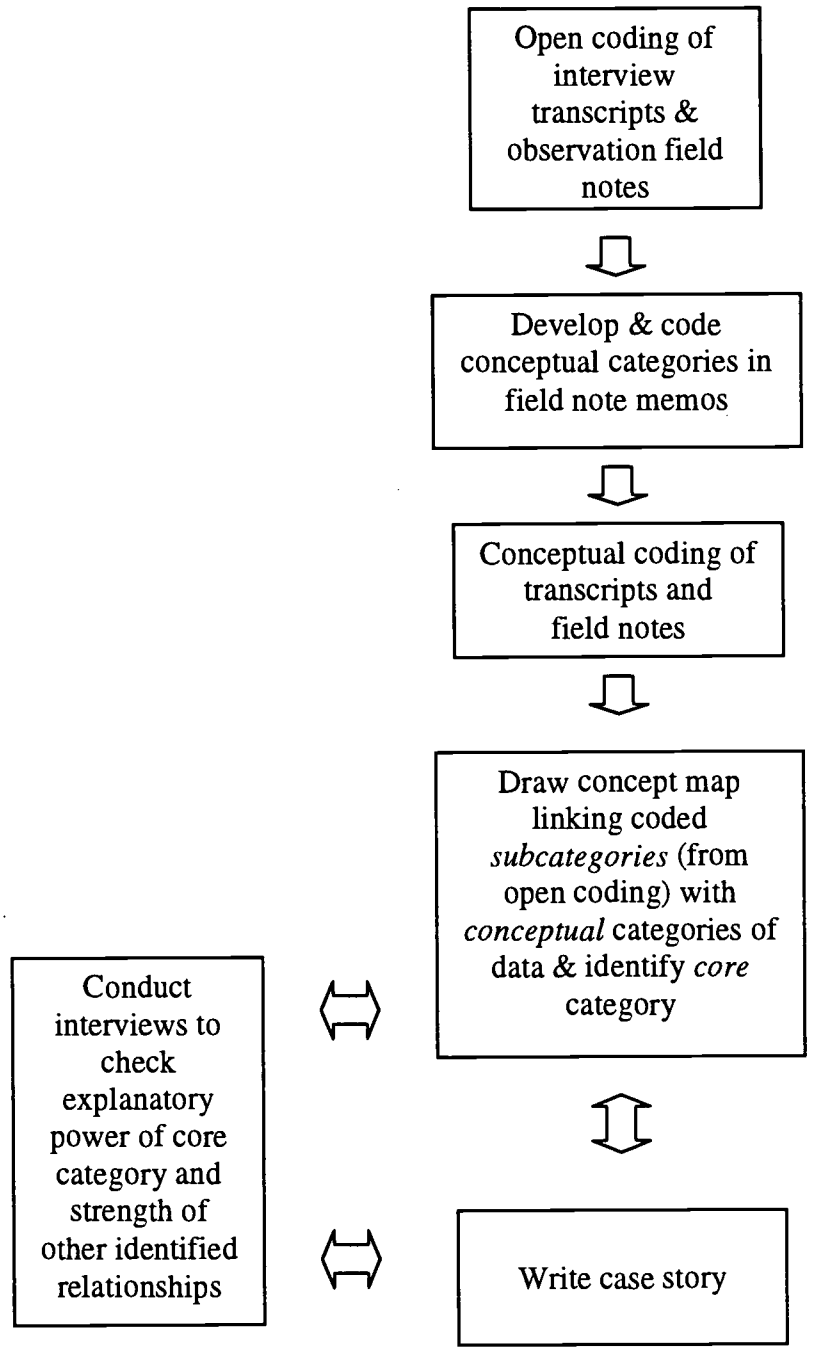
APPENDIX A:
Data Analysis



APPENDIX B: McKenzie Faculty

Code	Name	Age	Years-97-98	Subjects Taught	Free Period	Room Number	Coaching
M01	Leslie	31	5	Alg.2, Alg.1, Geometry	7	A108	volleyball
M03	Brett	46	11	Alg.2, Alg.1, Applied	7	B118	baseball
M04	Russ	37	13	Calc. BC, Calc. AB, Alg.1	1	A105	no
M05	Mike	44	24	Math 101, AP Stat, Alg.1, Math Lab	—	A102	no
M07	Ted	50	24	Adv. Alg./Trig, Alg.2, Geometry	6	A114	golf
M10	Keith	49	25	Alg.2 Basketball	6	A106 Gym	basketball
M11	Dave	29	4	Alg.1, Geometry Basketball	—	B116	basketball
M13	Andrea Dept. Co-Chair	41	19	Adv. Alg./Trig, Alg.1, Geometry	2	A116	no
M14	Betty	41	19	Math 105, Calc. AB, Geometry	6	A109	no
M16	Robin Dept. Co-Chair	39	15	Alg.2, Alg.1, Geometry	7 ½ year	A107	no
MP	Richard	65	17 Admin.	Social Studies, Coaching			football

APPENDIX C: Ackerton Faculty

Code	Name	Age	Years-97-98	Subjects Taught	Free Period	Room Number	Coaching
A01	Paul Dept. Chair	44	18	Calc. BC, CA/Trig, Geometry	3,7	M-101	No
A02	Allen	38	14	Alg.2, Alg.1, Geometry	4,8	M-103	Track
A03	Cyd	53	8	Precalc., Alg.1, Geometry	1,6	M-104	No
A04	Aaron	60	15	Calc. BC, CA/Trig, Geometry	1,5	M-107	No
A05	Suzy	27	4	Calc. AB, Alg.2, Alg.1	½ time teacher	M-106 M-107	No
A06	Wendy	27	4	Precalc., Alg.2, Alg.1	3,7	M-102	No
A07	Robert	37	5	Alg.2, Alg.1, Geometry	2,7	V-105	No
A08	Bill	31	6	Alg.2, Alg.1, Geometry	4,8	M-108	Baseball
A09	Donna	48	19	Computer AP Stat	1,5	Lab	No
A10	Karen Key Participant	27	4	Calc. AB, Precalc., Alg.1	4,8	V-104	Softball
A11	Jeff	31	6	Calc. BC, Alg.2, Alg.1	2,7	P-6	No
A12	Tamara	24	3	Precalc., Applied, Lab Geometry	1,6	M-105	No
A13	Nick	31	4	Alg.2, Alg.1, Geometry	2,6	M-106	No
A 14	Pam	48	3	Alg.2, Applied, Computer	3,6	Lab M-103	No
AP	Tom Principal	51	11 Admin.	P.E., Psychology			Track

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