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Small Steps: Teacher Change in a Reform Mathematics Curriculum

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Abstract

An experienced mathematics teacher in a rural high school in the United States was studied as she first implemented a reform calculus curriculum. Her instruction was compared to her previous practice using a curriculum not constructed with the reform movement in mind. Despite her early attempts to make her instruction more student-centered, the teachers' actions in the classroom were similar in many ways; demonstrating solutions to prototype problems was an important instructional strategy that she used in both curricula. However, the teacher showed an increased focus on conceptual knowledge and on the use of graphing calculator technology. The reform text was an influential part of this teacher's change process.

Problem and Its Background

Recently faculty at many universities have examined their calculus curriculum and the ways in which it is taught. To address concerns with calculus courses and their instruction, reform calculus curricula were developed, and their large-scale implementation began at various universities across the United States in the early 1990s. Currently these curricula are used in many secondary schools. They are only one component of the efforts to change mathematics education in secondary schools.

Classroom teachers are those who ultimately grapple with the changes advocated by reform movements. The changes advocated are not easily accomplished, and high school mathematics teachers can be among the most hesitant to modify their instructional practices (Wasley, Domoyer, & Maxwell, 1995). Knowledge of the process of mathematics teacher change can help inform those contemplating changes as well as those hoping to facilitate such changes.

The literature contains little research on high school mathematics teacher change, particularly regarding the implementation of a reform calculus curriculum at the high school level. Ferrini-Mundy and Graham believe that the calculus reform movement provides opportunities for "rich and interesting" (Ferrini-Mundy, & Graham, 1991, p. 633) research. They specifically called for research relating to teachers' use of reform calculus texts.

Goals and Conceptual Framework

The reform calculus movement had its roots in the 1980s and reflected a general dissatisfaction with the calculus course of its time. Among its goals are an increased focus on conceptual knowledge and use of more teacher strategies than just lecture. In general, the reform calculus curricula encourage the following:

(a) incorporation of technology;

(b) group work or collaborative learning;

(c) projects involving real-world applications;

(d) representation of concepts from numerical, algebraic, and geometric perspectives;

(e) verbal and written communication; and

(f) a focus on conceptual knowledge (Ross, 1996).

Of course, various curricula place different emphasis on each of these ideas. The text used by the teacher in this study, *Calculus* (Hughes-Hallett, et al., 1994) (to be referred to as RC, denoting 'Reform Calculus'), aspires to these goals. It is one of many reform calculus texts commercially available and is often considered a moderate attempt at reform.

My first goal was to compare one teacher's practice during her first-year implementing the RC relative to her practice using a text that is generally not considered to be reform in nature. Previously, this teacher used an edition of a calculus text authored before reform calculus texts were widely available: *Brief Calculus with Applications* (Larson, & Hostetler, 1987), (to be referred to as BR, denoting 'Before Reform'). These changes in approaches to the teaching of calculus led to the research question: What is the nature of any changes in one teacher's practice during her implementation of RC relative to her instruction using the BR? I define teacher practice as what the teacher does concerning instruction in the classroom or in preparation for instruction. Relative to her practice, a special focus was placed on the teacher's actions, her evaluation practices, technology use, representations used in instruction, and on the roles of conceptual and procedural knowledge. I define teacher beliefs as a "teacher's view or conception of the nature of mathematics, model or view of the nature of mathematics teaching, [and] model or view of the process of learning mathematics" (Ernest, 1989, p. 249).

The study described here was part of a doctoral dissertation completed at Illinois State University under the direction of Beverly S. Rich, Ph.D.

My second goal was to examine the nature of any changes in this teacher's practice throughout her first-year using the RC. As the teacher progresses through the RC, how stable are new strategies as she interacts with the text, with the particular content she is teaching, and with her students? Of particular interest is the extent to which any initiated changes endure. The difference in these two goals is that the second goal only looks at the changes in teacher practice over the course of the first year of implementation; it does not compare it to previous instruction using the BR text.

Research documents the extent to which both high school and university calculus teachers' have modified their practice. In general, many high school teachers have implemented more reform-orientated strategies into their mathematics classrooms (Bruckerhoff, 1994; Edwards, 1995; Ponte, Matos, Guimaraes, Leal, & Canavarro, 1994; Wilson, & Lloyd, 1995). In calculus classrooms, teacher change in practice (Edwards, 1996; Tucker & Leitzel, 1995) and beliefs (Edwards, 1996) have also been documented. Among the changes noted in these studies are an increased use of calculators and computers, cooperative learning, student projects, significant writing tasks, and modeling activities.

My third goal was to describe any influences the RC curricular materials may have on this teacher's change process. These effects are of interest because texts and other curricular material can serve as change agents: "Because many teachers rely on textbooks as a core for their teaching, a textbook is a reasonable candidate for communicating and providing guidance for change" (Ball, 1990, p. 257). The RC addressed in this study aspires to this goal; it is a harbinger of many of the changes espoused by the reform calculus movement.

While texts have been used in the past to try to influence instruction, they have had varying degrees of success in doing so. However, Ball states that texts "clearly can provide guidance to teachers . . . in selecting better mathematical tasks, and in creating different kinds of activities" (Ball, 1990, p. 257). Texts are unlikely a sufficient enough force to bring about all of the changes advocated by reform movements in mathematics education. However, texts reach a larger number of teachers than reform documents and policies (Ball, 1990).

Reform-orientated curricular materials have been found to influence teacher change at the secondary school level. Edwards (1995) studied three secondary school mathematics teachers implementing reform-orientated texts for the first time. All three teachers altered their practices in ways that included use of cooperative learning, students independently reading their texts, and a greater emphasis on mathematical connections. Edwards claimed that "the innovative ... materials seemed to have facilitated changes in instructional practices" (Edwards, 1995, p. 9). For certain teachers, the use of reform-orientated curricular materials has facilitated the change process. For others, their lack has been found to impede change (Wasley et al., 1995).

Method

In this qualitative study, the major techniques used to collect the data were nonparticipant observation, interviews, and written document collection. Data were used to generate a theory about one teacher's implementation of a reform calculus curriculum at the high school level. Grounded Theory (Strauss & Corbin, 1990) was used to generate this theory and verify it. It is theory building using an inductive process. This is particularly well suited to this study as there is little existing research about the process of teacher change in a reform calculus curriculum and even less about this process at the secondary level.

Description of Subject

In this case study, I focus on the teaching experiences of Beth (a pseudonym) who is a high school mathematics teacher. At the time when this study took place, she had taught mathematics for 13 years, during 7 of which she has taught a section of calculus. All 13 years were spent in her present high school located in a rural area of the Midwestern United States. She holds Bachelor's and Master's degrees in mathematics education and was one of three mathematics teachers in her department. Her class, the first year she implemented the RC, consisted of 10 students.

I selected Beth to be a participant in this study after it was learned that she had decided to choose a reform-oriented calculus textbook. Given her rather classical methods of teaching, I believed that the Beth's implementation of the reform curriculum would be a unique opportunity to examine a teacher involved in the process of change. Beth accepted my invitation without hesitation. Overall, she is a very open person; this openness included her willingness to examine her own instruction as she implemented the reform curriculum. Her openness yielded frankness regarding all facets of her own teaching during the data collection process.

Data Collection

Data collection techniques here included nonparticipant observation, teacher interviews, and written document acquisition. Use of multiple data sources allowed for "data triangulation" (Yin, 1994, p. 92). Triangulation of data reduces problems concerning construct validity.

I began data collection the summer before implementation of the RC when I conducted baseline interviews with the teacher. They focused on teacher beliefs and instructional practices. Beth's instruction from the previous curriculum was reconstructed using interviews that focused especially on lessons pertaining to limits, continuity, conceptual development of the derivative, the chain rule for differentiation, conceptual development of the integral, and integration by substitution. Informal observation data were also acquired during the second half of the last school year the teacher used the BR when the researcher spent 12 weeks in the teacher's calculus classroom. While no formal record of these

observations exists, it gave the researcher an opportunity to gain insight into the teacher's instruction in the previous curriculum.

The following school year, data collection consisted of observations of the teacher's instruction in the RC. The focus of the observations was Beth's instruction in the chapters devoted to the conceptual development of the derivative and integral. Also, lessons focusing on limits, continuity, the chain rule for differentiation, and integration by substitution were observed, with the exception of days entirely devoted to evaluation. For the remainder of the school year, a systematic sample of classroom observations was made. During this period, a minimum of one section in each chapter taught was observed. Lessons observed were audio taped, videotaped, and selectively transcribed. Handwritten field notes taken during each observation were used to construct a description of each observed lesson. This information was used to construct detailed notes of each class observed; on average, each description was five typed pages long. During the observations and the subsequent data analysis, the focus was on mathematics content, teacher actions and beliefs, assessment, technology use, and representations used in instruction. A total of 52 calculus lessons taught by the teacher in the RC were observed during the school year.

Teacher interviews were conducted after all observations, typically at the school immediately following the class observed. Any discussion of the Beth's planning process took place during these interviews that followed the observations. Depending on the teacher's schedule, the interviews were occasionally conducted later that day on the telephone. Longer interviews were also conducted before and after each chapter in the text and midway through the school year. All interviews were tape recorded and transcribed in their entirety. In all, 62 interviews were conducted. At the end of the school year, a final teacher interview was administered regarding the teaching and learning of mathematics and the Beth's own perceptions of her change process.

In addition, the following artifacts were collected from the teacher's instruction in both curricula:

(a) teacher lesson planning notes;

(b) all evaluation instruments and classroom handouts; and

(c) student notebooks to help document calculus lessons in both curricula.

Data Analysis

Qualitative methods were used to analyze the data collected for this study. They were analyzed using grounded theory methods (Strauss and Corbin, 1990). The particular manner in which the data were used is as followed. Field notes, interviews, and written documents were coded using conceptual codes. Coding the data helped the researcher find commonalties in it. Initially, these data were open-coded for rough categorization. During the coding process, the focus was on mathematics content, teacher actions and beliefs, assessment, technology use, and representations used in instruction. After initial coding, all documents were then re-examined as a part of the coding process. Axial coding techniques were then used to relate categories and their subcategories discovered during the open coding process. Any relationships between the different categories were examined to determine the presence of more abstract concepts that might link the less abstract categories (Strauss & Corbin, 1990). Concept maps were constructed to help in this process. Direct comparison of instruction in both curricula was also made. Multiple sources of data were used to validate the trends that emerged from the data. The multiple sources of data and their collection over 10 months reduced possible effects related to the teacher's own awareness as a participant in this study.

In order to compare evaluation instruments used by the teacher in the two curricula, all test and quiz questions were coded as procedural or conceptual. Evaluation questions were also coded as to whether or not they called for application of mathematics in a context. Comparison between the teacher's evaluation instruments was made using these criteria.

Results

At first glance, the teacher in this study maintained a relatively similar mode of instruction while using both curricula. Her practice revolved around demonstrating solutions to prototypical examples. However, several important changes in her practice were noted. These include an increased focus on conceptual knowledge and increased use of technology.

Teacher's Instruction in the BR curriculum

Beth's instruction in the BR curriculum followed a consistent pattern. Beth began class by grading students' homework, followed by students' questions on the previous night's assignment. Reading or introductory material in the text was rarely discussed in class and students were not required to read it: "The last book—myself, I read the sections [when planning], but nobody else did and all we did [were] problems". However, there were some exceptions to this. The BR's reading was occasionally, but not often, discussed in greater detail. When Beth did so, it was in the form of a lecture in which students participated by answering the teacher's questions the relating to various parts of the reading. These instances were early in the school year. For example, she discussed the reading's content in the text's first chapter in the lessons pertaining to limits and continuity.

Beth's presentation of new material followed a pattern that consisted primarily of solving prototype examples. She presented solutions to what she called the 'three-throughs' problems in the text (every third exercise in the problem set beginning with the third problem):

> I know a lot in this [previous] book ... I would give them enough examples so that mainly they had to just learn the examples that I did, and the other ones

> [in the assignment] matched fairly close[ly]. And so I didn't really challenge them to do new problems.

Here Beth largely guided students through the steps in the various types of problems. She would ask students to complete parts of the problems orally, using primarily lower-level questions. Normally, most of class time was used to present sample problems. Students would rarely have time to begin their assignment in class.

Teacher's Instruction in the RC

Insights into the Teacher's Plans For and Attempts at Change. Described here are the first stages of this teacher's change process, beginning with the teacher's choice of a reform calculus curriculum and continuing with its early implementation. Variations in her practice and the degree to which she was successful at her planned changes are also described. Insight into various factors that interacted with her change process is also provided.

In her last semester using the BR, Beth began her change process when confronted with the choice of a new calculus text. She enthusiastically began the process of text selection and sought out the advice of a university mathematics educator who recommended the RC (Hughes-Hallett, et al., 1994). After studying it, she decided that she wanted her school to adopt it. Beth chose this particular curriculum because she liked its application focus and its philosophy of learning: "Why I have picked this book. . . . in this [text's preface] about how the students learn from this book and the rule of three. I liked where they're going to make them do it. . . geometrically, numerically, and algebraically. . . Also they said their formal definitions and procedures evolve from the investigations of practical problems and that was another reason that I liked it. . . It had non-routine problems." (All quotes not cited are direct quotes from Beth.) The 'rule of three' refers to by the teacher pertains to studying various calculus concepts from three different points of view: algebraically, geometrically and numerically. This 'rule of three' is one of the cornerstones of the philosophy regarding the reform movement in calculus.

After the decision was made to adopt the RC, Beth made ambitious plans for its use, including many that were contrary to her past practices: "My number one goal would be to get them to read the book and number two would be for them to do more on their own ... for me not to do everything for them". She also hoped to have her class use graphing calculators. She also attended a week-long summer workshop for high school teachers on the reform calculus movement at a local university. This workshop's focus on projects had a particular effect on the teacher. Before the workshop, she seemed open to the idea of students completing projects, but after the workshop her enthusiasm for projects increased.

Overall, Beth looked forward to the upcoming implementation with enthusiasm, but she also had some concerns. Among her other concerns was the fact that the RC's problem sets were not constructed so that she could easily teach students how to solve the different problems using prototypical examples. This and the fact that the RC contained far fewer exercises than the BR influenced her to consider other instructional strategies.

When the school year began, Beth initiated some of her planned changes. She asked her students to read and take notes on the text reading and try some of the exercises before the lesson was discussed in class. Despite the Beth's enthusiasm for using the RC, the school year had a difficult start. Students' reaction to the course was both negative and vocal. One third of her students withdrew from the course in the first two weeks of the semester. Furthermore, the students that remained were often off-task and complained more than one might expect. Early in the school year, one student even commented in class: "I think we should go back to the old books and the old ways of teaching". Other students expressed similar sentiments.

Beth sensed her students' frustration but was unsure of its source: "They're frustrated . . . right now, and I don't know—I'm trying to teach it differently, but it's not that much different". She felt that one source of their frustration was her students' strong emphasis on earning high marks. This stressful beginning to the school year led to extreme teacher frustration.

As the semester progressed, students' negative reactions to the course did not decrease, but the teacher's level of frustration increased. She was also concerned that her students were having great difficulty understanding the review material found in the first part of the text. Student and teacher frustration finally influenced the teacher to modify her practice. Around three weeks into the school year, she stopped asking her students to read the text on their own and began demonstrating how to solve various problems before the students tried problems on their own:

> What happened at the beginning was that I tried to have them do it on their own and switched to trying to show them problems that matched [the assigned problems]. So I'll start them on [solving] the problems if I think they're going to struggle, but eventually I hope to get back where I don't have to do that, but with this group, I may not be able to.

However, Beth did not disregard the ideas in the RC's reading altogether. Instead, she began to present the reading material in the form of a lecture.

Although Beth's instruction remained similar in the two curricula in many ways, she was able to initiate important changes and hold on to hopes for continued change. Throughout the school year, she maintained a desire for students to complete projects. However, she never asked her students to complete the projects originally planned, citing time as a barrier.

General Portrait of the Teacher's Instruction in the RC. While some changes were never realized, Beth was able to accomplish other important changes, including an increased concept focus and graphing calculator use. Her increased

concept focus was influenced by the RC's conceptual focus. Over the course of the school year, she also used graphing calculators in important ways.

After the fluctuations in Beth's practice described earlier, a relatively stable pattern of instruction emerged during the teacher's first year using the RC. Class would normally begin with the teacher going around to students' desks to mark their homework. After students' homework was marked, Beth discussed the assignment. This discussion took on various forms. Sometimes she displayed a teacher-constructed answer key and made general remarks about how to solve various problems. When she had not constructed an answer key, she simply asked for student questions.

Following the discussion of homework, Beth presented the new material. This normally began with a lecture on the reading. Sometimes she would also discuss some of the examples found in the RC's reading. Occasionally, she would not cover a lesson's reading in class. This tended to be true when the topic was more procedural in nature.

An example of Beth's discussion of the text reading material can be found below in an extract from my notes. It comes from an introductory lesson on concepts related to the derivative. This lesson immediately followed one devoted to looking at the average rate of change of an object thrown into the air:

> The teacher introduced this section by saying: "We have not used the word derivative at all this year. Last year when I taught calculus and in previous years, my little definition of calculus was pretty much to learn to do derivatives and anti-derivatives and their applications. The derivative is a major topic in calculus and that is actually the start of what we're doing today. The derivative is just a rate of change." She then read from the text a discussion of the average change of the position function on the interval from a to $a + h$, making a connection with the first section that had discussed this idea in greater depth using the example of a grapefruit thrown in the air. She then referred to the point in the reading where the average rate of change of a function on the interval was defined for functions in general. She made connections between this and the definition of the average rate of change denoted by $\frac{\Delta y}{\Delta x}$.

Statements, such as these, that pointed out connections to previously studied ideas are indicators of the teacher's greater emphasis on concepts in the RC. This discussion continued:

> A student then asked the teacher if the average rate of change was "really just the change of y over the change in x", and the teacher replied "yes". This same student then asked "so what's the difference between this [the average rate of change over the interval from a to a+h] and the average velocity?" The teacher told him that they were the "Same. The average velocity and the difference quotient are the same … These two sections go together. The last section ... gives me one example [using the position function] and then this section goes for everything [all functions]. The average velocity that we found in the last section was just for the position function … It was a particular case. Now they're putting it for everything". The lesson continued where the teacher chose examples worked out in the text's reading to discuss. She intertwined this discussion with new, key definitions, which again connected back to the same ideas examined at in the previous day's lesson that examined the rate of change of an object thrown into the air. She also discussed, at length, the geometric visualization of the derivative of a function at a point. Finally, she summarized the two interpretations of the derivative at a point A.

After discussing the reading, Beth would typically present solutions to problems she chose from the text's exercise set. While presenting sample problems, she asked specific questions of different students as she carefully guided the class through the problems' solution processes. This discussion was often procedural in focus.

An important trend noticed during her presentation of sample problems was a tendency by Beth to sometimes give students rules beyond those found in the text to 'facilitate' solving the problems. This sometimes led to the proceduralization of a more conceptual problem. This tendency was especially prevalent when the teacher presented more procedural problems. Sometimes these rules were simply stated and not motivated by an explanation or discussion why the rule worked. However, this was not always true.

The final minutes of the class period were usually reserved for what Beth called "homework hints". The goal of the homework hints was to give the students a 'head start' on assigned problems that she had determined to be more difficult. Homework hints given varied from telling students what sample problems solved in class resembled assigned problems to starting a problem for students. Occasionally she would work out a problem out in its entirety.

At this point class time was nearly over. It was important to Beth that the majority of time was devoted to presenting new material. Little class time was allotted for students to begin their assignment as is common in many high school mathematics classrooms. At the end of class, Beth adjusted the homework assignment based on what sample problems had been presented in class.

Discussion

Comparing Beth's calculus instruction in both curricula, her practice remained unchanged in most ways. In both years, her goal was to show students how to do problems that she hoped would match those assigned. Despite this, she was

able to make modifications in her practice that included a greater focus on conceptual knowledge and the use of graphing calculators to teach calculus. She was able to accomplish these changes despite strong and sustained resistance from her students. This resistance and the teacher frustration that resulted from it influenced her to abandon several of the reform-orientated strategies implemented early in the school year.

The research on Beth's change shows that it is generally easier for teachers to make additions to practice than to modify existing practices (Garet & Mills, 1995). It is interesting to note that the changes in her instructional practice included both modifications and additions. The major addition to her instructional repertoire was her use of graphing calculator technology. The most important ways in which she modified her practice was an increased focus on concepts. For Beth, modifications of some prior practices proved especially difficult. This is demonstrated by the largely teacher-centered classroom that she maintained in spite a strong initial desire to put more of the responsibility for learning on her students.

This teacher was not only able to make additions but also modify her instruction in important ways. The primary way that she did this was through a greater focus on calculus concepts. The RC was very influential in helping her attain this focus. It is very likely that without it, she might not have changed to the same degree as she did. In a way, the RC served to help her overcome some of the barriers present in bringing about such a change.

Regarding my second goal, Beth's shift from practices early in the school year that encouraged more independent learning to instruction that focused more on demonstrating prototype examples was the major shift in her practice that took place during her first-year implementation. Giving students 'homework hints' was another instructional strategy that this teacher developed over the school year. This change also influenced the degree to which her classroom was teacher-centered.

The relative stability in this teacher's practice emerged despite her ambitious plans for change. Initially, she implemented many of her plans to use 'reform-orientated' strategies. However, her students resisted them. This resistance was key in this teacher's change process. Other research (Bruckerhoff, 1994; Duffy & Roehler, 1986) has found student resistance to be a change impediment. Without this resistance, she may have continued with the changes she had instituted at the beginning of the year and perhaps instituted even more as the year progressed. Had this occurred, her change process may have looked very different.

Changes in Instructional Practices

Two major trends emerged during Beth's first year using the RC that set it apart from her instruction using the BR: an increased focus on conceptual knowledge and use of technology. Her technology use was influenced by the RC, yet she also developed her own ways of integrating technology into her instruction. Her greater emphasis on conceptual knowledge was due to the more conceptual nature of the problems solved in class and completed on assignments as well as her choice to discuss concepts found in lesson's introductory reading of the RC.

Focus on conceptual knowledge. Beth's instruction in the RC focused to a much greater extent on important calculus concepts relative to that in the BR. This change was influenced, but not merely a result of, the RC text's conceptual focus. This greater focus on concepts was not without some struggle on the Beth's part: "You kind of struggle with the procedures or presenting concepts. I think that the older book—you really were doing more procedures where this one is actually more conceptually [orientated]—the new book is". This struggle was a difficult one for Beth, perhaps because of her own beliefs regarding the discipline of mathematics. She believed that she held more procedure-orientated beliefs: "In the new book they start from the conceptual view and so you're asked to do that. You know, I'm more of a numbers person". Her underlying beliefs are in many ways opposite to the views of the curriculum she had chosen. This underscores the importance in her change process of the instructional decisions she made that favored conceptual knowledge.

During her implementation of the RC, Beth made a *conscious choice* to focus on the introductory reading material. In the BR, she rarely discussed in-depth the conceptual ideas found in the reading even though they were often discussed in the BR's reading. Her decision to focus on the RC's reading was an important factor in her greater focus on concepts when using the new text. When she first used the RC, she asked students to read and study the text. While she quickly changed this practice, she did not abandon the ideas in the reading altogether and comfortably revert to her old routines. Instead, Beth adapted her strategies to include a presentation of the reading's ideas. Her choice to focus on the reading had important effects regarding her use of class time. It shifted the distribution of class time away from demonstrating solutions to prototype problems, which accounted for the majority of the class time when she used the BR, to a greater emphasis on discussing the concepts in the reading. The more problem solutions demonstrated in class, the more quickly she could cover material. For Beth, pacing and 'covering material' were of utmost importance. The fulfillment of pacing goals was often the greatest factor she used in determining whether or not a particular lesson 'went well'. Her decision to devote class time to the discussion of the reading was a difficult one for her, and she had to reaffirm it each time she planned a lesson. This underscores the importance of *her choice* to focus on the reading and its subsequent impact on her change process.

The nature of the problems discussed in class and those that Beth asked students to complete in their assignments also influenced her focus on concepts. The importance she placed on conceptually orientated exercises was particularly

influential. The emphasis in class that Beth placed on a particular problem was a *conscious choice* on her part and not a decision dictated by the RC. Again, this is a stronger indicator of teacher change, and not simply a case of a teacher carefully following a text. While using the RC, Beth gave added emphasis in several instances to problems of a highly conceptual nature. These often involved applications. This was done despite her strong concern for pacing. This is an indicator of stronger teacher changes than merely following closely a particular text.

Below I provide one instance in which Beth went beyond the RC's focus on concepts. In the chapter devoted to the conceptual development of the derivative, interpreting the meaning of the derivative in various contexts was studied. Beth liked the text's emphasis on asking students to explain the meaning behind a derivative in a contextual situation and saw it as typical of the RC's focus on concepts:

> Some of the problems ... it was just kind of neat some of the problems they would give—They would ask you to explain, in words, what [the derivative] meant. I've never been asked that before. It even made me stop and think 'what are they doing here?'.

Beth believed that the RC's focus on explaining the meaning of derivatives in applied settings was important and it influenced her to later write her own extensions of a similar nature for several problems in the RC. Such extensions were not something proposed by the RC and give further evidence of Beth's change relative to her focus on concepts.

Use of graphing calculator technology. Another important change in Beth's instruction concerns her use of graphing calculator technology. Edwards (1996) as well as Tucker and Leitzel (1995) describe calculus teachers' abilities to implement technology as they worked to reform their instruction. In her implementation of the BR, Beth used no technology other than the scientific calculator with the exception of a two-week add-on unit at the school year's end that focused on various graphing applications of the graphing calculator.

When using the RC, Beth furnished students with a graphing calculator, and they used it on a regular basis throughout the school year. Its use dropped off—but did not disappear—in her instruction chapters devoted to procedures for finding derivatives and anti-derivatives. Of course, the RC and its technological focus influenced this change; Beth commented several times how she would have had to eliminate some of the material in the RC if the appropriate technology had not been available.

While technology use by Beth was heavily influenced by the RC's technological focus, deeper changes regarding technology use by Beth were also noted. In several instances, she used technology in novel ways not called for by the RC. For example, she presented in class the solution to a problem that asked for the derivative of $f(x) =$ arctangent$(x) +$ arctangent$(1/x)$ for $x > 0$. After calculating a zero derivative for this function, she explained plans for showing students on the graphing calculator that $f(x)$ represents a horizontal line and, as such, has a derivative of 0. Beth wanted to "make sure they understand that's a constant function, and then what I was going to have them do was use their graphing calculator—that means the original function when I graph it—it better be a line" if it has a constant derivative. For her, the graphing calculator was becoming a tool that could help her reinforce and connect ideas together.

Further demonstrating the extent of her change with respect to technology, Beth started to use graphing calculators with her algebra classes in ways that she had not in the past. The algebra text she used did not advocate technology use, and it certainly could have been implemented without it. In prior years, she had used graphing calculators to a very limited extent to teach algebra. This was primarily during her presentation of linear and quadratic functions.

While the RC was very influential in the changes in her calculus course, it is certainly not responsible for the full extent of her change. The fact that technology use was becoming a part of her instructional decision-making in not just her calculus class, but also her other classes, demonstrates this.

For this teacher, the change process was influenced by several factors. Her students' beliefs and attitudes, the reform-orientated curricular materials, and prior and emerging teacher beliefs were all inter-related in their effects on the change process. The curriculum materials themselves, coupled with an open-attitude on the part of the teacher worked together as a catalyst for change. Student resistance worked to slow down the effect of this catalyst. In a way, it helped re-emerge the teacher's prior beliefs that were less aligned with the reform movement. The change process itself also influenced these same factors.

Conclusion

Because of the nature of this study, one can not conclude that all high school mathematics teachers would react the same way when using the RC for the first time. However, Beth's story helps those concerned with the teaching and learning of mathematics better understand the complex environment that is the high school calculus classroom and the positive impact that reform curricula can have on it. Since the RC materials appear to have had an important influence on Beth's practice, other high school calculus teachers in similar settings might also find them beneficial.

This teacher's change process was greatly influenced by the reform-oriented curricular materials as well as the students she taught. Such influences lead to potential research opportunities. What are the struggles of students new to learning in more reform-oriented classrooms, and how might their transition be eased? The students in this study had difficul-

ties reading the calculus text independently. How might teachers help students use more effectively reform mathematics texts?

The role that the RC played in this teacher's change process was critical. Reform-oriented curricular materials can be a change catalyst for high school mathematics teachers even in unexpected settings, such as this one. Studies of how teachers engaged in the reform process use successfully reform-oriented curricular materials and their accompanying ancillary materials would have important implications for teacher change. Which particular aspects of reform curricula promote change and which are less effective? Studies of ancillary materials may be an especially consideration for teachers using reform curricula who have little or no access to professional development opportunities. Such studies might have important implications for those hoping to promote teacher change as well as for those who design reform-oriented curricula.

The changes that this teacher underwent as she first used the RC are not 'revolutionary', and it would be difficult to argue otherwise. The changes discussed here are just 'small steps' towards a learning environment that focuses to a greater extent on understanding calculus and not merely on being able 'to do' calculus. Mathematics teachers hoping to change their instruction have had various degrees of success. Changing established classroom instructional routines is very difficult, yet this teacher made important progress in this area. The teacher's openness toward change and how this contributed positively can not be underestimated. It is particularly interesting that Beth accomplished these changes largely on her own, without any ongoing professional development or support of any kind. What Beth might have accomplished with the aid of an ongoing professional development program or collaboration with other teachers engaged in change will never be known but may have been significantly greater than seen here.

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