Mathematics Teacher’s Role in Promoting Classroom Discourse

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Abstract
Recent mathematics education reform calls for efforts to create collaborative and student-centered environments, where students have opportunities to reason and construct their understanding as part of a community of learners. Mathematics instruction should provide students opportunities to engage in mathematical inquiry and meaning making through discourse. While there have been successes to this end, traditional models of instruction still dominate mathematics education especially at the high school level. This can be attributed, in part to the teachers' role and their ability to successfully organize and facilitate collaborative classroom practices as called for by the reform movement. This qualitative study illustrates how one high school mathematics teacher engaged his students in classroom discourse and promoted in them the use of appropriate mathematics language to communicate their thinking and make sense of mathematics concepts. The study also shares students’ perceptions of the teaching approach. The findings of the study suggest that while the mathematical dispositions of students depend significantly on their prior experiences they can be transformed over time by a teacher’s pedagogical practices. This research recommends that high school mathematics teachers adopt some of the more recent reform-based instructional strategies that have been underutilized in these classrooms.

Keywords: Mathematics teacher, Discourse, Communication, Mathematical Language, Secondary school
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Introduction

In mathematics, studies have shown that instruction, especially at the high school level, remains overwhelmingly teacher-centered, with greater emphasis placed on lecturing than on helping students to think critically and apply their knowledge to real-world situations (Cobb, Wood, Yackel, & McNeal, 1992). According to Stodolsky and Grossman most high school mathematics teachers see mathematics as a rigid and fixed body of knowledge, and think that their responsibility is to transmit this knowledge to their students (1995, as cited in Staples, 2007, p. 165). Cuban (1984) delineated the features of such teacher-centered instruction as favoring teacher-talk over student-talk and include situations in which the teacher directs instruction to the whole class rather than working with small groups of students or with individual students.

In contrast to this approach, the National Council of Teachers of Mathematics (NCTM) advocates for the development of an inquiry-based mathematics tradition. In an inquiry-based environment, learning is viewed as an active, constructive activity in which students are encouraged to explore, develop conjectures, and problem solve. Students are also encouraged to discuss and communicate their ideas and results, often within small, cooperative groups as well as with their teachers. NCTM authenticates the value of inquiry-based mathematics instruction by calling for efforts aimed at creating collaborative and student-centered environments, where students have opportunities to reason and construct their understanding as part of a community of learners (NCTM, 1989, 1991, 2000). Mathematics instruction should provide students opportunities to engage in mathematical inquiry and meaning making through discourse, and teachers should encourage this process by remaining flexible and responsive to students’ response and feedback (NCTM, 2000).
A crucial aspect of a classroom in which students are actively engaged, is to focus on classroom discourse. Discourse is defined as “purposeful talk on a mathematics subject in which there are genuine contributions and interaction” (Pirie & Schwarzenberger, 1988, as cited in Truxaw, Gorgievski & DeFranco, 2008, p. 58). Discourse not only promotes the development of shared understandings and new insights but also contributes to deeper analyses of mathematics on the part of the teacher as well as the student (Manouchehri, 2007; Manouchehri & St. John, 2006). A key element of discourse is the need to use mathematics language and articulate mathematics concepts in order to learn both the language and the concepts.

**The study**

This study illustrates how one high school mathematics teacher orchestrated classroom discourse and promoted the development of mathematics language in order for students to better grasp the underlying mathematical concepts. The study also examines students’ mathematical dispositions as a result of participating in such a classroom environment in which the teacher encouraged discourse and the use of appropriate mathematics language in problem solving. Dispositions refer not simply to attitudes, but to the tendency to think and act in positive ways (NCTM, 1989). Students' mathematical dispositions are manifested in the way they approach mathematical tasks, whether with confidence, willingness to explore alternatives, perseverance, interest and in their tendency to reflect on their own thinking. As such, the mathematical dispositions of students are intertwined with their capabilities to explore, conjecture, reason, and communicate their mathematical thinking.

The current shifts in curricular and instructional contexts place special emphasis on students’ active engagement, on solving non-routine problems, on applying mathematics to new situations and on communication regarding mathematical problems. Such changes in the
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curriculum, due to their novelty as well as their difficulty in implementation may cause more affective responses in students and teachers (Lubienski, 2002). Since learning is always accompanied by motivational and other affective processes, these may impact on students’ construction of knowledge. Thus there is a need to research students’ experiences when classroom practices change from a predominantly behaviorist approach towards a more inquiry-based learning.

Literature

According to Stein (2007), reform-based mathematics is focused on the idea that mathematics should be taught in a way that encourages students to use “mathematical discourse to make conjectures, talk, question, and agree or disagree about problems in order to discover important mathematical concepts” (p. 285). According to Truxaw and DeFranco (2007) participating in a mathematical community through discourse is an important step for learning mathematics and for conceptual understanding. They note that mathematical communication is necessary for ideas to become objects of reflection, refinement, discussion, and amendment. Kabasakalian (2007) supports this point by noting that the vehicle that promotes understanding of mathematical concepts is the ability to process language, an ability that a lot of middle school and high school students still need to learn and develop. This position has also been endorsed by NCTM which calls for instructional programs to enable students, to use the language of mathematics to express mathematical ideas precisely, communicate their mathematical thinking coherently and clearly to peers, teachers, and others and to organize and consolidate their mathematical thinking through communication. NCTM notes that communication is an essential part of mathematics and mathematics education and formal mathematical terminology is an indispensable component of this communication (Davis, 2008). Noting the importance of
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communication in the mathematical process, Thompson and Rubenstein call for the need for students to know the meaning of mathematics vocabulary words, whether written or spoken, in order to better understand and communicate mathematical ideas (2000, as cited in Gay, 2008). In learning mathematics, it is important for students to use the correct mathematical terminology, learn how to translate mathematical expressions into verbal problems and how to translate verbal problems into mathematical expressions that can be worked with (Askey, 1999). Students will then be engaged constructively in mathematical discussions while solving problems by proposing, formulating, conjecturing, and justifying mathematical ideas and by evaluating the mathematical ideas of their peers.

In addition, noting the importance of communication in the mathematical process, Kotsopoulos (2007) points out that students experience interference when they borrow language from their everyday lives to use in their mathematics world, such that their inability to minimize this interference could potentially undermine their ability to learn. Based on this point, Adler (1999) suggests that it is important for teachers to set up learning opportunities that encourages students to use mathematical language themselves, so as to better grasp the underlying mathematical meaning of concepts (as cited in Kotsopoulos, 2007). To achieve these benefits outlined by Adler, teachers must create environments free of hierarchies and encourage collaborations amongst students. In the same token, they must remain mindful of their use of vocabulary because they directly contribute to students’ understanding or (mis?) understanding of concepts (Gay, 2008). By encouraging students to verbalize what they mean and reiterate what their peers have said, teachers can make it easier for reluctant students to contribute (Manouchehri & St. John, 2006). This is based on the premise that explicitly referencing and
building on the ideas of others, is a feature of academic and professional discourse (Choppin, 2007).

Our study contributes to the body of research by illustrating how a teacher can effectively orchestrate classroom discourse so that students better grasp the underlying mathematical meaning of concepts.

**Theoretical Consideration**

The study draws on the socio-constructivist theory of learning (Cobb, 1994; Cobb, Wood & Yackel, 1992). From a socio-constructivist perspective, a learning environment can be created where students construct their mathematical knowledge through interactive inquiry-based activities. Several key components are important for inquiry-based learning. These are exploring, conjecturing, generalizing and communication. The exploring process can promote students’ inquiry and investigation of the task while the conjecturing and generalizing processes provide a means for students to construct their own mathematical knowledge. The communication process helps build meaning and permanence for ideas (NCTM, 2000). The socio-constructivist perspective emphasizes the role of others in constructing understanding. Socio-constructivist theories call for students to co-construct their knowledge through collaboration with their peers on meaningful activities. Dialogue and collaboration are seen as key to learning success. The social context constructed in the course of their interaction helps to enhance the students’ thinking and learning in the classroom. Students’ active participation and decision-making in the daily life of the classroom and school build responsibility and ownership for learning. These, in turn, become intrinsic motivators for further learning and resiliency.

The teacher’s role from a socio-constructivist perspective is that of a facilitator to students learning; guiding and supporting students’ construction of viable mathematical ideas.
According to Bruner (1986), the constructivist teacher by offering appropriate tasks and opportunities for dialogue, guides the focus of students’ attention, thus unobtrusively directing their learning. A teacher teaching from a constructivist perspective must have the ability to pose tasks that bring about appropriate conceptual reorganizations in students’ thinking. Such a teacher must therefore be skilled in structuring the intellectual and social climate of the classroom so that students discuss, reflect on, and make sense of these tasks.

**Methods and Procedures**

This qualitative study is grounded in constructivist inquiry (Guba & Lincoln, 1989, 1994; Lincoln & Guba, 1985). The study is context specific. In this sense, the study intends to share the ideas and experiences of the participants and hopes that others will identify with the research context and apply the findings to their own particular settings. Participants of this study were secondary students enrolled in an *Introduction to Calculus* (IC) course in a public high school located in Midwest USA. The socio-economic background of students in this school district varies from low middle class to high middle class families. The school district mathematics program has three different calculus courses, namely, the *Advanced Placement BC* and *AB Calculus*, and the *Introduction to Calculus* (IC). Both AB and BC calculus courses represent college-level mathematics for which most colleges and universities, nationally and internationally, grant advanced placement (AP) and credit. Students who drop out of the prerequisite track for the advanced placement BC and AB courses may enroll in the *Introduction to Calculus* (IC) in the 12th grade, the final year of secondary school. Students may also transfer into the IC course during the first semester of their 12th grade year in lieu of receiving a poor grade in the advanced placement AB and BC courses. In any case, most students who enroll in this course assume that they are not as smart as those in the AP calculus classes. The IC course
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focuses on functions and limits, differential and integral calculus. There is no exam required for this course, which gives the classroom teacher flexibility to teach without the pressure that comes with preparing students for mandatory state tests. The research team included the classroom teacher, who taught from a constructivist perspective, and two university professors.

Data Sources

Data sources included transcripts of audiotapes from classrooms observations for an entire school year as students solved problems and communicated their mathematical ideas, students’ written responses to non-routine problems, researchers’ field notes and transcripts of audiotapes from in depth interviews with six selected students regarding their attitudes and experiences in the mathematics classroom. The interview questions were developed collaboratively by the research team. The research team had a focus group discussion once a month about their understanding and interpretation of the data. These discussions were also audiotaped. Data collection and analysis occurred independently and simultaneously.

Promoting classroom discourse and communication

The teacher in this study used word problems to promote mathematical discourse and communication. Word problems serve as a powerful tool to exploring mathematical concepts and forming connections (Kabasakalian, 2007). This viewpoint is supported by the NCTM (1991; 2000), which proposed that problem solving should be one of the key goals of mathematical instruction.

To engage his students in mathematical discourse, the classroom teacher incorporated four instructional strategies inspired by Hufferd-Ackles, Fuson, & Sherin (2004)’s, four levels of math talk learning community framework, namely Questioning, Explain math thinking, Source of mathematical ideas, and Responsibility for learning. These were modified for the context of
this study and renamed, Establishing expectations, Mathematics language, Mathematics community and Establishing formal discourse. The classroom teacher used the first strategy, *Establishing Expectations*, to communicate his expectations regarding how to talk and write about mathematics. This was the dominant strategy used by the teacher in the first six weeks of instruction. The second strategy, *Mathematics Language*, dominated classroom interaction from week seven through week twelve. In this strategy, the teacher encouraged the students to use adequate mathematics language for communication by shifting from informal to more formal mathematical language. In the third strategy, *Mathematics Community*, dominant from around week 13 to the end of the school year, the students used more formal mathematical language and became more confident in their abilities for problem solving and mathematical communication.

In the fourth strategy, *Establishing Formal Discourse*, students exhibited a sense of mathematical empowerment and communicated their ideas using formal mathematical language. This strategy dominated classroom interactions from around week 19 to the end of the school year.

These four strategies should not be viewed as linear and sequential. They were interactive and emerging in which at each stage of classroom discourse two or more of the instructional strategies were present but one of these was dominant. The four strategies are summarized below;

**Strategy 1** - Establishing expectations: Students listen and sequester tentative responses; teacher leads and dominates.

**Strategy 2** - Mathematics language: Students reflect and contribute truncated responses; teacher prompts and pursues.
Strategy 3 - Mathematics community: Students speak and attempt formal discourse; teacher observes and facilitates.

Strategy 4 - Establishing formal discourse: Students analyze and dominate the formal discourse; teacher monitors and assists.

Four sample lessons are selected for commentary because each lesson employs a particular pedagogical strategy. The lessons are presented in succession midway through the first semester, a time of the year when most students prefer the first strategy, accept Strategy 2, tolerate strategy 3, but resist strategy 4.

The mathematical content of each lesson pertains to the line that is tangent to a graph for a given function at a given point on a graph for the function. For each lesson, students use the same four tasks to investigate important mathematical ideas.

Given: Let function \( f = \{(x, y): x \in \mathbb{R} \text{ and } 0 \leq x \leq 2 \text{ and } y = 4x^2 + 5\} \) and consider the Line \( l \) that is tangent to a graph for function \( f \) at the point where \( x = 1 \).

Task A: Use a graphing calculator to view a graph of \( Y_2 = (4X^2+5)/(0 \leq X)/(X \leq 2) \) in [-1, 3.7] X [-5, 26]; draw a complete graph for function \( f \) on the grid provided.

Task B: Use either nDeriv\((Y_2,X,1)\) on the MATH menu or dy/dx on the CALC menu to find an approximate value for \( f'(1) \); use the definition to find the exact value.

Task C: Use Tangent on the DRAW menu to investigate a graph for Line \( l \); use an analytical method to find an exact equation for Line \( l \).

Task D: On the same axes as the graph for function \( f \), draw a complete graph for Line \( l \); plot and label the point of tangency.

For each lesson, an 8½×11 worksheet stated the pedagogical strategy for conducting the lesson, identified mathematical tasks for investigating important ideas, provided a blank grid for
drawing graphs, and allowed sufficient space for indicating methods, explaining thinking, and justifying responses. All four lessons revisited Tasks A, B, C, and D and thus relied on the same given function, the same tangent line, and the same graphs. However, the pedagogical strategy and mathematical content varied among lessons in that each successive lesson employed an increasingly sophisticated strategy and included an additional task that extended the lesson.

**Commentary on Lesson 1**

The worksheet for Lesson 1, titled *Listen Up and Take Notes*, directed students to:

- Complete Tasks A, B, C, and D; use Strategy 1; indicate your methods and justify your responses; in addition, find an equation for the line that is tangent to a graph for the function defined by the equation $y = 4x^3 + 5$ at the point where $x = 2$.

As such, the role of the students was to listen and to offer tentative responses by maintaining silence as they watched the teacher, by responding mentally to rhetorical questions posed by the teacher, and by copying the work of the teacher. The role of the teacher was to lead and to dominate the lesson by speaking in a purposeful manner, by demonstrating every detail on the chalkboard, by explaining his mathematical thinking, by justifying his mathematical methods, and by telling students what to write on the worksheet. The teacher purposefully employed Strategy 1 in order to build relationships with students and to connect with their prior experiences. When the worksheet for Lesson 1 was distributed to the class, students waited for directions and explanations. Students were comfortable when the teacher established social norms.

**Tchr:** I will talk about the complete graph for the given function $f$ and the Line $l$ that is tangent to the graph of $f$ at the point where $x$ equals one. I will use Strategy 1; I talk; you listen; pay attention; take good notes; you need to know this for
tomorrow. Hold your questions until I finish explaining everything. Ten points for completing the worksheet, provided you don’t interrupt the lesson. Points off for talking.

The critical features of Lesson 1 were first, the manner in which the teacher transformed his own informal language into formal language. He did this by using standard mathematical vocabulary and graphing calculator syntax to clarify a directive.

Tchr: Key it in. By it, I mean the expression \(4x^2 + 5\) and by “in”, I mean \(Y_2\) on the “Y=” screen. I’ll say it again without pronouns. Go to the function screen on your calculator by pressing the “Y=” key. On the function screen, enter the expression \(4x^2 + 5\) to define \(Y_2\).

The second critical feature of Lesson 1 was the manner in which students became aware of the important differences between informal language and formal language. That was, informal language was riddled with pronouns; formal language was clarified with standard mathematical vocabulary.

Tchr: [pointing to a graph on the chalkboard] See how it touches right here? See how it, this line, touches this graph right here, at this point? See how this line, Line \(l\), touches the graph of function \(f\) right here, at the point \((1, 8)\) where \(x\) is one and \(f\) of one is \(8\)? Line \(l\) is tangent to the graph for function \(f\) at the point where \(x\) equals \(1\).

The third critical feature of Lesson 1 was the manner in which students’ experiences in prior mathematics classes strongly influenced their attitudes, behavior, and expectations. Relying on old habits, students expected to remain silent and copy the work of the teacher. Students either answered rhetorical questions mentally without revealing their level of
understanding or they ignored rhetorical questions altogether with impunity. In either case, Lesson 1 was safe and virtually risk free for students. Moreover, students were also accustomed to earning participation points for their cooperation; they equated *cooperation* with *silence*. Students cooperated by letting the teacher respond to his own rhetorical questions.

As the lesson proceeded, the teacher completed Tasks A, B, C, and D, and then entertained questions from students. When students attempted to formulate questions, they reverted to old habits. Most troublesome for the teacher was the infantile language used by otherwise mature, successful and articulate students when they tried to pose mathematical questions. Typically, students avoided standard mathematical vocabulary; their questions were short and vague. The teacher must guess the meaning. For example,

S 2: I?

S 3: How do you do it?

S 4: About that. You know?

At the end of the lesson, students placed their completed worksheets into their portfolios; all students earned at least 9 out of 10 possible participation points. Generally, students were upbeat, satisfied with the lesson, and pleased with their points. The teacher, on the other hand, was concerned about cognition, wondering if students thought more clearly than they spoke. The teacher was also skeptical about participation points, conceding that Strategy 1 enabled students to amass points simply by maintaining silence while they copy notes from the chalkboard.

**Commentary on Lesson 2**

The worksheet for Lesson 2, titled *Say “It” in Words*, directed students to:
Complete Tasks A, B, C, and D; use Strategy 2; indicate your methods and justify your responses; in addition, write step-by-step instructions in general for finding an equation for the line that is tangent to a graph for any given function at any given point on a graph for the function.

As such, the role of the student was to reflect and to contribute truncated responses by formulating a brief but meaningful response before responding aloud; that was, to experiment with formal language. The role of the teacher was to prompt and pursue by posing questions in order to elicit truncated responses, by delving or challenging with follow up questions in order to engage students in brief conversations to clarify responses, and by remaining vigilant in order to ensure that classmates did not distract students who were formulating responses.

When the worksheet for Lesson 2 was distributed to the class, students waited patiently for directions and explanations. Students expected to listen, copy notes, remain silent and earn participation points; they were somewhat apprehensive when the teacher established social/behavioral norms.

Tchr: Strategy 2. I ask a question; you answer. Use vocabulary words; not pronouns.

No its. And don’t interrupt the speaker.

The critical features of Lesson 2 were first, the manner in which students perceived the role of the teacher, as the sole authority in the classroom. Instead of attempting the tasks, students waited for the teacher to start talking. Students seemed to equate teaching with telling. They did not seem to realize that the tasks for Lesson 2 were identical to the tasks for Lesson 1.

S 5: Can you tell us what to do?

Tchr: I did that yesterday. Do you recognize the function?

Grp: [chatter, agitation]
S 6: Can you explain it again, in English? I learn better when the teacher teaches.

Tchr: I taught it yesterday. I’m not so sure you learn better when the teacher teaches.

Grp: [chatter, agitation.]

When the teacher directed students to look in their portfolios for complete responses on the worksheet for Lesson 1, students indicated that Lesson 1 was less than effective. Although Lesson 1 was well suited for modeling formal mathematical language, it was not well suited for helping students to connect the formal language to important mathematical ideas. Nevertheless, students persisted in requesting yet another teacher dominated lesson that avoided standard mathematical vocabulary and notation.

Tchr: Okay, okay. Apparently, yesterday didn’t make sense. Maybe I did all the talking and maybe I was too formal. Okay, I’ll explain it again. I’ll use informal everyday English instead of standard mathematical vocabulary. Okay?

Grp: [chatter and agitation subside]

Tchr: We will talk about the complete graph for the given function \( f \) and the Line \( l \) that is tangent to the graph for function \( f \) at the point where \( x = 1 \).

S 6: English?

Students do not equate English with English. English does not refer to the standard English language. Rather, English refers to the informal language that students use for everyday communication. As such, English includes not only pronouns, slang and quasi-foreign expressions but also non-verbal glyphs, grunts, and gestures.

Tchr: Okay, okay, not formal, informal. In English.

Tchr: [mimicking and exaggerating informal language patterns] I will talk about it and this one. Plug it into the calculator and it’s approximately eight. It’s \( f \); so it’s \( 4x^2 \)
+ 5. When it’s zero, it’s five and when it’s one, it’s nine. Plug it into the original problem, work it out, it’s exactly eight. Plug it into the problem, work it out, it’s $y = 8x + 1$. So it’s 1. See?

Grp:  [chatter and agitation]

Tchr: The problem is: Too many pronouns. Each *it* refers to something different. You must say *it* in words. Clarify; use antecedents. Don’t use pronouns. Don’t say *it*.

Grp:  [silence]

The second critical feature of Lesson 2 was the manner in which students transitioned from informal language to formal language. The teacher employed Strategy 2 as a remedy for the problem in which students’ used informal language riddled with too many pronouns. By adhering to five powerful rules of engagement for classroom discourse, the teacher helped each and every student to formulate at least one meaningful response during the lesson.

Rule 1: Call upon each student individually by name.

Rule 2: Pose a question that the student should be able to understand.

Rule 3: Guarantee a reasonable length of time for the student to formulate a response.

Rule 4: Verify that the response is meaningful; delve or prompt to clarify, if needed.

Rule 5: Validate the significance of the response before engaging the next student.

In an example for the rules of engagement, the teacher called on a student who memorized vocabulary by using flashcards and by working with a tutor. The teacher posed a question and then listened carefully to the response to judge whether the response was meaningful. To conclude, the teacher validated the response by acknowledging the time and effort required to learn and use formal language.

Tchr: To start us off, (S7), in words, what does $f$ prime of $t$ denote?
S7: When \( t \) denotes a number in the domain of a function \( f \), then \( f \) prime of \( t \) denotes the slope of the line that is tangent to a graph for function \( f \) at the point where \( x \) equals \( t \).

Tchr: [Nodding affirmative.] Thank you, (S7), for using formal language. Memorized?

S7: [Nodding affirmative.]

Although (S7) responded without hesitation, Strategy 2 often involved more than a quick recitation of a memorized definition. Hesitation was expected but not always problematic. For example, classmates did not generally interrupt a student who they perceived as a high achiever. Hesitation became problematic, however, when classmates tried to help a student who they perceived as a low achiever. Impulsive whispers to a student who was taking time to formulate a response could jeopardize the guarantee of a reasonable length of time needed to formulate a response. By whispering, classmates unwittingly identified the students who they perceived to be low achievers.

Tchr: When trained observers come into my classroom, I want those observers to have a hard time distinguishing between high achievers and low achievers. I want everyone to look like a high achiever. When students are treated like high achievers, they behave like high achievers. So let’s treat everyone like high achievers.

S 8: What if they do need help?

Tchr: [Interpreting (S8) as: What if I can’t answer the question?] When I call on you, some rude classmate may say to you: 'Let me answer that question for you because I’m ever so much smarter than you.’ You don’t need that kind of help. Ignore it.
As the lesson proceeded, the teacher avoided calling on a student more than once unless every other student had an opportunity to respond. Students generally gave terse, truncated and vague responses. The teacher continued to prompt and delve until responses made sense. The significance of a response was more closely related to the process of formulating a meaningful response than to the practice of calculating a correct numerical result. In an example for the transition from informal language to formal language, a student responds to a question using pronouns and then formalized the response by replacing pronouns with standard mathematical vocabulary or notation.

Tchr: So, (S 9), $f$ of $x$ is $4x^2 + 5$. What is $f$ of zero?

S9: It’s five.

Tchr: What $it$ is five?

S9: Zero is five.

Tchr: Zero and five are two different numbers. Sorry, but zero is not five.

S9: It’s still five, you know.

Tchr: Yes. $It$ is still five. What $it$ is still five?

S9: You know. I just can’t say it.

Tchr: When you can’t say $it$ as a fact, ask $it$ as a question. We’ll give you a minute to collect your thoughts. What $it$ can’t you say?

S9: You know. How do you say what the $f$ of the zero is? Oh! $f$ of zero is five.

Tchr: Sounds good. Spoken with authority, like a college professor: $f$ of zero is five.

As students learned to speak with authority, they began to justify their own results; their dependence on the teacher, as the sole authority in the classroom, diminished.
On the following day, students worked independently on the additional task. The third critical feature of Lesson 2, was the manner in which students combined speaking with writing in order to clarify their thinking. Students attempted to write step-by-step instructions in general for finding an equation for the line that was tangent to the graph for any given function at any given point on a graph for the function. The teacher offered suggestions to help students get started.

Suggestion 1: Pick any step that makes sense to you and say it to yourself; use pronouns.
Suggestion 2: Write the step exactly the way you said it to yourself including pronouns.
Suggestion 3: Replace pronouns with standard mathematical vocabulary or notation.
Suggestion 4: Revise the step until it makes sense to you and to the person next to you.
Suggestion 5: Repeat the process and arrange the steps in an order that makes sense.

Multiple conversations emerged in the classroom as students attempted to write and revise the steps. As conversations developed, the teacher moved around the classroom to hear the comments. The teacher prompted and pursued some of the comments in order to facilitate as students transitioned from informal to formal discourse. Most students wrote a partial list of vague steps and had enough time to work on formalizing only one of them. Several students, however, wrote more complete lists that included more than one precise, clearly worded step.

Generally, students accepted Strategy 2 as a viable pedagogical strategy and valued its potential but they were not completely satisfied with Lesson 2. First, students felt that the teacher consumed too much time talking with individuals rather than to the whole class. Second, students felt threatened by lessons that involved academic risks and social spotlights. Third, students lost focus and questions become repetitive. Fourth, students disliked the inherent lack of closure for open-ended lessons. The teacher was encouraged because Lesson 2 provided for multiple levels of questioning, provided for varying levels of review on a need to know basis, and provided for
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differentiated levels of thinking, speaking and writing mathematically. The teacher, however, remained somewhat skeptical, commenting that students appeared to be happy to earn participation points for work that they did not value.

Commentary on Lesson 3

The worksheet for Lesson 3, titled Two by Two, directed students to:

- Complete Tasks A, B, C, and D; use Strategy 3; indicate your methods and justify your responses; in addition, work with a partner to memorize an analytical method for finding an equation for the line that is tangent to a graph for a given function at a given point.

The role of the students was to attempt using formal discourse by acquiring and practicing skills for thinking, speaking and writing about important mathematical ideas. The role of teacher was to observe and facilitate by walking around the classroom, by listening to conversations, and by coaching, challenging and encouraging students as they transitioned from informal language to formal discourse.

When the worksheet for Lesson 3 was distributed to the class, the teacher established social/behavioral norms.

Tchr: Today, the plan is for everyone to work with a partner and to complete Tasks A, B, C and D; more importantly, your job today is to make sure that both you and your partner memorize an analytical method for finding an equation for a Line $l$ that is tangent to the graph for a given function $f$ at the point where $x$ equals some constant $t$. Make sure that both of you understand your method thoroughly. Quiz tomorrow. The sum of your two scores will count for both of you.
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The critical features of Lesson 3 were first, the manner in which the class became aware of its collective intelligence, second, the manner in which students determined their partners, and third, the manner in which methods varied among the pairs of partners. In an example for the first critical feature of Lesson 3, the teacher helped the class became aware of its collective intelligence by connecting Lesson 3 to previous lessons.

Tchr: Last week, we used two different strategies to look at a Line \( l \) that is tangent to the graph for a given function \( f \) at the point where \( x = t \). We completed Lesson 1; I did all the talking; I explained Tasks A, B, C, and D thoroughly; you listened; you took notes; you kept your thoughts to yourselves. For you, Lesson 1 was probably very private, low risk, and comfortable. Then we did Lesson 2; we repeated the same tasks; no one seemed to remember them from Lesson 1. I asked questions; you took time to think; you gave short answers; you told us what you were thinking; you wrote step-by-step instructions; you tried to formalize the steps. Lesson 2 may have been a bit uncomfortable; you had to take a big risk; the spotlight was on you. You may have found that challenging but you did a good job.

Although no individual paper contained a complete list of eloquent steps, the class did well collectively. The teacher distributed a list that he compiled by selecting one step from each paper. The list contained multiple versions of some steps as well as overlapping steps. The list was not necessarily in a sequential order that makes sense. Several of the more formally worded quotes follow:

S 13: The \( y \)-coordinate for the point where \( x = t \) is the number \( f(t) \).

S 14: To find an equation for the line that is tangent to the graph for function \( f \) at the
point \((t, f(t))\), the slope \(m\) of that tangent line must be found.

S 15: Use the derivative to figure out the slope; \(m = \frac{dy}{dx}\bigg|_{x=t}\).

S 16: The slope \(m\) of the line that is tangent to the graph of \(f\) at \(x = t\) is \(m = f'(t)\).

S 17: \(f'(t)\) denotes the slope of the line that is tangent to \(f\) at the point where \(x = t\).

S 18: Use the definition \(f'(t) = \lim_{h \to 0} \frac{f(t+h) - f(t)}{(t+h) - t}\).

S 19: Use the Binomial Theorem to figure out \((t + h)^n\) when \(f\) is a power function.

S 22: We use the point \((x_1, y_1) = (t, f(t))\) and the slope \(m = f'(t)\).

S 23: Substitute numbers \(x_1 = t\), \(y_1 = f(t)\) and \(m = f'(t)\) to get \(y - f(t) = f'(t)(x - t)\).

Students read the list of quotes; they were pleased to find their own work quoted on the list and were eager to claim ownership. All of the quotes were significant but the quote of S19 calls for more detailed commentary. Students reviewed the Binomial Theorem, i.e., \((t + h)^n = \sum_{r=0}^{n} (nCr) t^{n-r} h^r\), during the opening days of the first semester at a time of year when the teacher relied primarily on Strategy 1 and when too many students had neither the calculator skills to evaluate \(nCr\) nor the notation skills to understand summations. Not until subsequent lessons, that employed Strategies 2 and 3 to inductively investigate the expansion of \((t + h)^n\) for various values of \(n\), did students acquire sufficient calculator skills and notation skills for expanding the summation into polynomial form.

In Lesson 3 students worked in partners. Work varied among the pairs of partners who used standard mathematical vocabulary and standard mathematical notation in various ways (graphical, tabular, analytical, and verbal) to explain their thinking. The analytical method of
choice varied among students; some students preferred to use either Point-Slope Form exclusively or Slope-Intercept Form exclusively while other students preferred to use a combination of the two forms. Regardless, nearly all students could use at least one form with confidence to determine an equation for the tangent line. More importantly, students acquired communication skills for clarifying their explanations and justifications. When students clarified their communication, they clarified their thinking.

At the end of the lesson, students placed their completed worksheets into their portfolios and took extra care to store the list of quotes in a prominent place. Their own individual work clearly had value for students but their collective work appeared to have added value. Every student earned participation points not for writing correct answers on the worksheet but for connecting formal mathematical language with important mathematical ideas. Generally, students were pleased with their points and were becoming more tolerant of Strategy 3. As students became more collaborative and less competitive, the teacher felt reassured, commenting that students not only valued their points but also valued their work.

**Commentary on Lesson 4**

The worksheet for Lesson 4, titled *The Disgruntled Curmudgeon*, directed students to:

- Complete Tasks A, B, C, and D; use Strategy 4; indicate your methods and justify your responses; in addition, draw a graph in general that represents any function $g$ in the family \( \{ (x, y): x \in \mathbb{R} \text{ and } 0 \leq x \leq 2 \text{ and } n \in \mathbb{J}^+ \text{ and } y = 4xn + 5 \} \);
- draw a line that is tangent to the graph for function $g$ at the point where \( x = t \);
- state the coordinates in general for the point of tangency and for the $y$-intercept of the line.
As such, the role of the student was to analyze and dominate the formal discourse by thinking mathematically, by speaking loudly, and by writing clearly on the chalkboard. The role of the teacher was to monitor and to assist, by watching carefully for signs of stress, and when the discourse lulled, by helping students connect their own responses in earlier lessons to possible contributions in Lesson 4. When the worksheet for Lesson 4 was distributed to the class, students waited for directions and explanations; no one requested a teacher-dominated lesson. Students were somewhat resistant as the teacher established social norms.

**Tchr:** Today, use Strategy 4. You talk; I listen. Today, everyone gets 10 points provided that everyone makes at least one meaningful contribution. So don’t hog the conversation; leave something for others to say.

The critical features of Lesson 4 were first, the manner in which students distinguished between meaningful contributions and less than meaningful contributions. Statements that either explained a method or justified a response were meaningful. Likewise, statements that either validated or challenged a contribution were meaningful. In addition, thought provoking questions and reasonable conjectures were meaningful. Even incorrect statements could be meaningful provided that they initiated an exchange of mathematical ideas. On the other hand, less than meaningful contributions included unsupported claims, private side conversations, impulsive whispers, off task behaviors, distracting interruptions, and random comments.

**Tchr:** Simply saying, “I don’t know.” is not a meaningful contribution.

**S29:** What about “I don’t know blank.” and you say something mathematical. Is that meaningful enough?
Tchr: I don’t know how to talk about blank. I don’t know how to think about blank. I don’t know how to write about blank. Yes, those are all meaningful enough if you fill in the blank with something specific.

The second critical feature of the lesson was the manner in which students maintained the formality of the class discussion. In an example for the second critical feature of Lesson 4, students relied on a physical prop, the Disgruntled Curmudgeon - a beanbag caricature of a grumpy old man, to facilitate class discussion. The beanbag encouraged students to take turns and discouraged students from monopolizing the conversation. Only the person holding the beanbag could contribute to the discussion.

Tchr: One person speaks at a time. You may speak only in the company of the Disgruntled Curmudgeon. If you are not holding the beanbag, you may not speak. Be careful; he’s mean; the Disgruntled Curmudgeon will take five points away from you each time you speak out of turn, meaningful or otherwise. Don’t interrupt the speaker. You don’t want to end up with a negative score.

For Tasks A, B, C and D, students took turns at the chalkboard to contribute pieces and parts of the complete response that they learned and rehearsed in Lessons 1, 2 and 3. Some students spoke as they wrote; others wrote in silence and then read the contribution aloud. Although their mathematical language was not flawless, students spoke with authority.

In the third critical feature of Lesson 4, students encountered the additional task for which their contributions were unrehearsed. In times of stress, students reverted to old habits. Unrehearsed contributions were at best informal questions directed at the teacher rather than authoritative statements directed at the class; at worst, unrehearsed contributions were less than
meaningful pleas for a teacher dominated lesson that avoided standard mathematical vocabulary and notation.

S 32: [directed at teacher] Why are you making us guess the right answer. This class is just a big guessing game.

Tchr: Can you be more specific?

S 32: [directed at teacher] What do we put (in the calculator) for $n$? Alpha N? Or do I just guess (a number)?

Tchr: [shrugging] $n$ is a constant; we don’t have a specific value for $n$. I’m guessing that we should hold off on the calculator for now.

The teacher continued to monitor the discussion and interpreted any lapse into old habits as an indicator of stress. Instead of reverting to Strategy 1 himself, the teacher assisted by reminding students to transform their questions into statements and to connecting the additional task with Tasks A, B, C, and D.

S 33: [plotting and labeling the point at $(0,5)$] I’ll do zero, five.

S 34: [directed at teacher] How did she know that?

Tchr: We have a challenger; (S 33) made a statement without justification and (S 34) wants justification. Don’t ask me, ask her.

S 34: [directed at (S 33)] How did you know that?

S 33: It says it on the paper. Wait, I can’t say it.

Tchr: That’s terrific. You know what not to say. That’s progress. Now look for words.

S 34: [pausing to formulate a response] It says $x$ is a real number and $x$ is greater than or equal to zero. Can I just say that? What about $y$?

Tchr: Turn your questions into a statement. Try to use the word because.
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S 34: [pausing to formulate a response] The endpoint must be \((0, 5)\) because the smallest \(x\) is zero … and \(0^n\) is always zero, so \(g(0)\) is five.

Tchr  That makes sense to me; you plotted and labeled an endpoint, that’s one of the essential features of a complete graph.

Although students did not completely finish Lesson 4 by the end of the class period, they made significant progress. They produced a generalized graph for function \(g\), plotted and labeled endpoints, plotted and labeled the point of tangency, drew the tangent line and began to discuss an equation for the tangent line. Most students spoke with neither authority nor clarity. A few students, however, made somewhat formal summary statements, for example;

S 37: [Writing \(y - (4t^n + 5) = (4nt^{n-1}) (x - t)\) on the chalk board and reading it aloud] I did more with \(g\) prime. I worked it all out and it’s…[Writing \(g'(t) = \lim_{h \to 0} \frac{g(t+h) - g(t)}{(t+h) - (t)} = 4nt^{n-1}\) on the chalkboard] Does it always work this way?

Tchr: That’s the kind of question that mathematicians ask. We’ll see. Will you finish up (your meaningful contribution) tomorrow? Can you tell us what \(it\) you are talking about?

The following day, (S37) justified his contribution step by step, referring to his conclusion as a short cut for his analytical work. With minor adjustments of course, his short cut would be the Power Rule; a significant accomplishment for a high school student.

S 37: Can I use the short cut on the test instead of writing out all these steps?

Tchr: Logical short cuts, like yours, are what mathematicians call theorems. So, if you state your short cut clearly and explicitly (by) using standard mathematical
vocabulary and notation, then you’ll have a theorem. You may always use theorems on tests.

As the lesson proceeded, students determined the $y$-intercept for the tangent line in general. Some students, feeling overwhelmed by the breadth and depth of the discussion, lost their focus.

S 38: [Writing $y = (4nt^{n-1}) (x - t) + (4t^n + 5)$ on the chalk board and reading it aloud]

S 39: [Writing $y = (4nt^{n-1}) (x - 0) + 5$ on the chalkboard and reading it aloud]

S 40: [Erases $(x - 0)$ and writes $y = (4nt^{n-1}) (0 - t) + 5$ on the chalkboard] …because the $y$-intercept is five when the $x$ is zero, not when the $t$ is zero. [Simplifying $(4nt^{n-1}) (0 - t) + 5$ step by step on the chalkboard] … So when the $x$ is zero, the $y$ is $-4nt^n + 5$.

S 41: I thought $it$ was $4nt^{n-1}$.

S 40: [Responds to (S 41) by mimicking and exaggerating the teacher] My $it$ and your $it$ are two different $its$. What $it$ do you want to talk about?

Student (S40) used standard mathematical vocabulary, including $y$-intercept, point of tangency, and derivative, in an attempt to clarify the distinction between the point where $x = 0$ and the point where $x = t$ and to explain the slope of the tangent line. Regardless, (S 41) was not alone in feeling disengaged. The teacher assisted by reassuring (S41) that the important mathematical ideas would make sense in due time and by reassuring the class as a whole that they were making commendable progress even if they did not understand every detail yet. At the end of the lesson, students placed their completed worksheets into their portfolios; every student earned 10 out of 10 possible participation points. Student attitudes about Strategy 4 were divided. A few students seemed to become empowered and convinced about the meaningfulness of their classroom discourses. Most others remained either passive resistors or active opponents; participation
points were a small reward for their discomfort. The teacher, on the other hand was no longer skeptical about participation points, commenting that with Strategy 4, students earned their points.

**Summary of the four lessons**

All together, the four sample lessons consumed seven 50-minute class periods. The lessons appeared to be time consuming and repetitive. However in addition to learning about tangent lines, students not only learned to use basic mathematical skills from arithmetic through calculus but also learned to use formal language skills to clarify their thinking and to communicate important mathematical ideas. Students continued to use all four strategies during the remainder of the school year to intuitively explore concrete problems associated with important calculus ideas associated with functions, rates, and accumulations. Attitudes varied among students. Not all students liked every strategy. Not all students preferred the same strategy. Students changed their preferences over time. Most students lost their dependency on Strategy 1 and came to prefer Strategies 2 and 3. As their confidence grew, their resistance to Strategy 4 diminished slowly but did not dissipate completely.

Although the teacher clearly valued Strategy 4 as the most powerful of the four strategies, students needed time to accept a classroom culture that differed significantly from their prior experiences. Students whose prior mathematics classes focused mainly on deductive reasoning, abstract problems, and sequential processes; encountered a classroom culture that valued inductive reasoning, concrete problems, and random processes. Students whose prior mathematical communication focused mainly on using algorithms to perform computations; encountered a classroom culture that valued communication, both verbal and written, together with multiple representations for defending mathematical ideas and processes. Perhaps with
earlier exposure to all four strategies in their high school mathematics classes, students also came to value Strategy 4.

**Discussion**

This study illustrated how one secondary mathematics teacher engaged his students in classroom discourse and promoted in them the use of appropriate mathematics language to communicate their thinking. The researchers were also interested in understanding the temperament of students as it related to teacher pedagogical practices. Naturally there was a mixture of responses from the students as they engaged in the problem solving situations. At the onset, most of the students were more inclined to the traditional method of teaching, believing they could not learn effectively without the teacher telling them when their answers were right or wrong, though most of them simultaneously agreed it was perhaps more beneficial for them to figure out the answers to the problems themselves. According to research conducted by Kawanaka and Stigler (1999) these students’ responses are fairly typical in the United States, as most students have primarily experienced only traditional modes of instruction where the teacher explained mathematics and they practiced demonstrated procedures (Staples, 2007).

Although properly enacted, it has been observed by many researchers that not all students respond favorably to reform-based mathematics instruction. In description of her current disposition to the teaching method one of the students, Amy said:

“We’ve all adapted to not saying anything. I don’t know if that’s particularly good. Teacher needs to reinforce the right answer. So, if you say something and it’s wrong, then go ‘that’s wrong.’ not ‘well, what do you think? well ‘honestly, I don’t know’. So, I found that if the answers aren’t reinforced I will just lose track of what’s going on and then I won’t even know if what I said is right or wrong.”
This response is not unusual as Turner et al. (2002) pointed out that “students’ lack of participation in classroom discourse can be a result of self-handicapping, failure avoidance, or a preference for avoiding novelty” i.e. the novelty of reform-based mathematics discourse (as cited in Truxaw & DeFranco, 2007, p. 287). Similarly, Lampert (1990) found that sometimes students who disagree with concepts remain silent rather than express a mathematical argument (as cited in Truxaw & DeFranco, 2007, p. 287). Stein (2007) further supports these findings by noting that the use of mathematical discourse in classroom is difficult, as the same students participate in every discussion, with others contributing only when they are called on, and even then their contributions are sparse. In this study, Amy like most other students showed a preference for the traditional method of teaching which positions the teacher as the primary reference, focusing on providing right answers, instead of her current teacher’s focus on extending the incorrect answers into collaboratively developed solutions (Staples & Colonis, 2007).

Truxaw and DeFranco (2007) note that responses such as Amy’s are expected as mathematics discourse does not happen overnight, particularly if students have experienced only teacher-directed, procedure-oriented mathematics classrooms. Their observation is proven true, as Amy showed more appreciation for the teaching approach in her later statement.

“I get frustrated when I can’t do math, when I don’t know what to say. But when I am able to communicate my thinking using mathematical vocabulary, I think that’s cool. That’s an accomplishment. So, I won’t say that this class was a waste of time. Ask me next year, in college [laughing]. Because, maybe I’ll go to college and find out I learned a lot. I don’t see that happening but it’s possible”.

Following the findings of this study it is evident, as has been proven by countless other studies, that students’ mathematical dispositions are significantly dependent on prior
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mathematical experiences. Students’ bring with them to class a range of prior experiences and orientations towards mathematics and school, experiences that significantly affect how receptive they are to new teaching strategies and how much the teacher has to do to engage them. As evidence of this when asked about their mathematical experiences, almost all the students that participated in the study recalled their experiences in middle and high school mathematics classes mostly focusing on memorization of facts and vocabulary, direct instruction, homework, taking tests, and less communication. In response to a question on her perception of the mathematics class Casey, another student, stated that:

“I feel that in previous math classes I have had, it is been a lot more play by the rules, take the notes and you have homework every night. This class is a lot different. It is more discussion. I want to say I like a much more strict classroom…”.

Given the historical resilience of traditional mathematics teaching, as documented by Jacobs et al. (2006); and Stigler and Hiebert (1999), it is not surprising that as evidenced by Staples (2007), the mathematical histories of the students in this study comprised a significant part of their context, with their past experiences with traditional mathematics shaping their beliefs and perceptions about the nature of mathematics and themselves as learners and doers of mathematics. However following the immersion of the students in the current classroom setting, most of the students became more open to the reform-based strategy as indicated in Dan’s statement:

“I learned that there’s more than one way to learn math. In the past…, we’ve gone over a section and then you’d do the homework for that section that night and the process repeats everyday without any change. In this new way that I’ve been learning, it is not with homework but with group discussions and taking notes. It varies. That’s a good
way to learn it because it keeps you interested more than it would if you just did the same thing over and over again.”

Reform-based mathematics teaching requires the teacher to be simultaneously very active, by providing guidance and structure, and at the same time unimposing. Although some students may be more receptive to new learning practices, not all students respond well to novelty. This trend has been noted by Chazan (2000); and Heaton (2000) to name a few. According to Heaton (2000) “the development of new norms and students’ proficiency with new practices may not proceed fluidly… Many of the practices of a collaborative community are novel to the students.” (p. 211). As evidenced in this study by the participant Casey, relative to the prevalence of traditional models of teaching, it is reasonable to expect that some students may be resistant to these reform-based instructions.

**Significance**

Although the need for meaningful classroom discourse is now universally accepted among education researchers, its implementation has fallen short of the goals as outlined in the NCTM *Standards* (Kabasakalian, 2007), with traditional models of instruction still dominating the educational landscape, especially in secondary level classes (Staples, 2007). In most traditional mathematics classes, the prevailing type of discourse is univocal (Truxaw & DeFranco, 2007), whereby the teacher’s questioning and feedback are used to convey information to students, leading towards the teacher’s point of view. This is in contrast to dialogic discourse that involves give-and-take communication in which students actively construct meaning (Knuth & Peressini, 2001, as cited in Truxaw & DeFranco, 2007, p. 268). Dialogue in this context is student-driven, and the teacher is astute in recognizing when a student’s (mis?)conception can be utilized to encourage further thinking. Teacher education
needs to be improved to emphasize facilitation of mathematical discourse amongst students. Reiterated by Staples and Colonis (2007), the skillful facilitation of discussions is something both novice and experienced teachers find challenging.

A myriad of factors has contributed to the lack of implementation of more collaborative inquiry-based learning, and the staying power of traditional models of teaching (Staples, 2007). The differences between teachers’ and students’ epistemologies especially, have created difficulties in implementing reform-based practices. Effectively applying reform-based practices requires a teacher to possess a deep understanding of mathematics, a teacher who knows the mathematical concepts that students need, knows them in the context of a network of related concepts, knows what must be known before, and what will later be added to form a solid conceptual structure” (Skemp, 1987, as cited in Kabasakalian, 2007, p. 4).

To encourage discourse, teachers must show their students that they value understanding concepts rather than just getting the right answers (Truxaw & DeFranco, 2007). In their study, Staples and Colonis (2007) observed that when a teacher responded only to group questions, i.e. questions that no one in the group could answer, the teacher implicitly positioned the students to consider one another’s questions, responses, and ways of reasoning; thereby promoting dialogue that could turn into collaborative discussion, amongst group members. Teachers must manage the delicate balance of centralizing and guiding students’ thinking while being careful not to overpower the meaning-making and discursive process. Nathan and Knuth (2003) in a two-year study of an elementary school teacher, trying to institute a more student-centered classroom, noted that inappropriately applying the teacher’s new role, could leave a mathematical void as teachers choose not to use their position to shape the mathematical trajectory, although simultaneously enhancing the students’ voices and ideas.
Conclusion

Although in recent years there has been significant objection to the type of reform-based mathematics proposed by the NCTM, ample research has shown that the repetition and memorization emphasized by traditional mathematical teaching practices, superficially addresses these concerns (Manouchehri, 2007). In this study, we examined the pedagogical strategies used by the IC teacher to foster mathematical discourse and promote in students the use of mathematics language to communicate their thinking. The four teaching strategies utilized in this study represent the teacher’s role during the discursive process (first and second strategy), and the process by which the student’s ability to implement these discursive practices developed over time (third and fourth strategy). The findings of the study suggest that students’ mathematical dispositions can be transformed over time by a teacher’s pedagogical practices. This process of transformation may not be perceived as linear and sequential. In addition, not all students would accept this pedagogy as viable and useful for them. Some may extremely resist this change. However as noted by Sfard (2003), there is substantial evidence to show that instruction focused on meaning that emphasizes investigation, conjectures, communication and collaborative conclusion, is more effective than those that try to circumvent it (as cited in Sanchez, 2006). This research recommends that high school mathematics teachers adopt some of the more recent reform-based instructional strategies that have been underutilized in these classrooms.
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References


