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Research Questions

If high school students are given instruction in Bloom's Taxonomy of the Cognitive Domain and in posing questions at its various levels, will this lead to richer mathematics content-related classroom discussions?

If such a change occurs, will students identify discussion as contributing significantly to their mathematics learning?

Rationale

Concerns about students' acquisition and application of higher level thinking skills have reached an all time high. Students must be taught to go beyond low level comprehension and mere regurgitation of facts and formulas if they are to be adequately prepared to become the problem solvers of the future. This goal is also reflected on high-stakes assessments by which students, teachers, and schools are measured. Indeed, according to the Florida Department of Education, "the primary purpose of the FCAT (Florida Comprehensive Assessment Test) is to assess student achievement of the high-order cognitive skills represented in the *Sunshine State Standards* (SSS) in Reading, Writing, Mathematics, and Science." (http://www.firn.edu/doe/sas/fcat.htm). More than ever before critical thinking skills must be part of the curriculum.

Research has shown that discussion promotes deeper understanding, leads to higher-level thinking and problem-solving, and improves communications skills (Gambrell, 1196). Research by Raphael and her colleagues found that effective discussions are more likely to occur in situations that embrace opportunities for participation by all students, that promote acceptance, and value personal responses and that include strategy instruction for enhancing discussion (as cited in Santa, Havens & Valdes, 2004).

In light of the necessity that my students develop an ability to engage critically with concepts, my assessment of the classroom “discussion” in one of my mathematics classes was that it was deficient. Discussion was seldom student-generated, was routinely dominated by teacher talk and interrogation, which Cazden (1988) refers to as the IRE model of discourse. In this model the teacher initiates (I) talk by posing a question, the students respond (R), and the teacher evaluates (E) the responses. According to Santa et al, (2004), this model “seldom results in acquisition of knowledge that students can use to make inferences or draw conclusions” and “becomes a means of assessment rather than instruction.” Even when my students worked in small groups there was little discussion of ideas and what discussion occurred could be classified as predominantly at the lower cognitive levels.

Goldenberg (1993) advocates a constructivist model of discussion in which students engage in instructional conversations to construct their own meaning. Santa et al (2004) assert that “as students talk, they test their ideas and consider the ideas of others.” This research supported my belief that students learn more when they wrestle with ideas collaboratively and that meaningful discussion is a key ingredient in that process. My effort to make this a reality in my classroom was my primary motivation to conduct this research. I was unsatisfied with the quality of discussion I saw in this class. Thus, I felt that I needed to find a way to generate a level of discussion reflective of the critical thinking in which I wanted my students to engage.

The assessment of my students' classroom discussion as "deficient" was based on Benjamin Bloom's hierarchy of levels in the cognitive domain (1956), a taxonomy of thinking commonly referenced among educators when discussing critical thinking. Most of the statements and questions my students generated were found to fall into Bloom's classifications of Knowledge, Comprehension, and Application, classifications at the lower end of the hierarchy.

It occurred to me that I was assessing students' oral communication by a standard that I had not shared with them. My customary practice is to clearly communicate to my students the performance expectations I hold for them and the standard by which these will be assessed, and yet in this case I had not done so. I wondered what effect sharing this information with them might have on their discussions. Investigating this effect became the central focus of my action research.

Background/Context

The Partnership in Academic Communities is a mathematics, science, and technology program for middle and high school students from the Miami-Southridge Senior High School feeder pattern of Miami-Dade County Public Schools. The goal of the program is to prepare students who might otherwise not have such an opportunity for success in post-secondary education. Students are selected following the sixth grade year and remain with the program until high school graduation. Participating students are bused from their neighborhoods to the Florida International University campus each morning where they attend three hours of advanced mathematics, science and computer classes before returning to their home schools for the remainder of the school day. High expectations are held for all students in this program. Students are required to take specific honors level mathematics and science courses for all six years and must repeat any courses in which they earn grades lower than “C.” Small classes, expert teachers, innovative curricula and techniques, and the availability of extra tutorial assistance are characteristics of the program that help to create an environment in which the students can meet these expectations. Students whose grades drop below a “C” average are required to attend Saturday School tutoring.

During the 2003-04 school year PAC students were 51% female and 49% male. The ethnic composition of program participants was 32% African-American, 64% Hispanic, 1% White, and 3% Other. Approximately 85% of the students qualified for free or reduced lunch and the majority were from single-parent homes.

This study was conducted with a class of ten high school seniors, four boys and six girls, who were studying precalculus. The ethnic composition of the class was 20% African-American, 10% Afro-Caribbean, and 70% Hispanic. A number of these students had quite distinguished records of academic achievement. Five of the ten later graduated in the Top Twenty-five of their graduating class. Nine of the students gained university admission for the 2004-05 school year.

During the fall of 2003 I conducted an intervention with this class that focused broadly on communication in mathematics. While both written and oral communication was addressed to some extent, written communication received greater emphasis at that time. As a result of that intervention my students' ability to communicate in writing about mathematical concepts, processes, and reasoning improved. They became more articulate when writing summaries of new learning, describing their reasoning about a problem, and expressing questions they had about new material. They also became aware of the necessity to use mathematical terminology appropriately and to self-edit written work to ensure clarity and remove ambiguity.

Despite the improvement I witnessed in the written communication of this group of students, I saw virtually no improvement in their oral communication. During whole-class instruction, they seldom made statements or asked questions that demonstrated more than perfunctory mental engagement with the topic of study. Class "discussion" persistently lacked depth and richness. My attempts to place the responsibility for discussion on the students continued to fail as they worked in cooperative groups with little or no meaningful discussion of the concepts. What little discussion they generated generally amounted to a comparison of answers to the assigned problems and/or the search for the source of any differences in those answers. No matter how "rich" the questions I posed to the students in terms of generating critical thinking, student-initiated discussion seemed frozen at a very superficial level. My dissatisfaction with this state of affairs compelled me to undertake my action research.

The intervention I undertook was implemented in two phases. During the first phase students were introduced to a new instructional strategy, reciprocal teaching. Reciprocal teaching is a reading comprehension strategy that takes the form of a dialogue focusing on a particular piece of expository text (North Central Regional Educational Laboratory, 2004). Students would first read a passage from their textbook and then engage in summarizing, clarifying, question-generating, and predicting, the four steps in the reciprocal teaching strategy. Each new mathematics topic over a period of six weeks was introduced by reading from the textbook employing this reciprocal teaching strategy. Not only did we utilize this strategy in class, but I also encouraged the students to practice it when rereading the text at home, holding a “dialogue” with themselves. I hoped that through repeated application of these steps they would learn to engage with new ideas by conducting a dialogue about the topic either with each other (as in the classroom experiences) or with themselves (as when alone at home).

The second phase of my intervention was direct instruction on Bloom’s Taxonomy of Cognitive Skills. On the day I had planned to teach this lesson, most of the class was absent due to a special activity at their home school. Since only four students were present that day, I modified my original plan. These four students conducted online research and prepared a presentation on Bloom’s taxonomy to be presented to the rest of the class the following day. This modification worked out quite well. The “teaching” students created transparencies, handouts and even an oral quiz covering the material for their lesson presentation. The other students were very receptive to the lesson. Following this instructional period, all students practiced creating and answering questions about a recently studied mathematics topic at the various levels of the taxonomy. This was a great review of both the taxonomy and the mathematics content.

After the Bloom's Taxonomy lesson and follow-up question-writing activity, reciprocal teaching was no longer used as a formal structure for any class sessions. Bloom's Taxonomy was referenced occasionally, either by the students or by me, as we analyzed questions encountered in our textbook on various assignments. However, creating questions which aligned with Bloom's various levels was not a requirement of any additional assignments.

Literature Review

Since the release of the National Council of Teachers of Mathematics first set of standards in1989, there has been a call for greater emphasis on communication in the mathematics classroom. According to *NCTM Principles and Standards for School Mathematics* (2000), "Students who have opportunities, encouragement, and support for speaking, writing, reading, and listening in mathematics classes reap dual benefits: they communicate to learn mathematics, and they learn to communicate mathematically" (p. 61). Masingila and Prus-Wisniowska (1996) assert that "When students are encouraged and required to communicate mathematically with other students, with the teacher, and with themselves, they have opportunities to explore, organize, and connect their thinking" (p. 95).

In 1948, Benjamin Bloom and a group of colleagues began the task of classifying educational goals and objectives. Their work on the hierarchy of the cognitive domain classifies knowledge into six categories which are arranged from less to more complex. It was published in 1956 and is commonly referred to as Bloom's Taxonomy of the Cognitive Domain (Bloom et al, 1956). The six classifications are knowledge/recall, comprehension, application, analysis, synthesis and evaluation. While there is some disagreement about the exact arrangement of synthesis and evaluation (Chiron, 2004), it is commonly accepted that analysis, synthesis, and evaluation comprise the higher order skills. Research has shown that students' retention is increased when they have learned to handle a topic at the higher levels of the taxonomy because doing so requires elaboration (Chiron, 2004).

Summarizing 22 key studies and 11 research summaries, Cotton asserts that "instruction in thinking skills promotes intellectual growth and fosters academic achievement gains. Instructional approaches found to promote thinking skill development include redirection, probing, and reinforcement; asking higher-order questions during classroom discussion, and lengthening wait-time during classroom questioning" (1991). She further concludes that student performance has been shown to improve as a result of both direct teaching and inferential learning of thinking skills.

Pugalee (1997; 2001) found that, as students become involved in reflecting and synthesizing in order to communicate about mathematics, in addition to learning mathematics concepts, they develop thinking skills and metacognitive behaviors.

The oral and written communication of students provides, for the teacher, a way of "…gaining insight into what students know and are able to do, and for making important decisions about instruction and intervention" (Greenes & Schulman, 1996, p. 169).

According to Huinker and Laughlin, (1996) "thinking and talking are important steps in the process of bringing meaning into students' writing…As students talk about their experiences and test their new ideas with words, they become aware of what they really know and what more they need to learn." Huinker and Laughlin also claim that discussion is key to building a learning community within the classroom. (p. 81). Research indicates the benefits of dialogue, yet most mathematics classroom discussion is "going over answers and mistakes" (Tanner & Casados, 1998, p. 342). NCTM (2000) calls for students to "gradually take more responsibility for participating in whole-class discussions and responding to one another directly. They should become better at listening, paraphrasing, questioning, and interpreting others' ideas." (p. 61)

Research clearly supports giving all students opportunities to develop communication skills and to use communication as a learning tool as they study mathematics. Pugalee (2001) offers that such opportunities will produce students who are comfortable expressing to others the results of their thinking in both written and oral form. He maintains that it is imperative for teachers and schools to do this, by stating, "Providing such experiences is pivotal in developing communication processes that promote mathematical literacy for all students." (p. 298)

"Conversations about content occur naturally when cooperative groups focus on accomplishing a task" (Santa et al, 2004). Reciprocal teaching is a cooperative group instructional strategy developed by Palinscar and Brown (1984, 1986) that involves dialogue about a section of text. The dialogue may take place between students and the teacher or between different students. Often the strategy is introduced by teacher-student dialogue and later moves to student-to-student (North Central Regional Educational Laboratory, n.d.). The research of Palinscar and Brown found that students' comprehension of material was enhanced through the reciprocal teaching strategy. They were better able to summarize the material and to predict the kinds of questions teachers might ask on a test (North Central Regional Educational Laboratory, n.d). Later research by Rosenshine and Meister (1994) found that the effectiveness of this strategy increased as students faced more challenging academic demands.

Tools

Data was collected from three sources: surveys, written assignments in which students generated questions about new mathematics topics, and audio-recordings of oral interactions in the classroom.

A pre-intervention survey was utilized to confirm students' lack of familiarity with Bloom's Cognitive Taxonomy and to gauge the value students assigned to discussion as a learning strategy in mathematics. Students were asked to complete a similar survey following the intervention.

Students also completed a pre-intervention assignment requiring them to generate and answer questions about a new mathematics topic in a passage read from their textbook. The questions they wrote were classified using Bloom's categories, to establish the students' baseline question-posing ability. If their questions showed a predominance of lower level engagement with the topic, as I suspected they would, this would allow me to later verify that any changes that occurred could be tied to the intervention and not to a pre-existing skill. Three subsequent similar assignments, two during and one following the intervention period, were evaluated and compared to this baseline.

Two initial audio recordings of a regular mathematics class session were transcribed and analyzed, again to establish the baseline cognitive level of oral interactions. Additional class sessions were recorded, transcribed, and analyzed, one each week for six weeks following the two-month long intervention period. When class sessions involved small group work, each group was separately recorded and analyzed.

Tool # 1: Pre/Post Survey

1. Rank the importance to your success learning new mathematics concepts of each of the following classroom activities: (1 = "not at all important", 5 ="essential", and 2-4 are gradations between these extremes.)
    A. Taking notes _______
    B. Reading the textbook _______

C. Summarizing the lesson (written) _______
D. Discussion with classmates _______
E. Asking questions _______
F. Working practice problems _______

2. How familiar are you with Bloom's Taxonomy of the Cognitive Domain?
   A. Very familiar
   B. Somewhat familiar
   C. Never heard of it

3. If you answered "A" or "B" above, tell what you know about Bloom's Taxonomy on the lines below:

<u>Data</u>

Tool # 1, Pre/post surveys:

Question # 1, Pre-survey

Below each ranking is the number of respondents choosing that ranking on the pre-survey. The mean ranking of each learning strategy is found in the far right column.

	Ranking	***1***	***2***	***3***	***4***	***5***	**Mean Ranking**
A. Taking Notes		0	1	2	5	2	3.8
B. Reading the Textbook		0	3	4	3	0	3.0
C. Summarizing the lesson (written)		2	0	0	4	4	3.8
D. Discussion with classmates		2	2	5	1	0	2.5
E. Asking Questions		0	2	4	3	1	3.3
F. Working Practice Problems		0	0	3	3	4	4.1

Question # 1, Post-Survey

Below each ranking is the number of respondents choosing that ranking on the post-survey. The mean ranking of each learning strategy is found in the far right column.

	Ranking	*1*	*2*	*3*	*4*	*5*	Mean Ranking
A. Taking Notes		1	2	1	3	3	3.5
B. Reading the Textbook		0	2	4	4	0	3.2
C. Summarizing the lesson (written)		2	0	0	4	4	3.8
D. Discussion with classmates		0	1	3	5	1	3.6
E. Asking Questions		0	1	2	5	2	3.8
F. Working Practice Problems		0	0	2	4	4	4.2

On the post-survey the greatest change occurred in the mean ranking of “discussion with classmates” with an increase of 1.1 in the mean ranking. “Asking questions” showed the second greatest change with an increase of 0.5 in the mean ranking.

Question # 2, Pre-Survey

All students answered that they had "Never heard of" Bloom's Cognitive Taxonomy.

Question # 2, Post-Survey

8 students answered "Very familiar", and 2 students answered "Somewhat familiar"

Question # 3, Pre-Survey

Left blank by all students

Question # 3, Post-Survey

There were 10 correct responses regarding Bloom's Taxonomy of Cognitive Skills. Most students identified it as a way of classifying questions and/or activities that students do when they learn. Two students listed some of the cognitive levels correctly. Three students listed all six classifications correctly and identified those considered to be "higher order."

Tool # 2: Question-writing assignments

Question-writing Assignments (10 students-8 written questions each)

The percent recorded below each level of Bloom's Taxonomy is the percent of the 80 student-produced questions on each assignment that match the level.

Assignment:	Knowledge ?'s	Comprehension ?'s	Application ?'s	Analysis ?'s	Synthesis ?'s	Evaluation ?'s
Pre-assessment	28.75 %	48.75 %	20 %	2.5 %	0 %	0 %
# 1	32.5 %	36.25 %	27.5 %	2.5 %	0 %	1.25 %
# 2	18.75 %	40 %	25 %	11.25 %	3.75 %	1.25 %
Post-assessment	15 %	21.25 %	35 %	13.75 %	8.75 %	6.25 %

Before the intervention 97.5 % of the questions students wrote were classified as Knowledge/recall, Comprehension, or Application questions. During the earliest stages of the intervention there was a slight (1.25 %), though insignificant, increase in the percentage of questions that were classified as Analysis, Synthesis, or Evaluation questions. During a later stage of the intervention and following the intervention there was a more significant reduction in the percent of student questions classified as Knowledge, Comprehension, and Application and a concomitant increase in the percent of Analysis, Synthesis, or Evaluation questions. During the post-assessment 71.25 % of the questions written were classified Knowledge/recall, Comprehension, or Application and 28.75 % were classified Analysis, Synthesis, or Evaluation.

Tool # 3, Audio transcription analysis:

Audio Recording Transcription Data

Below each Bloom's category is the percent of all student talk during the tape-recorded lesson that fits the classification category. Each student statement or question was categorized and percents were calculated by comparing the number classified in the category to the total number of all students' utterances. Any off-topic remarks students made such as joking with each other, asking for supplies, or other non-content-related remarks were classified in the "Irrelevant" category.

Tape #	% Knowledge	% Comprehension	% Application	% Analysis	% Synthesis	% Evaluation	% Irrelevant
Pre # 1	26%	32%	16%	3%	0	0	23%
Pre # 2	23%	30%	29%	0	0	0	18%
Post # 1	24%	16%	24%	11%	4%	7%	14%
Post #	19%	17%	15%	13%	5%	10%	21%

2							
Post # 3	16%	25%	16%	16%	2%	12%	13%
Post # 4	8%	28%	20%	18%	6%	9%	11%
Post # 5	21%	19%	19%	9%	10%	6%	16%
Post # 6	11%	17%	22%	11%	8%	12%	19%

During the two pre-assessments of students' oral interactions 70+% of the discussion was classified at the lower levels of the cognitive hierarchy. During the six weeks following the intervention significantly more discussion occurred that was classified as "higher level". "Lower level" interactions decreased from to approximately 50 % of all discussion. No appreciable change in the amount of "irrelevant" or off-topic discussion occurred.

Results/Conclusions

After my precalculus students received instruction on Bloom's Taxonomy of the Cognitive Domain, and practice in posing questions at its various levels, their class discussions showed marked improvement in the critical thinking levels demonstrated. The frequency of students' statements and questions that could be classified in Bloom's higher cognitive levels increased. Audio recordings of classroom discussion revealed a decrease from 70+% to approximately 50 % "lower level" interactions. This reduction can be attributed to the increase in the percentage of "higher level" discussion, since there was no appreciable change in the amount of "irrelevant" or off-topic discussion.

Prior to this study students did not rank class discussion as highly valuable to their learning in mathematics class. When compared with other learning activities class discussion ranked last in importance. Given my assessment of their discussions as deficient, this ranking was appropriate. After the study, students' appreciation of class discussion as a valuable learning activity increased significantly and was similar to the value identified for the other learning strategies. On the post-survey they ranked this activity second in learning value only to working practice problems and equal in value with writing a summary of the material studied. This data supports the conclusion that students were able to recognize that the richer discussions resulting from the intervention made discussion a valuable learning activity.

"Asking questions" as a learning strategy was also valued more following the study. Although the increase in value placed on this strategy was less significant than that observed for the strategy of "discussion with classmates", responses on the post-survey ranked it among the top three of the identified strategies. "Asking questions" as an activity was a focus during much of the intervention and is also closely related to "discussion with classmates" because a large amount of class discussion was focused around student-generated questions.

The pre and post-survey results indicate that my students had no pre-existing knowledge about Bloom's Taxonomy of the Cognitive Domain. Thus, I conclude that the intervention undertaken is responsible for their increased knowledge about this hierarchy of cognitive skills.

The percent of higher-level questions students created during the question-generating activities increased significantly following the implementation of reciprocal teaching and Bloom's taxonomy instruction. Clearly, the intervention resulted in a significant improvement in the students' question posing ability.

This study was conducted during the second half of the school year, a time when the precalculus course content is most challenging. Topics in trigonometry and other concepts which are the underpinnings of calculus were covered during and following the intervention. These topics have historically been among the most challenging that my precalculus students face each year, and my students have often struggled academically with this portion of the curriculum. This class was successful with these challenging topics and I did not see the usual downturn in grades that I have seen in previous years during these units of study. I attribute this, at least in part, to the increased discussion of concepts that occurred as a result of the intervention. The increased discussion allowed students to clarify and refine their learning collaboratively prior to applying new ideas while individually solving problems on assignments and tests.

The data supports the conclusion that if students are taught to pose higher level questions, the overall level of their discussion will increase. By teaching my students about Bloom's Taxonomy, I informed them of my expectations, that is the kind of discussion I valued and why I placed value in it. I also gave them the tools they needed to meet my expectations, specifically the language that characterized the various levels. The data also supports the fact that when they engaged in the “new and improved variety” of discussion, they recognized its value to their learning of mathematics.

Recommendations/Policy Implications

My research suggests that if mathematics teachers incorporate direct instruction in higher level thinking into their curriculum, students will benefit. Time spent giving such instruction to students will be well spent since it will improve students’ ability to engage critically with challenging content and to pose good questions which can lead to deeper understanding of concepts. Students should be taught how to classify questions and tasks according to Bloom’s Taxonomy and what the specific language is that leads to each level classification. Giving students this background will allow the teacher to shift greater responsibility for classroom discussion and learning to the students, thus creating more autonomous learners.

If mathematics teachers are to incorporate direct instruction of critical thinking into the curriculum, then schools of education will need to place greater emphasis on this aspect of preservice teacher preparation. Currently pre-service training addresses Bloom’s Taxonomy in the context of a theoretical background for lesson planning and question-posing by teachers and not as content to be shared with students. If teachers are to help their students understand and use the various levels described in the taxonomy, this approach during their training should change.

If mathematics teachers are to incorporate direct instruction of critical thinking into the curriculum, then course outlines and learning goals need to reflect this. What is reflected in the state and district course outlines is what is valued and, ultimately, what is taught. Principals and other administrators will encourage teachers to teach students these critical thinking tools and skills if course guidelines aspire to them. Districts and state departments of education should incorporate specific critical thinking objectives into all mathematics courses. If what we want to turn out of our schools are graduates ready to be the problem-solvers of tomorrow's workforce, then critical thinking should be valued, encouraged, taught.

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