Mathematical Power: Exploring Critical Pedagogy In Mathematics and Statistics

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> "Always remember that the use of algebra is to free people from bondage."-- Mary Everest Boole, *Philosophy and Fun of Algebra* (1909)

> "It no longer suffices to know how things are constituted: we need to seek how things should be constituted so that this world of ours may present less suffering and destitution." -- 19th-century French statistician Eugene Burét

Though traditionally viewed as value-free, mathematics is actually one of the most powerful, yet underutilized, venues for working towards the goals of critical pedagogy—social, political and economic justice for all. This emerging awareness is due to how critical mathematics educators such as Frankenstein, Skovsmose and Gutstein have applied the work of Freire. Freire's argument that critical education involves problem posing that challenges all to reconsider and recreate prior knowledge reads like a progressive definition of mathematical thinking. Frankenstein (1990) supports the idea that critical mathematics should involve the ability to ask basic statistical questions in order to deepen one's appreciation of particular issues and should not be taught as isolated formulas with little relevance to individual experiences.

At first, mathematics seems an unlikely vehicle for liberation. As Anderson (1997, p. 295) asserts, "By junior high school, the overwhelming majority of our youth are convinced that mathematics teachers are their enemies and, even worse, that mathematics is some sort of poison or mind controlling drug that teachers try to force upon them." Anderson's quote is not as extreme as it may seem, in light of accounts of math abuse (e.g., Fiore 1999). Also, many citizens (and teachers) seem to have (NCTM 2000, p. 12) "a pervasive societal belief in North America that only some students are capable of learning mathematics [as opposed to learning to read and write]." Mathematics classes are therefore viewed as gatekeepers to keep the intellectually "less gifted" from joining an exclusive club, thus creating a perpetual lower class of citizen. This is connected to the reality that mathematics qualifications continue to be an admission ticket for most high-paying jobs. Furthermore, Frankenstein (1983, p.12) explains how “politically, people can be more easily oppressed when they cannot break through the numerical lies and obfuscations thrown at them on a daily basis.” Frankenstein (1987) and Skovsmose (1994) assert that knowing mathematics and statistics is a key part of moving towards more democratic economic, political and social structures in society.

Freire (1970) describes “self-depreciation” as a condition derived from the internalization of the oppressors’ opinions. Schools reinforce the idea that students are not capable of learning mathematics and this becomes reality. Studies on self-efficacy (e.g., Bandura 1994) further support the effect of internalization of perceived influences of authority figures on abilities to successfully perform tasks. This continued labeling of individuals as failures and the accompanying alienation that many continue to experience are due, in large part, to the interactions among social, political and economic structures of the U.S. political economy, functioning both as a determining factor and a social filter in the phenomenon of unrealized potential and alienation (Frankenstein & Powell 1989).

Because of the importance of the relationship between individual belief in ability to perform tasks and the actual performance, it is crucial to confront false negative internalizations. Perhaps one of the most powerful ways is to have the instructor make it a point to join sides with the student in a revolution (using mathematical thinking as a tool) against social inequities and the “culture of silence” that conceals them. Freire (1970) criticized as “The Banking Model of Education” the traditional view of students as receptacles filled passively by teachers. We support an ideology that responds to this critique, similar to the ‘public educator’ (Ernest 1991, p. 202). Critical understanding of data prompts students to make decisions about how a society is structured and enables them to act from a more informed position on societal structures and processes (Frankenstein & Powell, 1989).

Traditional mathematics instruction also rarely makes connections between applications and theory and even fewer connections to culturally relevant issues in students’ lives. Anderson (1997, p. 296) describes how mathematics is one of the few subjects typically presented with “little or no historical, cultural, or political references," an approach which "reinforces the institutionalization of Eurocentrism, class elitism and sexism" and results in censorship of mathematical knowledge of certain cultures as "childlike and primitive." The recent emergence of mathematics curricula that include mathematics history and multiculturalism (Bidwell 1993, Lumpkin 1997) has started to help students see mathematics as an ongoing creative and cultural (indeed, multicultural) process rather than a received fixed set of rules and abstractions. This is important but does not always lead to actively empowering students or getting them to grapple deeply with equity issues, cultural/political biases or assumptions. For example, it is unlikely a class would discuss why a piece of mathematics is sometimes associated with a person who followed the non-Western originators by centuries (e.g., Pascal's triangle and Gaussian elimination were discovered centuries earlier by Chinese) or the role that *non*-statistical considerations played in deciding not to adjust the 2000 Census.

Hatfield et al. (2000) wrote an elementary/middle school methods book whose "culturally relevant mathematics" chapter includes not only multiculturalism (e.g., connections with African Americans, Native Americans, Hispanic Americans, Asian Americans, etc.) but also (p. 19) "the effect of mathematics on any culture and its people; the right for *all* people to acquire the mathematical power for success in today's world, that is, *equity*." This is consistent with "The Equity Principle," the first of the six unifying principles of National Council of Teachers of Mathematics (NCTM) (2000). This principle includes some discussion of technology equity and the roles of learning style, speed, competition, culture and language. Culturally relevant pedagogy has certainly been explored in great depth (e.g., Ladson-Billings 1995), but the application to mathematics has been done by only a few (e.g., Gutstein et al., 1997).

'Reading The World' With Mathematics

As Gutstein (2003a, p.45) applies the work of Freire, "reading the world with mathematics means to use mathematics to understand relations of power, resource inequities and disparate opportunities between different social groups and to understand explicit discrimination based on race, class, gender, language and other differences." We see the explicit mathematical connections by raising three questions: How can people recognize, analyze or fight against social inequalities without the tools to analyze mathematics inequalities? How can people talk about what is unfair without tools such as proportional reasoning to calculate what would be expected as a fair share and how much statistical deviation from that might be tolerated as innocuous? How can people produce or interpret depictions of quantitative information without awareness of pitfalls (e.g., Huff 1993, Paulos 1988)?

Use of mathematics' analytical reasoning and tools (e.g., data analysis, graphing and modeling) to explore several specific, concrete real-life scenarios which stimulate a sense of social justice could influence student empowerment. As Lee asks (1995, p.11), "In mathematics, instead of studying statistics with sports and weather numbers, why not look at employment in light of ethnicity?" Data sets that are not merely simulated or taken from "safe" areas of life, but that take on important social issues have the potential for (unexpectedly) sustained engagement with mathematics as students encounter deep relevance to their lives. Activities and resources have been articulated by Frankenstein (1990), Gutstein and Peterson (2005), etc. Also, Lesser (2005) found roughly 10% of datasets in major dataset repositories to be readily suitable for social justice teaching.

Examples Of Applying Mathematics To Social Justice

Let us now share specific examples of social justice topics to which instructors have applied mathematics in the classroom. Critical pedagogy in mathematics has been used with students of a variety of grade levels, even as young as upper elementary school. When Kitchen and Lear (2000) offered fourth- and fifth-grade Latinas neutral-appearing body measurement activities of various women and of the (disproportionate) Barbie doll, the girls' analyses prompted them "to question their views of themselves, which were largely based on their body type." Other educators have extended the activity to male superhero action figures as well as to discussion of the sweatshop labor and multi-culturalism of the dolls (Mukhopadhyay 2005).

Also, a root cause of prejudice is over-generalizing (i.e., stereotyping) and this might be initially confronted through an algebra activity such as described by Lesser (2000) in which high school students generate diverse lists of functions (e.g., constant, linear, square, cubic, radical, absolute value, rational, exponential, or log) and possible traits [e.g., even, odd, increasing, decreasing, continuous, one-to-one, or $f(a + b)= f(a) +$

f(b)]. This shows how hard it is to find one trait that fits all functions and how hard it is to describe a function fully from just one of its traits. This could also be done with a collection of shapes and geometric traits such as equilateral, equiangular, convex, having a pair of parallel sides, having a right angle, having line symmetry, etc.

Lesser contributed the following problem to an algebra textbook (Mayes & Lesser 1998, p. 156):

> Objectification objection: In popular usage, the phrase "treating as an object" has negative connotations, because it implies an entity as rich as a human being can be reduced to a single dimension, such as gender, a physical characteristic, ethnicity, perceived sexual appeal, financial status, sexual orientation, religion, or occupation. Would it be just as foolish to say that we know everything about a function or its behavior from one particular classification of it (e.g., whether or not it is an even function)? Explain.

Tellingly, this problem was one of several critical pedagogy-type problems that were deleted from the subsequent edition of the textbook (against Lesser's wishes). On a larger scale, the choice of what books are adopted for a state's public schools is usually made by an appointed board. The social, political and educational composition of such boards may not always be fully supportive of student emancipation. This could be particularly critical in states such as Texas, California, New Mexico, Hawaii, and District of Columbia, where there are more minorities than Anglos.

Peterson (1995) and Gutstein (2003a) have explored classroom activities to simulate distribution of wealth (between continents and within the United States), a topic that often appears in the news. Wilson (2004) reports that median Hispanic and black households in the U.S. have less than 10% of the wealth typical Anglo households have. Algebra verifies that even if all salaries rise at the same percentage rate, the dollars gap between any two people's salaries would simply increase at that rate, too. Students can discuss the Census Bureau's Gini index of income inequality.

In one activity, fifth-graders used data to produce their own conclusions about federal spending, such as that one Stealth Bomber could pay the annual compensation packages of 38,000 teachers (Peterson 2003). To supplement and ground such concrete examples with a more general abstract framework, instructors in introductory college courses have shown how the concepts of mathematics and statistics can be applied explicitly to philosophical normative ethics as a way to explore or critique a particular perspective of judging when society is better off. For example, Lesser and Nordenhaug (2004) explore pitfalls of the rule-utilitarian concept of "greatest good for the greatest number."

Gutstein (2003b) had middle school students discuss a newspaper article about racial disparities in mortgage loan approvals, allowing them the opportunity to differentiate between "individual racism" (e.g., a white loan officer rejecting an applicant of color because of her race) and "structural racism" (e.g., why African-Americans have less collateral)." Gutstein (2002) also had his middle school students explore racial profiling (applying simulation, expected value and proportion to see if stops and searches are racially fair) and socioeconomic and racial patterns in SAT scores (e.g., scores highly positively correlated with family income).

Another real-life topic is random drug testing. Statistical reasoning shows that when the drug tested for is rare in the population, a significant fraction (even the majority) of positives can be false positives (e.g., Lyublinskaya 2005). Students can simulate this quite informally by filling in a 2x2 table of "actual user status" versus "what the drug test says." For example, if a test that is 95% accurate is given to a population containing 3% drug users, then a positive drug test result means there is a 63% chance that person is really a nonuser! Paulos (1988, pp. 66-67) asserts, "To subject people who test positive to stigmas, especially when most of them may be false positives, is counterproductive and wrong." On a more critical note, it is not uncommon for "random" drug testing to include a disproportionately high percentage of minorities.

The first author explored with high school and university students the implausibility implicit in the claim made by some (e.g., Pambianco 2000) that no innocent person has ever been falsely executed by civil authority under the death penalty (Lesser & Nordenhaug 2004). The classes were asked for estimates of the probability that a typical death penalty case resulting in execution is indeed "the correct decision," and students typically volunteer numbers ranging from .70 to .98. It was suggested that we see what happens by giving the judicial system more benefit of the doubt and use .995. The 2004 *Statistical Abstract of the United States* says that there were 4744 executions performed by United States civil authorities during 1930-2003. Raising .995 to the power 4744 suggests that the probability that all 4744 executions were correct decisions is about 1 in 21 billion! We then explored the fairness of the death penalty, such as what roles the race of the defendant or of the murder victim play in whether the defendant is sentenced to death. Classes tracked down primary source data themselves or, when time was limited, work from a textbook exercise such as in Moore & McCabe (1989, pp. 232-233), whose three-way table classifies 326 actual murder cases. This exercise is mathematically quite rich because of a paradoxical result: "a higher percent of white defendants are sentenced to death overall, but for both black and white victims a higher percent of black defendants are sentenced to death." This reversal generated animated discussion in the classroom and illustrates how a statistical claim can depend on the human or political choice of how data are disaggregated. Mathematics education researchers have long documented the power of conflict or paradox to motivate student learning (e.g., Shaughnessy 1977, Movshovitz-Hadar & Hadass 1990, Wilensky 1995, Lesser 1998). Lesser (2001a) offered preservice secondary teachers a similar opportunity to look for possible inequities in hiring and salary datasets.

The first author team-taught a field-based integrated block set of elementary preservice courses during the fall 2004 semester at an elementary school in an unincorporated community in the southwest United States. Of the 90% Hispanic population in that community, 75% speak Spanish in the home. One hundred percent of the district's elementary school students receive free or reduced lunch. Ongoing work there includes developing a culturally relevant set of school-based programs within a service-learning framework, such as a Mayan math project and Parent Power Nights with parents, children and preservice teachers working together on mathematically and culturally rich activities (e.g., Munter 2004).

A mathematics and social studies connection made with those preservice elementary teachers was the making of flat maps. A 3-dimensional curved surface cannot be perfectly projected onto a 2-dimensional plane without some kind of distortion, so each projection will have tradeoffs. For example, the traditional Mercator projection preserves shapes and angles, but exaggerates the size of countries (e.g., Greenland) farther from the equator. The more recent Peters projection preserves sizes, but somewhat distorts shapes. Even students who had heard of more than one map projection were generally shocked to realize what a difference the choice of projection can make. Adapting an activity from Gutstein (2001), the first author showed the preservice teachers two maps published by Rand McNally and asked "How many times larger than Greenland does Africa look?" For one map projection (Miller Cylindrical), teachers' estimates clustered around 2, but for another (Goode's Homolosine Equal Area), estimates clustered around 8 or 9 (the true answer is about 14). From one map, all 30 teachers said (incorrectly) that Alaska was bigger than Mexico, but made the opposite conclusion from the second map. When reflecting on this activity, some had to work through the idea that which projection is more "correct" is not an inherent property, but depends upon what is being asked for. For example, while we want an equal-area projection to compare areas, we would prefer an azimuthal equidistant projection if we were airplane pilots and a conformal projection (e.g., Mercator) if we were navigators or surveyors, etc. It does not take great imagination to discuss how someone might make a map choice for political reasons, to make his country appear larger or more central in the world. A general lesson learned by one preservice teacher was "how teacher's [sic] really need to be careful of where they get their information and how they present it to their students." This is just another example of what Frankenstein (2005) calls the "politics of mathematical knowledge," in which seemingly neutral procedures or summaries depend highly on choice of average, choice of a variable's definition, choice of disaggregation, etc.

While this type of teaching has its own inherent value and goal, educators are starting to find empirical evidence that suggests students will be more engaged in learn-ing in this environment. Gutstein (2003a) found far more student engagement when his middle-school students made a scatterplot of SAT scores and income than when they made a much more conventional "real-world" scatterplot of heights of children and same-sex parent. Investigating a course for preservice teachers designed to develop understand-ing of equity through data-based statistical inquiry, Makar (2004) found a significant correlation between prospective teachers' degree of engagement with their topic of inquiry and the depth of statistical evidence they used, particularly for minority students.

As Derry, Levin and Schauble (1995) explain, statistics represent controversial knowledge (even among expert statisticians whose different positions on probabilistic foundations—e.g., frequentist or Bayesian—have immediate impact on their practice) and therefore should not be thought of as something for the teacher to hand down as fixed, universally-accepted concepts. Instead, students should participate in the statistics controversy and gain the tools to construct evidential arguments that many adolescents and adults struggle to construct (Kuhn 1991). Such a teaching approach has been successfully used as an intervention for at-risk seventh graders (Osana, Leath & Thompson 2004). Johnson and Johnson (1992) found that controversy tends to yield many benefits that might ease the mind of an instructor wanting to use a more critical approach, such as greater mastery and retention of subject matter, greater ability to generalize, higher quality decisions and solutions to complex problems and more frequent creative insights. Seeing that mathematics can have fallibility or conflicting answers should be a powerful experience for students that may help them that much more readily imagine the possibility of such experiences involving far less abstract social constructions and institutions.

ADDRESSING PEDAGOGICAL PITFALLS

In an introductory college statistics lesson about scatterplots a few weeks before the 2004 Presidential election, a University of Texas at El Paso faculty member illustrated the tool of scatterplots by facilitating discussion of the sequence of plots that strongly suggest that the butterfly ballot of Florida's Palm Beach County confused many voters in the 2000 Presidential election (Adams 2001). Students were very engaged, though this untenured faculty member wondered if it was potentially perilous to introduce an example so connected to political controversy. The authors affirm that the psychological implications of equity demand many views, more understanding of the election process and critical analysis of policies that impact the future of all students.

However, Gutstein (2003b) cautions that classroom teachers must take care in introducing potentially volatile or normally undiscussed topics to make sure that students have already learned "to take seriously their roles as learners and knowledge creators" and that students will not be unduly demoralized or paralyzed by the bleakness of some data that they "see themselves in." Many students view their situations as personal rather than problems woven into the institutional fabric of society. Most often individual disadvantages are not unique and not the result of individual failure but due to the failure of society to ensure equality and justice for all (Frankenstein 1990).

The key is not to presume reaching definitive answers to all questions, but to nurture the students' overall spirit of critical inquiry as they gain mathematical power in general, while empowering themselves to understand more deeply a meaningful situation (and thereby making mathematics itself unexpectedly meaningful to them). Ernest (1991) suggests that students of many backgrounds may not be used to controversy, conflict and rational argument in the classroom, especially younger learners. He adds that public educators will have to address powerful contradictions such as "personal empowerment versus examination success" and "ethnomathematics versus abstract mathematics" (pp. 213-214). Ernest (1991, p. 212) also warns that the public educator "is at risk of being seen as attempting to subvert mathematics education into a propagandist activity" and must anticipate the opposition of conservative critiques (e.g., Ravitch 2005).

Another tension is that Freirean pedagogy calls for teachers to be explicit in their own views while creating space for students to develop their own views apart from what they might think the teacher wants. What may help support this balance is the reality that with such a wide variety of issues and areas, the mathematics teacher will not possibly be able to answer all of the questions students will raise, empowering the students to share the role of "expert" and search for the information to answer their own questions.

Another perception that needs to be addressed by a critical educator is whether the time devoted to social justice issues might keep the required "purely mathematical" goals of the course from being met. Gutstein (2003a) addressed this by making it a point to have a well-respected rigorous rich curriculum aligned with NCTM (2000) in place as the "main curriculum" so that the social justice projects he added to the course would not be seen as interfering with normative goals.

Perhaps critical pedagogy in mathematics instruction is best or most naturally implemented in stages, not unlike the stages of multicultural, antiracist education articulated to Barbara Miner by Lee (1995): surface stage (one-shot events and signs), transitional (self-contained 1-3 week unit of study), structural change (elements of the unit integrated into existing units) and social change stage (curriculum leads to changes outside school). Most attempts at implementation rarely go past the surface stage. One-time events like parent night, guest speakers and posters may touch the surface of the problem, but do not deal with the social, economic and political roots of the situation. Letting change stop at this superficial level gives credibility to discrimination by treating ethnic and minority students as interesting oddities rather than as accepted stakeholders in education. And traditional parent nights place the teachers as the masters who determine what is important in mathematical understanding with little awareness of how concepts really apply to local environments.

Other instructors integrate critical pedagogy goals with occasional activities dressed in more conventional trappings. For example, by discussing song lyrics containing mathematical language, Lesser (2001b) found a simple means to encourage reflection on popular culture along with mathematics. Aceves (2004) teaches his first- and second-graders culturally-rich mathematics (from counting to algebra) using “mythic pedagogy” that could safely pass for a multicultural, holistic approach to a conventional observer’s eye. But it goes deeper, allowing his elementary students to experience their culture as something that is dynamic, empowering and interdisciplinary with a nurturing and egalitarian worldview that places “their history within a universal context where being part of an ethnic group is a reflection—not a separation—of their humanity” (p.275). Preservice teachers in the first author’s course had the opportunity to observe, discuss and reflect upon Aceves’ teaching. One wrote, “If there is one thing I learned from watching Mr. Aceves teach is that it’s okay to teach by another way just as long as it is used to teach the basics of the class.”

Some pitfalls may hit hardest some of the very groups who are underserved. As De La Cruz (2000, p.22) relates, “ ... teachers are finding that reform-based mathematics instruction places more demands on facility with oral and written English. They do not have the strategies, however, that enable them to work more effectively with their limited-English-language students.” The cultural and political aspects of critical pedagogy may take extra work to communicate effectively, taking care the questions are posed in straightforward language that is not unduly technical or biased. Some instructors have found it helpful to give students a reading guide with discussion questions to prepare them for facilitating the ensuing class discussion. Mathematics instructors new to critical pedagogy may benefit from starting slowly, using focus groups of students or community members to learn about their lives, hardships and interests. All instructors should prepare to persevere and not expect overnight success.

Implications For Mathematics Teachers

Ernest (1991) includes very specific traits about how a public educator would teach, assess and use resources. Suggestions include not only creating a community of learners, using cooperative group work and projects for engagement and mastery, but also autonomous projects to give students the chance to pursue personally meaningful directions. It is no small thing for a mathematics instructor to reach, experience or respond to the realization that his or her very pedagogical practices may inadvertently or implicitly portray mathematics as an absolute, authoritarian discipline that contributes to students' feeling excluded and disempowered. Many students and teachers have the same conception of mathematics that their previous teachers and texts presented. They have internalized the "reified typification of mathematics" and have been unsuccessful in learning or remembering mathematics (Frankenstein 1990). Awareness of this influence and reflection on how to change this powerful chain of intellectual neglect is important.

One aspect of hope from Freire's work is teachers' and students' development of critical consciousness—which he maintains can emerge only through dialogical, problem posing education that moves past reflection towards action. Teachers must show students that they can understand how mathematics works and how to use it in their own interest. Teachers must also engage in this understanding themselves for change to occur.

Teachers hopefully already know that curriculum need not be neutral, as dramatically demonstrated by some of the "how much poison gas needed to kill" problems used in Nazi-era German textbooks (Cohen 1953, Shulman 2002). While today's books generally avoid such grossly blatant evils, they still require critical examination by mathematics teachers for less blatant evils (e.g., gender stereotypes in word problem scenarios) that unduly or uncritically reinforce an oppressive or unhealthy social hierarchy or world-view. For example, teachers should note whether the "real-life" application problems in the textbook are simply focused on maximizing profit, while ignoring the human or environmental dimension, such as a typical offshore oil pipeline cost minimization problem (e.g., Swokowski 1988, p. 171). Frankenstein (1983, p. 12) maintains that even the most trivial math applications are biased (such as a grocery bill calculation presupposing the naturalness of everyone having to buy food from grocery stores) and that even a problem with no real-life data has “the non-neutral hidden message that learning math must be divorced from helping real people understand and control the real world.”

There are clearly degrees of critical-ness in curricula. For example, on global human survival issues, Kenschaft (2002) clearly goes further than Schaufele and Zumoff (1993) towards raising questions from a critical perspective. Many solid reform curricula that include higher-order thinking might be used as a foundation for the instructor to add that next critical element as desired. Even if a teacher cannot choose her textbook, she can and should insert additional examples, such as those from this paper. Social justice is more meaningful and lasting when classes seek out examples that speak strongest to their locality, life and times rather than wait for a fixed collection someone else has compiled.

A mathematics instructor employing critical pedagogy should consider critical methods to analyze his or her philosophy of assessing students. Perhaps he or she will recognize, as did Romagnano (2001), that subjectivity is inherent in mathematics assessment, whether it is a teacher-made test or an SAT or an Advanced Placement test.

Directions For Future Investigations

On a global level, it will be interesting to follow the emergence of relevant organizations (e.g., the Critical Mathematics Education Group; Radical Statistics group), classes (e.g., the University of Georgia’s “Rethinking Mathematics Education from a Critical Pedagogy Perspective”), resources (e.g., Gutstein & Peterson 2005) and conferences (e.g., Mathematics Education and Society). As the aims of the Mathematics Education and Society Conference (2005) declare:

There is a need for discussing widely the social, cultural and political dimensions of mathematics education; for disseminating research that explores those dimensions; for addressing methodological issues of that type of research; for planning international co-operation in the area; and for developing a strong research community interested in this view on mathematics education.

It would be interesting to observe and interview teachers to see if the nature and magnitude of transitioning from traditional "transmission" teaching to an active-learning approach differs from transitioning from an active-learning approach to critical pedagogy. And, are there mathematics teachers who had a critical pedagogy approach from the outset and what might they have in common?

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