Critical Literacy in Math and Science

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This paper is designed to expand the notion of literacy from content literacy in mathematics and science, such as, teaching skills, decoding the printed word, and increasing fluency to one that incorporates reading, writing, and thinking about content-specific texts such as scientific studies, word problems, and textbooks from a critical literacy perspective.

Keywords: Critical literacy, Mathematics, Science

Introduction

Critical literacy aims to challenge the status quo by disrupting commonplace notions of socially constructed concepts such as race, class, gender, sexuality, power, and privilege. It allows for a multitude of viewpoints, highlights socio-political issues located in texts, and promotes social justice through political activism (Lewis, Flint, & Van Sluys, 2002). The critical reader understands that how we read is as important as what we read and asks questions about the construction of texts/knowledge and power relationships: Who is the intended audience? What is the hidden agenda? How does the text reflect and shape notions of power and privilege? What is included? What is excluded? How is the text trying to position the reader? As such, critical literacy interrogates texts in order to identify and challenge social constructs, ideologies, underlying assumptions, and the power structures that intentionally and unintentionally perpetuate social inequalities and injustices. It is important that we question the production of knowledge and search for the hidden agendas in school curricula, governmental legislation, corporate policies, and mass media.

The contributors in this paper are informed by the theory and perspectives of critical pedagogues inspired by the work of Paolo Freire. Over three decades ago, Brazilian educator Paulo Freire articulated a philosophy of education for peasants in his book *Education for Critical Consciousness* (1974). In his approach to literacy, Freire used generative words situated in everyday events of the workers to teach them to decode and dialogue about the social, economic, and political inequalities of the reality in which they lived. While the workers learned to read the word, they were also learning to "perceive themselves in dialectical relationship with their social reality" in order to create change (p. 34). Freire also critiqued the "banking method" of education, where students were trained to adapt to their world of oppression. Education, he argued, should not be an exercise of domination; banking education "treats students as objects of assistance" (p. 83). Instead, education should be about liberation, for "people to come to feel like masters of their thinking by discussing the thinking and views of the world explicitly or implicitly manifest in their own suggestions and those of their comrades" (p. 124).

Further, Freire (1970/1998) advocated for a critical pedagogy that was grounded in the "present, existential, concrete situation" (p. 76). He envisioned a teaching praxis that began with the lived experiences of students, accessing their emotional and ethical ties to the situations in which they struggled for voice and equity. Pedagogy that dwells on the social injustices of a given context can trigger student "moral outrage" (Iyer, Leach & Pedersen, 2004) and increase student participation. The emotion that fuels outrage, unlike that which underpins guilt, can become a source of political agency in die service of the disadvantaged. When outrage is buttressed with strong problem- solving skills, students are able to envision how they are implicated in the experiences of others, and how they might go about redressing the situation for the benefit of all.

Mathematics education often seems bereft of ethical principles that might hide moral outrage, but it does, in theory, furnish students with strong problem-solving skills. These skills are both quantitative and qualitative insofar as students master procedural and conceptual knowledge and learn when and how to apply that knowledge in various contexts. In the language of school mathematics, the "concrete situation" to which Freire refers might be considered the "real life" application. "Real life" applications have the potential to tap student lived experience and trigger ethical reflection. Most examples of "real life" applications, however, are less concerned with citizenship and social justice and more concerned with enhancing mastery of mathematical skills.

Critical Mathematics Education

"Critical mathematics education" is an attempt to reconceive school mathematics as a site of political power, ethical contestation, and moral outrage. Critical mathematics education refers to a set of concerns or principles that function as catalysts for reconceiving and redesigning the lived experience of school mathematics. These concerns or principles are meant to target issues of political agency in society through an examination of mathematics education. The approach addresses political issues in relation to teaching and learning mathematics, confronts the problems of access and opportunity according to skin color, gender, and class, and examines the cultural reinscription of power through applications of mathematics in society (Skovsmose & Borba, 2004). Various proponents of critical mathematics education have pursued this agenda in different ways: designing new mathematics curricula that address social justice issues (Gutstein, 2006), studying the role of mathematics teacher disposition toward social justice pedagogy (Rodriguez & Kitchen, 2005; Zevenbergen, 2004), deconstructing the instructional strategies unique to school mathematics that inhibit increased participation (deFreitas, 2004; Walshaw, 2005), generating a sociopolitical ethics of mathematics education (Skovsmose, 2005; Valero, 2004), and offering visions of alternative teaching practices (Brown, 2001). Although many of these authors define their unique approach in different terms, one can trace a collective movement in the research community that takes form in relation to the Freirian concept of the critical. As a paradigm for student-centered teaching practice, critical mathematics education springs from Freire's critical agenda and offers educators and researchers a wide range of methodologies for exploring the concerns listed above.

It is not, however, a panacea. Gutstein (2008) remarks that the challenges to critical mathematics education often seem insurmountable when one is faced with the stalwart institutional practices that currently structure, school mathematics and policy. Mechanisms of cultural reproduction that continue to sustain systemic inequity in/through education cannot simply be named and then easily abolished. Despite the efforts of many in the last century, studies continue to reveal correlations between socioeconomic status and mathematics achievement and indicate that little progress has been made regarding these patterns of inequity (Gates, 2006). Studies of mathematics teacher practice continue to show that the vast majority of mathematics teachers are still teaching skill and drill in ways that serve only a select set of students (Confrey & Kazak, 2006).

Because application problems rely on a shared understanding of the "real," they tend to produce large differences in measured achievement between social classes. Applications and "realistic" (asks have proven to be the most problematic, or rather the most revealing, in terms of differentiated cultural performances (Cooper & Dunne, 2004). Empirical work on assessment items has shown that students' confusion about the border between the "real" life, or the "everyday" realm, and the mathematical is correlated to socioeconomic position, gender, and ethnicity (Cooper, 1998a, 1998b). In other words, when students are asked to complete an application, their actions will be conditioned and constituted by their sociocultural position. Studies have shown that students who are designated working class are three times more likely to solve a "realistic" problem with a "realistic" answer (taking into account subjective and ethical issues) and fail to read the code of the problem as one demanding a mathematical solution (Cooper & Dunne, 2004). Since these "realistic" applications are a reflection of reform movements in mathematics that attempt to move away from the esoteric and toward more "meaningful curriculum," it seems crucial that we unravel the ways that they may not address our aim of increasing mathematics participation in schools. Instead, they may demand an even more esoteric performance by introducing another level of code based on one's own enculturation into the discursive practices of school mathematics.

Skovsmose and Borba (2004) are careful to suggest that the critical approach must always attend to the "what if not" of school mathematics, that it must investigate the possible–think the otherwise–and explore "what could be" (p. 211). They argue that researchers and educators must imagine alternatives that trouble the current situation by actively and creatively generating visions or descriptions of a mathematics education that is more inclusive, more playful, and more relevant. The approach is profoundly hopeful and imaginative and offers educators a positive (and critical) means for professional development. "It confronts what is the case with what is not the case but what could become the case" (p. 214).

One way of practicing critical mathematics is to revise what is offered through the mainstream curricula using the concerns mentioned above as a guide. Consider, for instance, the "real" life applications generated by "The Consortium of Mathematics and its Applications" (COMAP) (www.comap.com), which is a nonprofit organization dedicated to enhancing mathematics instruction through emphasis on modelling. The term modelling is used to refer to the practice of "real life" problem solving through the use of mathematical applications. In practice, modelling is used to "understand, predict and control events in the real world" (Dossey, McCrone, Giordano, & Weir, 2002). Like any good application problem, modeling problems do not necessarily prescribe the kinds of tools or methods that might be appropriate in obtaining a solution. A good application problem refrains from supplying instructions or specifying the best tools for the job. After all, deciding whether a particular method is suitable or not should be part of the problem-solving process. This decision process or reflective deliberation–the stage when one reflects on the suitability of the mathematical methods to the given problem–is one place where ethical reflection' might enter the application of mathematics.

Textbooks too often specify the appropriate tool to be used for the given problem and leave out the crucial ethical moment of reflecting on whether the means suit the ends. COMAP comes close to creating this moment of ethical reflection, since they create curriculum that aims to capture the messiness of "real life" problems and each year sponsor a series of contests for students at various levels. These contests involve one messy problem and no scripted solution technique. Teams of four high school students from all over the world have thirty-six hours to create a solution and submit it to COMAP via the Internet.

Unfortunately, since its inception, COMAP's high school mathematical modelling contest problems are almost always without ethical or political context. The messiness of these problems pertains to the complex and difficult physical aspects of the "real" world but avoids the ethical messiness of student agency and political action. I don't mean to detract from this other kind of messiness, but rather to point to the infrequency of problems that are couched in political or ethical issues. Successful students–such as those who select to participate in the COMAP contests–are trained to read the "real" or "realistic" application task as one without ethical significance. For instance, the 2006 contest problems, although wonderfully challenging, were woefully disconnected from the complexity of the ethical world. Consider this problem about a "South Sea Island Resort":

A South Sea island chain has decided to transform one of their islands into a resort. This roughly circular island, about 5 kilometers across, contains a mountain that covers the entire island. The mountain is approximately conical, is about 1000 meters high at the center, appears to be sandy, and has little vegetation on it. It has been proposed to lease some fire-fighting ships and wash the mountain into the harbor. It is desired to accomplish this as quickly as possible.

Build a mathematical model for washing away the mountain. Use your model to respond to the questions below.

— How should the stream of water be directed at the mountain, as a (function of time?)

— How long will it take using a single fire-fighting ship?

— Could the use of 2 (or 3, 4, etc.) fire-fighting ships decrease the time by more than a factor of 2 (or 3, 4, etc.)?

— Make a recommendation to the resort committee about what to do.

(COMAP, http://www.comap.com/highschool/contests/himcm/2006problems.html)

The problem is a "fake" problem and is easily recognized as unrealistic from an environmental perspective. Moreover, the driving principle behind the application is profit, as is often the case in school mathematics. If the mountain of sand were actually washed into the surrounding water, one could well. Imagine that the cost to marine life would be unimaginable. The problem refuses to address any of the environmental or political issues that might be relevant to the context. Rather, the problem hails the student as businessman or engineer and demands that the best solution be one acceptable to a resort committee. It is conceivable that a team response might take into consideration the environmental damage of flattening the island, since the task does not prescribe the method of solution and thereby allows for distinct answers, but the guiding questions would dissuade one from pursuing this aspect of the problem. The code for determining the preferred kind of solution is found in the statement: "It is desired to accomplish this as quickly as possible."

In order to make this problem more "critical," while still inviting mathematical application, one could ask students to consider the problem from multiple perspectives, each of which having different desired solutions. One could add a few statements regarding the environmental impact of the task, such as: "A ring of coral reef with 1 km diameter surrounds the island. Every cubic meter of sand deposited on the reef kills 1 square meter of coral." Students could then be asked to create two models, one favouring the resort committee interests and the other favouring an island environment committee. The problem would begin to access the ethical dimensions of applying mathematics in this context. In designing the task as a debate about the contested value of each alternative action, and in attending to the ways that particular solutions will serve particular segments of society, the students are enacting critical mathematics practices. Another approach might involve rewriting the code statement: "It is desired to accomplish this as quickly as possible while minimizing the damage to the local environment." This minor change in the statement forces the students to recognize the ethical consequences of their desired efficiency. By introducing the conditional into the statement, the best solution is still the one that maximizes the speed of completing the task, but within the constraints of ethical action. This sort of modification can be achieved by teachers on a daily basis by revising typical textbook questions so that they address the student in terms other than profit and consumerism.

Critical Science Education

Although science literacy (as articulated by the American Association for the Advancement of Science and the National Science Teachers Association) has been at the forefront of the national agenda for many decades, the qualities and characteristics associated with those whom are science literate only marginally address habits of mind that are fundamental to critical literacy. We would argue that there is a fundamental difference, for example, between critically analyzing data and taking a critical stance against the potential political and economical motives behind scientific claims. Based upon that data, skepticism as it relates to science literacy is limited to the evaluation of claims and data connected to scientific inquiry - it has not widely been connected to evaluating the political, social and economic forces behind research agendas and scientific messages coming out of inquiry communities. Furthermore, science literacy has failed to address those cultural aspects of the enterprise that by design or unintended consequence results in the marginalization of others. We want to confront this disparity by calling for an expanded view of what it is meant to be science literate.

Therefore, we argue that individuals (teachers, students, and the broader public) need to cultivate a skeptical mind wherein one questions, for example, the source of information, and the political and/or economic forces driving the dissemination of the information. In this process, one also searches for the untold story, considers how the ways in which information may be used to control or marginalize others, and seeks opposing viewpoints. To develop understandings about the nature of science and the epistemology of scientific knowledge, it has been argued that students must engage their own epistemological orientations and beliefs about scientific proof, logic, and justification (e.g., Craven, Hand, & Prain, 2002; Lawrence, Hand, & Prain, 1998).

Regardless of these differing levels of power within the domain of science, each branch is itself immersed in a culture of politics, policy, and economics. This immersion removes the enterprise of science from a pure, objective praxis to one that is subjective, contextually bound, and culture-laden. For example, people (from scientific as well as non-scientific communities) from around the world have been arguing for years that worldwide climate change is certainly occurring and detrimental effects are being felt globally. The effects of global warming impact both societal and geographic features of countless countries. It is widely recognized that climate change is a naturally occurring, cyclic event. However, since the industrial revolution, there appears to be an increase in atmospheric carbon dioxide (a heat trapping gas) resulting from human activity, specifically through the emissions of fossil fuels. To many scientists, there is compelling evidence suggesting that global warming is occurring at an unprecedented rate. The data includes such things as speed of glacial ice melting (glacial retreat), the rise of sea levels, and the shifting of plant and animal communities worldwide. Despite the global debate on climate change, a 2006 poll revealed that only 3 in 10 individuals agreed that humans were a primary cause of global warming and only 49 % of the people surveyed believed that climate change was in issue for concern ("Poll," 2006).

Surprisingly, the "science" of global warming was called into question (Eilperin, 2006). This may have been in part due to interference by the United States Government. In March 2001, President Bush reported that he, along with his administration, would not sign the Kyoto Treaty, an international accord that set greenhouse gas emission limits. President Bush pointed to several "scientific findings" supporting his stance. However, in the winter of 2007, Congress began investigating reports that scientists who studied climate change were pressured by the executive branch to downplay (or not report) findings that supported the argument for increasing global temperatures (Herbert, 2007).

The investigation concluded that governmental pressures did indeed exist for scientists who studied climate change. Specifically, a survey was sent out to 1600 scientists by the Union of Concerned Scientists and the Government Accountability Project to obtain responses concerning science and political pressures. Of the surveys returned, 43% of respondents reported that their work was edited to the point where the meaning of their findings were changed, 46% of the respondents indicated that administrative requirements negatively affected their work on climate change, and 67% indicated that the work-related environment for federally funded climate research was worse now than five years prior (Union of Concerned Scientists, 2007). Furthermore, in 2005, Rick Piltz, a senior official in the government office for climate research resigned in protest over the editing of scientific documents for sake of "toning down" findings related to global warming.

These examples (for others see Kennedy, 2004; Collingridge & Reeve, 1986) beg the question, "What other (scientific) information might be excluded from reports concerning matters of public health and education?" The answer is, disturbingly enough, quite a lot. Students should learn to ask questions such as: How is the science being distorted? Who is benefitting from this issue/argument? Who is the target audience and why? Is the science being used to change behaviour? Are multiple perspectives of the topic being introduced? And students should also learn to question the curriculum: Why was the curriculum funded? How does the funding agency benefit? What is the hidden agenda?

Although the critical literacy approach to teaching appears to be gaining momentum in schools across many disciplines, we conclude by stating the particular importance of the continuing the search for instructional approaches in a field (science) traditionally taught as a rhetoric of conclusions (Schwab, 1962) - aimed at causing shifts in students' conceptual understandings of the nature of knowledge and the cultural biases inherent in the scientific enterprise.

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