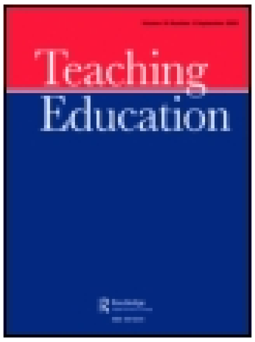

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Teaching Critical Literacy Principles to Math and Science Educators

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This article discusses the attitudes of math and science educators toward incorporating literacy activities into their teaching and offers suggestions for ways that teacher educators can encourage the integration of critical literacy principles into their lesson and unit planning. Emphases placed on textbooks, correct answers, multiple choice or other short answer forms of assessment, and an overall prioritizing of "covering content" over "having time to address questions and differing points of view" have made these students, as a whole, more resistant to the idea of incorporating critical literacy in math and science education. As a result, this article advocates the importance for teacher educators to encourage their students to develop lessons that promote critical literacy in math and science and model for them creative and effective ways in which this can be done. Through creating lessons focusing on issues of power, problems and their complexity and examining multiple perspectives, they will better understand that strategies of critical literacy are dynamic and can adapt to any context in which they are used. Student work samples that support these concepts are provided.

Introduction

> The prof's ok. The course sux. I still don't get what the point of this class is. Sensitivity training? New techniques to involve ESL students? Hell knows. I read both books and still don't get the point of the class. It's probably applicable to lit and ESL teachers, but for science is a complete waste. (Anonymous, www.ratemyprofessor.com)

The preceding quote was left on a message board at ratemyprofessor.com, a web site that invites students to leave anonymous Internet feedback about their professors and courses. It was written by a student who took a course that I teach for pre-service secondary education teachers in New York City titled "Language, literacy, and culture in education". The two books to which this student is referring are

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required texts for the course, *The light in their eyes: Creating multicultural learning communities* (1999) by Sonia Nieto and *The skin that we speak: Thoughts on language and culture in the classroom* (2002), edited by Lisa Delpit and Joanne Kilgour Dowdy.

I teach at a large public university in New York City, and the course that this student was complaining about is designed to help prepare our teacher candidates to work in some of the most culturally and linguistically diverse public high schools in the US. It involves studying the work of scholars such as Paolo Freire, Ira Shor, Sonia Nieto, Victoria Purcell-Gates, Gloria Ladson-Billings, Asa G. Hilliard III, Lisa Delpit, Herbert Kohl and others that write about issues such as critical literacy, code-switching, accommodation of students, linguistic discrimination and other topics that are pertinent to education, particularly in areas with diverse student populations.

As part of their coursework, students are asked to design integrated lessons that teach critical literacy within their content areas and devise "strategic plans" for how they will create secondary classroom environments that will promote critical literacy and critical thinking. For the purposes of this article, critical literacy will be operationally defined using Ira Shor's 1992 definition:

> Habits of thought, reading, writing, and speaking which go beneath surface meaning, first impressions, dominant myths, official pronouncements, traditional clichés, received wisdom, and mere opinions, to understand the deep meaning, root causes, social context, personal ideology, and personal consequences of any action, event, object, process, organization, experience, text, subject matter, policy, mass media, or discourse. (Shor, 1992, p. 129)

All students in the Secondary Education Department at my college are required to take the "Language, literacy, and culture in education" course, including students with secondary education majors and minors in English, social studies, science, math, art, music, physical education, family and consumer science, etc., and most of them find it to be an eye-opening, positive part of their teacher preparation program. The students who complain the most and see the least relevance between the course content and what they perceive they *should* or *will* be teaching, 9 times out of 10 come from one of two programs, science or math education.

In the four semesters that I've taught this course, I've noticed a definite pattern emerge with regard to the students' attitudes toward the topics presented. I am in no way passing judgment or privileging one group of students over another, I am simply stating what I have observed. The English and social studies education students tend to embrace the topics readily and seem to have little trouble applying them to their fieldwork observations, class discussions and reflective journals. The art, music, theater, physical education and family and consumer science education students often make use of their creative abilities to connect the course concepts to their content areas, even if at times they must think imaginatively in order to apply literacy concepts to content areas that place a lot of emphasis on hands-on skills and performance tasks.

The math and science students are, as the old saying goes, "a whole 'nother story". They are much harder to "win over" and are often quite vocal about the fact that they

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want to teach math and science, not literacy. Csongor and Craig (2005) point out, "Communication, whether verbal or written, is an essential tool in our society. Yet we find students in mathematics classes resisting efforts aimed at improving their skills in this area. They consider the usual writing assignments boring" (p. 181).

Attitudinal Difference Number 1: Reliance on the textbook as the sole source of information

In my experience, math and science teachers have several qualities that set them apart from educators in other subject areas and in order to teach them about topics such as critical literacy, it is important that we, as teacher educators, recognize and address these attitudinal differences. One thing that sets math and science apart from other subjects in education is that in these subject areas, one textbook is often the sole source of information for a course. The textbook is relied upon heavily and is rarely ever questioned or presented to students as having been written from a particular author's, editor's or publishing company's perspective, let alone a particular cultural, political or linguistic stance.

Conversely, in the humanities, students are more encouraged and accustomed to using multiple texts, genres and interpretations and often have an easier time looking at topics from several, often conflicting, points of view. One of my graduate students named Denise, who teaches middle school science and is now getting her masters degree in secondary literacy education, summed it up nicely when she wrote:

> Since I began teaching science, I have been one of those teachers mentioned in all the textbooks that is guilty of relying mostly on the science textbook as a major source of science information. … It was not until I entered the literacy program that I have been taught to look at the text, and not just written text, in a more critical way. … Looking at text critically takes some practice, in my opinion. Up until now, I don't think I paid much attention to the critical aspects of certain texts. I read them for what they were and not much more.

Similarly, Burns (2004) writes about her experiences as a math teacher whose views about writing in math instruction have changed dramatically over a period of years:

> The results that I experienced with my students were what clinched my commitment to making writing a regular part of math instruction. Not only did I see how writing helped students think more deeply and clearly about mathematics, but I also discovered that students' writing was an invaluable tool for me to assess their learning. Writing in math class supports learning because it requires students to organize, clarify and reflect on their own ideas—all useful processes for making sense of mathematics. In addition, when students write, their papers provide a window into their understandings, their misconceptions and their feelings about the content they're learning. (Burns, 2004, p. 30)

This change in attitude, however, only came after Burns was able to overcome her own issues and fears regarding writing. She writes:

> One reason I chose mathematics for my undergraduate major was that it didn't require papers. Math homework called for solving problems or proving theorems, and that was just fine with me. Math and writing, like oil and water, seemed to have little in

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> common. And for my first 20 years as a middle school and elementary school teacher, writing played no role in my math teaching. (Burns, 2004, p. 30)

Attitudinal Difference Number 2: Emphasis on getting correct answers

A second quality that I believe is more prominent in math and science educators than those from other disciplines is related to the emphasis that is placed in these subjects on getting the "correct answer", something that is discussed far less often in art, music or English classes. I believe that this emphasis on correct answers and final products makes it far more difficult, for example, for these future educators to "buy into" a course such as "Language, literacy, and culture in education" that teaches students about multiple perspectives and approaches to literacy education in all content area teaching.

Burns (2005) discusses the ways in which she *used to* assess the students in her math classes before she began implementing writing into her teaching:

> The problem was that when a student gave a correct response, I assumed that both the student who had answered correctly and his or her classmates understood the mathematics behind the problem. I never probed students' level of understanding behind their responses; I just happily continued along my teaching trajectory. As a result, I never really knew what students were thinking or whether their correct answers masked incorrect ideas. I only knew that they had given the answer I sought. (Burns, 2005, p. 27)

What is ironic about this lack of questioning concerning students' answers is the fact that the very disciplines of science and mathematics were both born from people's need to question the world around them and set out to prove or disprove theories that they had about how it functions. What a shame that these subjects are often the ones in which students are encouraged to question and explore multiple perspectives the least and told, instead, to simply accept the facts as they are written in a textbook. Darwin and Descartes would not be impressed.

One of my undergraduate science education students, Margarita, wrote in a reflective paper about critical literacy:

> Science is a subject that is always changing, and questioning is an important part of this process. Effective questioning is, in my opinion, also important and probably the first step in acquiring a critical stance. Even though there is not enough space for questioning scientific notions along the curriculum because of the requirements, I believe that one of the most important things students can learn from science classes is exactly that, to question and inquire until they find answers, and following that, to continue questioning and learning, because their primary answer does not have to be the definitive one. There might always be aspects and perspectives that they may have ignored, which would render totally different answers.

Attitudinal Difference Number 3: There's no time to teach content *and* literacy

This leads me to point out one final difference that I have noted between math and science education students and their counterparts in the arts and humanities: Math

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and science teachers tend to think that they have no time to *depart from their content teaching* to teach critical literacy and other forms of literacy and language education in the classroom, whereas students in other subject areas often recognize that it is precisely this type of high level, complex cognitive work that fosters lifelong learning and allows students to connect content area learning to their own lives and make it meaningful.

In a 1997 survey of teachers who were members of the National Council of Teachers of Mathematics (NCTM), "The senior high school teachers surveyed were far more likely than the elementary school teachers to say that writing about mathematics takes too much time" (Silver, 1999, p. 389). Interestingly, however:

> Among the 117 respondents, those who described their students as above average were the least likely to say that writing about mathematics takes too much time. The extended comments of those with average or below-average students underlined the tension between the obligation to cover predetermined course content and concern for the depth and retention of student comprehension of math principles. (Silver, 1999, p. 389)

In the international 2003 Trends in Mathematics and Science Study (TIMSS), the data show that the achievement of fourth grade Caucasian students in science and math in the US has declined since 1995. According to Pratt (2005):

> This can be attributed to multiple and widespread reports from elementary teachers that the increased emphasis on literacy, which began in the early 1990s, squeezed much of the quality standards-based science out of the early elementary grades. (Pratt, 2005, p. 11)

So, the question remains, how can math and science teachers keep necessary content in their curricula, while supporting students' critical literacy development at the same time?

Sabrina, a math education undergraduate student, wrote about this negotiation of her role as a critical educator and mathematics teacher:

> Although it may be difficult for mathematics teachers to create an environment that promotes a critical stance, critical literacy can still be taught. In every subject, students should be able to connect what they have learned to themselves and to the world. They should also be able to hold certain views about the material they are reading, and we as teachers need to help students explore these views. … The students will pose problems on their own and I will use those to scaffold their learning.

Sabrina recognizes that *even in math*, without "text-to-self connections", students will be less likely to be actively engaged with the material.

A similar quandary exists in science education with respect to teachers incorporating what they believe to be "time-consuming" aspects of critical literacy into an area of study that is commonly assessed using summative, rather than formative evaluations. In an article titled "Knowing when you don't know: Supporting teaching and learning using a new generation of tests" that appeared in *The Science Teacher*, a secondary publication of the National Science Teachers Association (NSTA), Doane, Rice and Zachos (2006) describe what they term "new performance assessments in science", such as one created by Cindy Sargent, a New York State earth science teacher, that use critical literacy and critical education principles to help the teacher ascertain specific areas of concern for future instruction. Her "Cubes and liquids" assessment:

> … begins with a story of how Socrates became a philosopher. … Students, when asked to make predictions about whether a particular cube will float or sink in a particular liquid, need to consider that they may not have sufficient information to make a good prediction. In other words, they must discover, as Socrates did, the value of knowing when they do not know. (Doane *et al.*, 2006, p. 48)

Using the Socrates story as a springboard, students are then asked to predict which of several objects will float or sink in a variety of indistinguishable liquids of varying densities. At the end of the assessment, students are rated on a series of learning goals, rather than being graded on the assessment in its entirety. If this is considered to be a "new form of assessment" in science, it is likely that the traditional, more commonly used forms of assessment are multiple choice exams and the like.

The authors make a point of arguing that "the Cubes and Liquids activity is *efficient* because it does not take time away from instruction" and that "learning begins with the first administration of the assessment" (Doane *et al.*, 2006, p. 48). Furthermore, they assert that assessments such as these "assure that the goals are higher level thinking skills, that is, at the level of Application or higher in the cognitive domain of Bloom's Taxonomy of educational objectives (Bloom, 1956)" (p. 48). Science teachers' concerns about incorporating aspects of critical literacy into their courses will only be allayed when many more of their colleagues "buy into" the fact that units such as the one created by Cindy Sargent can, in fact, teach critical literacy and science concepts *simultaneously*. Unfortunately, this article depicts this type of learning in science to be innovative and new, rather than commonplace.

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Teaching Classroom Applications of Critical Literacy Concepts

Taking into account what I've said about the challenges in teaching math and science educators about language and literacy in the classroom, I would like to offer one suggestion for how to help these students better understand the need for and teaching of critical literacy in secondary science and math classrooms and share some of the successful lesson ideas that my students have developed. One of the best articles that I have found to teach *classroom application* of critical literacy concepts to teachers from all secondary content areas is called "Critical literacy as comprehension: Expanding reader response" by Maureen McLaughlin and Glenn DeVoogd (2004). In this article, the authors present a theoretical framework of critical literacy and put forth four principles of critical literacy, which include: focusing on issues of power and promoting reflection, transformation, and action; focusing on a problem and its complexity; understanding that strategies of critical literacy are dynamic and can adapt to the contexts in which they are used; and examining multiple perspectives.

As part of my secondary literacy education courses, at both the undergraduate and graduate levels, students are required to design lessons or units in their disciplines that will compel their students to develop critical stances and write reflective papers in which they explain how and why these lessons will promote the "principles of critical literacy" outlined in the McLaughlin and DeVoogd (2004) article. They must further explain how they, as secondary teachers, will craft environments that promote critical stances in their classrooms and make critical literacy events significant aspects of their teaching. After creating the lessons and writing the reflective papers, students share their critical literacy lessons verbally with the whole class and give each other feedback. Again, students from math and science education often have the most difficulty with this assignment and lament that in their fieldwork observations of practicing teachers, they do not see this kind of teaching being done in science and math classes in the schools where they are observing. After struggling, however, many of them come up with excellent ideas for incorporating critical literacy concepts and methodologies into science and math classrooms.

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Critical Literacy Lesson in Math: Solving exponential equations about Chlamydia

One example of such a lesson was developed by Jessica, a math education student who created a critical literacy lesson about setting up and solving exponential equations using statistical data about skyrocketing Chlamydia rates among teenagers in the US. This lesson began with an anticipatory set in which the class was asked to name health issues that pose significant problems in the US. The teacher then read statistics to the class from The Centers for Disease Control and Prevention that state the prevalence of current health concerns such as teenage birth rate, cancer, obesity and sexually transmitted diseases (STDs). After the initial discussion, Jessica passed out copies of the statistical report, including graphs and charts displaying the rate of Chlamydia in the US from 1984–2004. She asked the students to analyze the information as she read statements aloud from the article to peak students' interest. She then taught the students how to solve an exponential equation, using Chlamydia as an example: The prevalence of Chlamydia among young women increases according to the model P(t) = 4000e rt, where r is the rate of increase and t is the time in years with t = o corresponding to 2004. What is the expected number of reported cases of Chlamydia among women in the US in 2024? After working through the original equation as a whole class, Jessica then assigned students questions to solve with partners, such as "Find the expected number of Chlamydia cases in females ages 15–19 according to the model after the same 20 years". She allowed students time to complete the problems to the best of their abilities before bringing the class back together to go over the problems with the students' assistance. She incorporated several critical questions, such as: Why do you think the rates of reported Chlamydia increased so drastically? What effects can these rates have on our country? And, most importantly, what can we do to help solve this problem? These critical questions were addressed by students in small groups. Jessica emphasized to the students that they will have different perspectives on this topic and encouraged them to introduce their beliefs to the class for everyone to consider.

At the conclusion of this lesson, Jessica asked her students to reflect on information that they gleaned from the statistical reports, charts, and graphs and use their prior knowledge about exponential equations to recommend what might be done to solve the problem. For homework, students were asked to research other health problems in the US, such as cancer and AIDS, raise questions about the problems and "seek alternative explanations" as to why the problems are so severe. In a reflective paper that Jessica wrote about the lesson she stated, "This critical literacy lesson will create a different perspective for the students on solving exponential equations. They will look at exponential equations and relate them to real life problems, which can promote critical thinking".

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Critical Literacy Lesson in Earth Science: Examining the relationship between human population growth and animal extinction rates

Another example of a critical literacy lesson was developed by Christine, a graduate student in earth science. She developed a lesson whereby students were asked to examine the relationships between increases in human population and the extinction rates of bird and mammal species. In this lesson, students were asked to reflect on the fact that humans are in a position of power in relation to other species on Earth and examine the deleterious effects that the human population has had on other species. The lesson began with Christine asking her students to complete a graph with numerical data that were unexplained. Then, they critically evaluated the results of their graphs and tried to determine what the numerical data and graph could possibly represent. She demonstrated a read-a-loud and think-a-loud using a section of their textbook titled *Endangered species: What's happening?* and challenged students to take a critical stance. She used an overhead projector to model the plotting of a few points on the graph that the students were given. The information they were plotting was not labeled or known to the students. They were then asked to finish the plotting on their hand-outs and then plot the remainder of the graph on the overhead as a group. She elicited from the students that there seemed to be a correlation between the factors graphed.

Christine asked the students to think about what the data might represent. After several guesses, the students deduced that the left axis represented human population in millions. Christine then discussed the right axis and told the students that it represented the number of bird and mammal species that have become extinct. She asked students why they thought only birds and mammals were represented and what other organisms were discounted and why. Other critical questions asked included: Does there seem to be a correlation between human population and extinctions? Did species become extinct before there were humans on Earth? Do humans cause all extinctions now? Why should we care about other species? What can be done to reduce human-caused extinctions? The students shared their responses in small discussion groups and came up with several factors that contribute to the extinction of species, including habitat alteration, commercial hunting, sport hunting, pest control, competition with species that humans introduce to an environment, subsistence hunting for food, and pollution. Finally, as a whole class, the students predicted and discussed the multiple perspectives that various "interest groups" would have about this issue. These included farmers, various environmental protection agencies, The National Rifle Association (NRA), People for the Ethical Treatment of Animals (PETA), and others. For homework, the students were asked to create a graphic representation of these multiple perspectives and be prepared to share them during the next class.

This lesson, as Christine stated in her reflective paper, "may cause students to feel an obligation to take action to protect those species" and "reveal the factors contributing to the complexity of the situation", aspects of critical or empowering education that were written about extensively by Freire (1970) and Shor (1992) among others. This lesson even asked students about multiple perspectives in relation to scientific data and statistics, something that is rarely done in high school science classes. It did this when the students were asked the critical questions, "Why are only birds and mammals represented on the chart?" and "Why aren't other endangered organisms, such as plants, insects, or invertebrates mentioned in the data?"

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Critical Literacy Lesson in Physics: The benefits of plate tectonics

Finally, Suleman, a graduate student in physics education, created a critical literacy lesson about the *benefits* of plate tectonics, a topic that is rarely, if ever, discussed in high school physics and earth science classes. What makes this topic intriguing is the fact that plate tectonics or movements are normally associated exclusively with earthquakes and tsunamis, complex problems of our modern society that are difficult to predict and cause great devastation. In his critical literacy lesson, Suleman chose to focus on the positive aspects of plate tectonics, such as the creation of oceans, land formations, soil improvement, regulation of global chemistry and concentration of metals to name a few. He asked students to consider what the Earth would be like without oceans or without an atmosphere and fostered critical thinking about this traditionally one-sided topic, as it is presented in most high school science classes.

At the onset of the lesson, Suleman showed students the map of Great Zimbabwe, a civilization that collapsed in a matter of a few seconds due to an earthquake during the fifteenth century. He discussed that earthquakes are the result of plate movements, as are tsunamis. He emphasized that tsunamis and earthquakes are complex problems that are difficult to predict. He then provided students with an article discussing the benefits of plate tectonics and broke the class up into small groups. The students were asked to visualize and juxtapose the information from the map with the article. In their groups, the students were asked to consider the following: How are the benefits of plate tectonics different from the causes and effects of it? What are some of the benefits outlined in the article? What new vocabulary is presented in the article? The students were then asked to diagram their responses and to create a word wall of new vocabulary and definitions, including geophysics, carbon dioxide cycle, acid rain, subduction, and biosphere. Finally, they compared and contrasted the information in their textbooks on plate tectonics theory with the ideas presented in two other current articles on the benefits of plate tectonics. Suleman asked the students to consider why this information may have been left out of their textbooks and emphasized that in science, research is ongoing and that new discoveries are made throughout the world on a daily basis.

Suleman commented in his reflective paper:

> This lesson promotes critical literacy through the use of alternate views of learning. The students use newspaper articles instead of traditionally assigned textbooks. It promotes critical literacy because it focuses on an issue that is not usually described in the textbook. It shows a transformation in the content of a topic. The benefits of plate tectonics are not discussed in the school's textbooks. Thus, it is challenging an existing body of knowledge on plate tectonics.

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Concluding Remarks

Working with science and math education students poses particular challenges to teacher educators in the field of literacy and language education. These challenges come largely as a result of the kind of prior educational experiences that these students bring to their teacher education programs and the ways in which they imagine math and science schooling *should look*, based upon their own prior experiences as students and the kinds of pedagogical strategies that they witness as part of their fieldwork observations and student teaching placements.

Mason and McFeetors (2002), in an article about interactive writing in mathematics class in *Mathematics Teacher*, support this when they say:

> Many teachers are recognizing the advantages that student writing may provide in an academic mathematics environment—developing students' understanding of ideas (Pugalee, 1997), enabling teachers to identify incomplete conceptions (Chapman, 1996), and contributing to a more interactive relationship between student and teacher (Dougherty, 1996). However, writing to learn mathematics is not something that most teachers experienced when they were students. (Mason & McFeetors, 2002, p. 532)

Silver (1999) supports a similar view when discussing a 1997 survey in which "almost half (43%) of the 117 NCTM mathematics teachers who responded to this survey said they had never heard of Writing to Learn (WTL) or had never used it in their classes" (p. 389).

Carlson (2000), in an article in *The Science Teacher* titled "Scientific literacy", recommends several effective literacy strategies that science teachers can use to support English language learners in their classes, including using graphic organizers, KWL charts, blank outlines for student note-taking, word banks and word walls. Furthermore, she advocates using pre-writing and pre-reading activities, familiarizing students with the structure of the textbook at the beginning of the year, and doing "jigsaw" cooperative learning activities to teach difficult vocabulary. These strategies are successful, but rarely seen in high school science classrooms, particularly in the advanced sciences, such as chemistry and physics. It is also interesting to note that the focus of this article is on teaching *English language learners* using these literacy strategies, not all students.

Martin (2002) also advocates that science teachers incorporate more literacy instruction into their classes in an article titled "Reading, writing, and comprehending: Encouraging active reading in the science classroom". He suggests the use of prediction and anticipation guides, SQ3R, KWL charts, learning logs, response journals and admit/exit slips, all strategies that have been developed to boost student reading comprehension in the content areas. He learned these strategies in a reading course that he attended at Shenandoah University in Virginia and a training session sponsored by the National Science Foundation (NSF) called "Reading and writing in the science classroom". He concludes his article by urging his colleagues to seek out professional development in this area, a clear sign that the strategies discussed in his article are not familiar to all science teachers.

Emphases placed on textbooks, correct answers, multiple choice or other short answer forms of assessment, and an overall prioritizing of "covering content" over "having time to address questions and differing points of view" have made math and science students, as a whole, more resistant to the idea of incorporating critical literacy into their teaching. As a result, it is necessary that we, as teacher educators, *particularly encourage* educators in these subject areas to develop lessons that promote critical literacy in math and science and model for them creative and effective ways in which this can be done. Through creating lessons focusing on issues of power, problems and their complexity and examining multiple perspectives, they will better understand that strategies of critical literacy are dynamic and can adapt to any context in which they are used (McLaughlin & DeVoogd, 2004). Only then will science and math classrooms return to the true origins and traditions of their disciplines, those that promote questioning, inquiry, experimentation, transformation, and critical thinking.

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