THE PRACTICE OF CRITICAL DISCOURSE IN SCIENCE CLASSROOMS

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A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (NRC 2012) describes a vision of students developing an understanding of the practices of science and engineering to build and revise their understanding of how the natural world and designed systems work. This National Research Council report poses a question: What might scientific and engineering practices look like in a science classroom? Many science teachers have their students memorize the scientific method as described in the first chapter of a textbook. This approach persists in spite of long-standing and consistent statements about the fact that the actual practices of science and engineering are quite different. Teaching the scientific method in an algorithmic manner takes away from the creativity and critical thinking necessary for true science instruction.

However, some science teachers actively involve students in the practices of science and try to have students acquire knowledge, learn skills, and develop abilities that help them understand science and engineering and develop competencies that will be important in everyday living. For students in these science classrooms, the world is one of scientific questions and engineering problems. Further, once the questions and problems have proposed answers and solutions, peers have to be convinced of their adequacy and efficacy. This last component introduces the role of conversations, critical discourse, and argumentation.

Earlier articles introduced scientific and engineering practices and various strategies in science classrooms (Bybee 2011; Duschl 2012; Sneider 2012; Krajcik and Merritt 2012; Reiser, Berland, and Kenyon 2012). In this article, we provide science teachers with a discussion that clarifies and justifies critical discourse and suggestions for promoting critical discourse and argumentation in science classrooms.

To most effectively engage students in the practices of science and engineering, one must provide opportunities for *conversation* (dynamic exchange of ideas and reflection), *critical discourse* (accentuating connections between ideas and evidence), and *argumentation* (use of evidence to process and learn about ideas) in the classroom. These are primary tools for communication and making ideas public in science and engineering. Through sharing ideas in the classroom, students make and defend statements about their understandings and are provided occasions for examining their own thinking and sense making (NRC 2005). As students make their ideas public, teachers can evaluate understanding by monitoring how students use evidence to support a claim. Argumentation (different from a polemic in nonscientific contexts) promotes as much understanding of a situation as possible and persuades peers of the validity of a specific idea (NRC 2008). As students learn to argue, they apply their emerging scientific knowledge in an attempt to justify claims and identify shortcomings in others' arguments. Critical discourse through acts of talk and argumentation in the classroom provide opportunities to enhance conceptual understanding and strengthen students' scientific reasoning capabilities.

Essential elements of argumentation: An example

In this example, the science teacher sets the stage for students to develop knowledge of the relationship of heat energy to the perpetual motion of particles and changes of state. Prior to students observing similar-sized pieces of dry ice in two different but identical-sized beakers (one beaker containing hot water and the other cold water), the teacher establishes expectations. The teacher informs students of rules, including respecting all classmates and their ideas and listening to and thinking carefully about what others say. Then the teacher informs students that they will be responsible for describing and drawing in their science notebooks their observations of the dry ice in both beakers.

Within cooperative groups, students prepare an evidence-based explanation as to why the temperature of the water in the beakers affected the sublimation rate of dry ice (instruction on the concept of sublimation occurred earlier in the unit). Bybee (2010) asserts that communicating scientific explanations and defending a scientific argument are instructional strategies that enhance students' development of 21st-century workforce skills. After students develop explanations within their groups, the entire class is seated in a large circle with students facing each other to promote a natural flow to the conversation. Students share the explanations they developed with their small groups. This configuration promotes student-to-student interaction rather than a question-and-response exchange with the teacher. The teacher addresses naive conceptions by distinguishing between steam and fog and informing students that the fog they observed emanating from both beakers was caused by CO_2 gas emitted from the dry ice encountering air and the water vapor in the air condensing into fog. Students explicate their reasoning by providing evidence in the form of quantitative data, which was recorded on a stopwatch within separate groups while the dry ice sublimated in each beaker.

Promoting critical discourse and argumentation

The following are essential elements to fostering critical discourse in science classrooms.

1. *Establish norms for discourse*. Norms include respecting others' ideas, listening to others, maintaining focus on the concept, and practicing mutual accountability (Worth et al. 2009). Students must be comfortable sharing their observations, challenging the claims of their classmates, and taking risks to share their ideas. Explicit instruction and modeling about rules and classroom behavior will enhance the quality of the discourse. It is recommended that students be informed that they are challenging the presenters' claims and not the presenter.
2. *Have a learning outcome*. Just as scientists and engineers use laboratory notes to prepare documents for public presentation to the larger scientific community, students need an avenue to communicate their gathered information. This avenue may take the form of using scientific evidence to develop a written explanation to support or refute a stated hypothesis or arrive at a group consensus as a result of contributions of others' ideas. This element marks the shift from divergent to convergent thinking and reasoning as students focus on sharing their findings (NRC 2005). Progress in science is supported by a community and culture in which one's work and reasoning are continually critiqued.
3. *Provide two opposing evidenced-based explanations or solutions*. Allow students to select the best explanation (science) or best solution (engineering) and state why they believe it is best. Situations with differing points of view reinforce the value placed in science on examining alternative ideas and thinking about one's ideas (Keeley 2008). This cognitive dissonance also can lead to students explaining what they have learned and how their ideas have changed as a result of engaging in critical discourse.
4. *Emphasize student observation and inference*. Opportunities to explain, critique, and justify their observations allow students to engage in the practices of science and engineering rather than just being told about them. Emphasizing these skills serves as rudimentary scaffolding for making claims and supporting them with evidence during argumentation (Llewellyn and Rajesh 2011). Prompting students to evaluate a claim or convince others of its validity provides learners with an important learning opportunity.
5. *Address naive conceptions*. Oftentimes, learners' ideas are prescientific and have limited usefulness because they do not hold accepted scientific explanations. Addressing naive conceptions will increase the likelihood of students gaining a secure understanding of scientific concepts. Beliefs are transformed not solely by confirming evidence but also by negotiating alternative hypotheses (Khine 2012). Knowing why the wrong answer is wrong is just as important as knowing why the right answer is right.
6. *Use prior knowledge to generate data*. Emphasize that the practices of science and engineering are ways to investigate and explain the natural world. Students can come to believe science is a compilation of truths to be memorized if we do not make it clear that science fundamentally depends on evidence that can be logically and independently verified (Alberts 2009). Providing data that show an interesting pattern in need of an explanation is also a tangible way to incorporate the practices of mathematics into our instruction.

Valuing critical discourse, recognizing cultural diversity, and promoting equity

Students in our science classrooms today come from a variety of cultural backgrounds and have many different ways of thinking about and interpreting the world. Additionally, some of our students may have discourse experiences that differ from their teachers'. (Let us be mindful, however, that there are no native speakers of science.) Emerging literature indicates that when provided with equitable science learning opportunities, students of color, students from low-income families, and English language learners (and other nonmainstream students) demonstrate higher levels of science achievement and develop into successful learners while maintaining cultural identities (Lee 2011). If science teachers focus on deficits in student language, it may become an impediment toward building on the strengths students bring to classrooms and creating conditions conducive to critical discourse and argumentation.

Providing equitable learning opportunities for critical discourse and argumentation involves valuing and respecting students' prior knowledge and the experiences they bring to the classroom from their home and community. A key element to fostering robust student verbal interactions is valuing the diverse social and linguistic traditions of our students. When nonmainstream students enter into the practices of science and engineering, they do not leave their cultural beliefs and practices at the classroom door. A classroom environment that provides students from diverse backgrounds with opportunities to engage in the practice of scientific argumentation can actually serve as a productive entry point for students from diverse communities (NRC 2012). By engaging them in science and engineering practice of argumentation centered on evidence, we provide nonmainstream students with rich language opportunities and model what scientists and engineers do in the scientific community. In addition, such experiences provide opportunities for students to develop learning outcomes of language-arts standards. Instruction that engages nonmainstream

FIGURE 1 The practice of scientific argumentation

Engaging in argument	Engaging students in argument from evidence at the elementary school level includes the following:	Engaging students in argument from evidence at the middle school level includes the following:	Engaging students in argument from evidence at the high school level includes the following:
The practice of argumentation focuses on sharing and interpreting ideas and observations. Engaging in argumentation means comparing and differentiating between these ideas and observations to build scientific knowledge. This scientific and engineering practice makes student thinking visible through the use of evidence and reason to develop an explanation.	• Distinguishing evidence from opinion • Listening to others' arguments and asking questions to clarify their reasoning • Constructing an argument for one's own interpretation of natural phenomena and collecting data	• Identifying which aspects of evidence support or refute an argument • Critiquing by asking questions about one's own findings and those of others • Identifying weaknesses in data or a claim and then explaining why their criteria in support of a claim are justified	• Distinguishing among a claim, warrants, qualifiers, and data • Identifying the flaws in one's own argument and modifying and improving them in response to criticism • Constructing an evidence-based model to refute the validity of a competing argument

students in this approach is more likely to help them view themselves as successful science learners and become members of a science learning community while remaining members of their own community.

Application in a science classroom

The last academic year (2011–12) found one author (Huff) participating in frequent parent-teacher conferences and meetings with colleagues within his district because of the diverse learning needs of the nonmainstream students in his science classes. One particular student had a learning disability and moderate to severe bilateral hearing loss; an assistive listening and technology device was used in the classroom so the student could hear the instruction. This student was an English language learner who entered the district from Ethiopia two years ago. The parent-teacher conferences regarding this student were very meaningful because they provided insights into her communication patterns and how she worked to overcome her hearing loss while developing her English language proficiency. Her education needs in the classroom were addressed through additional consultation with the district teacher for the deaf and the English-as-a-second-language teacher regarding program accommodations from her individualized education program. This accommodation was implemented in a small-group setting and promoted risk taking while nurturing an increased sense of confidence as she shared her thinking. Additional classroom accommodations implemented to meet her vocabulary and pronunciation needs included limiting linguistic demands by having her draw and label diagrams and pictures of content and asking her to orally explain her thinking through these drawings and observations. This strategy was also an effective learning strategy for mainstream students because it allowed me (Huff) to begin implementing an evidence-based explanation framework where students make a claim, provide evidence to support the claim, and provide reasoning that articulates why evidence supports the claim (NRC 2007). Moreover, this approach was successful with mainstream students because it enabled me (Huff) to scaffold students' observations toward more sophisticated explanations while providing equitable opportunities for all students to become increasingly confident and competent in talking about their thinking. Figure 1 contains a progression of argumentation. Assessing nonmainstream students' level of engagement in the practice of scientific argumentation took different forms. Exit tickets and timing student responses served as efficient formative assessments. More complex methods of assessment involved taping student conversations to analyze how students made connections to ideas and how ideas evolved through the influence of instruction.

The importance of critical discourse in science classrooms

Argumentation is a central activity of scientists; however, collaborative discourse in today's science classroom is virtually absent during instruction. The absence of argument is a product of the overemphasis of teachers, curricula, and textbooks on acquired knowledge at the expense of how we know (Osborne 2010). This overemphasis on knowing content at the expense of engaging in the practices of science often has a pejorative effect, because it leaves students with the idea that science consists of solved problems and theories to be transmitted. Osborne goes on to state that "deep within our cultural fabric, education is still seen simplistically as a process of transmission where knowledge is presented as a set of unequivocal and uncontested facts transferred from expert to novice." Much of the talk in today's science classrooms funnels through the teacher in what can be described as an initiate-response-evaluate approach to instruction. In this instructional strategy, the teacher asks a question, prompts a student for a response, and then follows with a comment that evaluates the student's response. This instructional format emphasizes content knowledge, because the student supplies the teacher with a conclusion—an expected fact or information, not a claim supported by evidence or a comparison and contrast that distinguishes different viewpoints.

For students to engage in the practice of scientific argumentation, they must go beyond just giving a correct answer that centers on a scientific idea. Engaging in true scientific argumentation requires students to justify an idea and apply evidence and logical reasoning to support their viewpoints. Developing an understanding of science and appropriating the syntactic, semantic, and pragmatic components of its language requires students to engage in practicing and using discourse (NRC 2007). Although society has come to recognize the countless benefits derived from science, there is less appreciation for the ability to use evidence in developing explanations, which causes students to represent information clearly and convincingly.

Conclusion

Manipulating knowledge through critical discourse and argumentation rather than just assimilating it allows students to process their ideas and observations. Embracing this science and engineering practice also provides a meaningful way for students to reflect on what they know and what ideas need to be refined to become consistent with scientific conceptions. Effective science instruction considers students' prior knowledge, experiences, and beliefs in order to provide an equitable science experience for all students.

Argumentation is a hallmark of the practicing scientist and engineer and is essential to justifying one's explanation. Successful science education is about students engaging in the practices of science and eschewing the monolith of textbook material to be memorized and recalled. It fosters scientific habits of mind emphasizing logic and data while being skeptical of claims absent of this evidence. Critical discourse and argumentation improve the quality of the learning experience, promote reason and critical thinking, and provide students with the capacity to use persuasive language to develop their scientific knowledge. ■

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