Teaching Science Through Inquiry

Seven common myths about this time-honored approach

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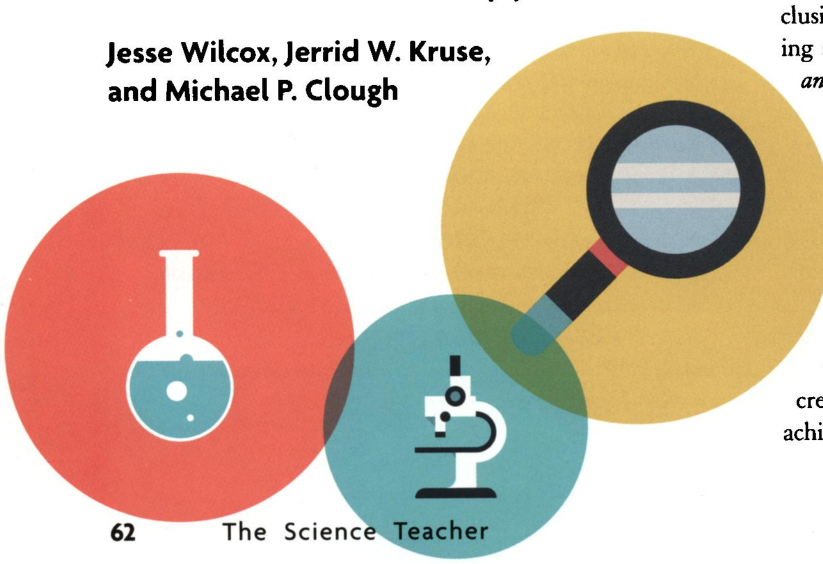
Science education efforts have long emphasized inquiry, and inquiry and scientific practices are prominent in contemporary science education reform documents (NRC 1996; NGSS Lead States 2013). However, inquiry has not become commonplace in science teaching, in part because of misunderstandings regarding what it means and entails (Demir and Abell 2010).

Understandably, confusion about inquiry results in misconceptions and misgivings about its use in the science classroom. A major goal of the authors of *A Framework for K–12 Science Education* (NRC 2012) and the *Next Generation Science Standards* (NGSS Lead States 2013) was to clarify this meaning and the relationship between "inquiry" and "science and engineering practices." For instance, "...because the term 'inquiry,' extensively referred to in previous standards documents, has been interpreted over time in many different ways throughout the science education community, part of our intent in articulating the [science and engineering] practices...is to better specify what is meant by inquiry in science" (*A Framework for K–12 Science Education,* NRC 2012, p. 30).

While inquiry can mean many things, in this article we exclusively address the teaching of science *through* inquiry. Teaching science through inquiry refers to the *pedagogical decisions and actions that teachers make* to promote scientific practices such as asking testable questions, creating and carrying out investigations, analyzing and interpreting data, drawing warranted conclusions, and constructing explanations that promote a deep conceptual understanding of fundamental science ideas. These outcomes closely align with the scientific practices identified by the *NGSS.* While the *NGSS* clarifies the practices students should engage in, teaching science through inquiry is still shrouded by misunderstandings. This article addresses common myths that create resistance to teaching *through* inquiry and interfere with achieving desired science education goals.



Myth #1: Teaching science through inquiry means students discover science ideas on their own

Teaching science through inquiry has been criticized for providing insufficient guidance to students (Kirschner, Sweller, and Clark 2006). This view wrongly equates teaching science through inquiry with "discovery learning" and ignores the scaffolding that the former entails (Hmelo-Silver, Duncan, and Chinn 2007). Without teacher intervention, students will become frustrated when taught science through inquiry as they alone will rarely create meaning similar to that of the scientific community. Expecting students to develop accepted science ideas on their own ignores the counterintuitive nature of much scientific thinking (Wolpert 1992) and the significant struggles scientists experienced throughout history when developing the science ideas we accept today.

Teaching science through inquiry occurs along a continuum from more guided to more open approaches (NRC 2000), and the teacher's interaction with students is crucial all along that continuum (Figure 1). Early in the school year, and with more complex experiences, science teachers must extensively assist students by implementing teacher actions that promote reasoned student decision making. However, as the year progresses and students' scientific practices and conceptual understanding improve, these scaffolding efforts should be progressively modified so that student decision making is more extensive and conceptually complex. Determining just how much guidance students need is oftentimes challenging. Too often, as the next myth addresses, teachers provide so much guidance that students need not think about or conceptually understand what they are doing.

Myth #2: Teaching science through inquiry is achieved merely through hands-on activities

Teaching science through inquiry is not achieved merely through implementing hands-on activities. This point is well-established in the science education literature:

- "There is a danger in equating inquiry-based instruction with the currently accepted notion of hands-on science in which teachers provide students with a series of hands-on activities that often are unconnected to substantive science content" (Crawford 2000, p. 918).

FIGURE 1

The teacher's crucial role in teaching science through inquiry (Clough 2002).

- Determine whether the experience is to primarily be an exploratory or application activity.
- Structure and scaffold activities so that students must access and employ previously studied science ideas. That is, ensure that activities reflect a spiraling curriculum.
- Require students to make explicit their prior knowledge.
- Where appropriate, include students in setting the lab question to be investigated.
- Where appropriate, have students invent laboratory procedures (consider safety, equipment, and cognitive issues).
- Ask questions that spark ideas and reduce student frustration.
- When students cannot invent laboratory procedures, structure the experience so students must be mentally engaged in the lab.
- Initially use materials and equipment that are no more complex than necessary and scaffold to more complex materials when needed.
- Require students to consider and defend what data is relevant and irrelevant.
- Have students decide what their data means.
- Require students to apply mathematical reasoning to problems.
- Make students responsible for communicating their lab work in a clear manner.
- Have students make decisions and assess progress.
- Refrain from summative evaluations of students' ideas and interpretations.
- Encourage students to collaborate with one another in their decision making.

- "There are important differences between tasks and projects that encourage hands-on doing and those that encourage doing with understanding" (Bransford, Brown, and Cocking 2000, p. 24).
- "It's not just a matter of having hands-on experience in science, it's important to have minds-on experience as well. The learner has to think things through and reconstruct their interpretation of things" (Driver 1997).

The distinction between teaching science merely through hands-on activities and teaching science through inquiry is the degree to which students must mentally engage. Whereas cookbook activities make most decisions for students, teaching science through inquiry demands that students make decisions, ask questions, consider alternatives, and think critically. Teaching science through inquiry is not just having students manipulate materials but rather an effort to promote mental effort and meaning-making.

Directive activities can be restructured to teach science through inquiry (Clark, Clough, and Berg 2000; Clough 2002). The cognitive demands of an inquiry activity as well as safety issues affect how much structure is necessary. When such issues require specific directions, the key is to ensure that students are engaged in thinking about the conceptual and/or safety issue so that students come to deeply understand the rationale for the direction they are following. Because teachers want to assist students with their cognitive struggles, teachers often do too much thinking for the students. To avoid doing this, ask yourself the following two questions while planning activities and interacting with students:

- What decisions can and should students make?
- How can I assist students by asking carefully crafted questions that make them think and make connections rather than doing the thinking for them?

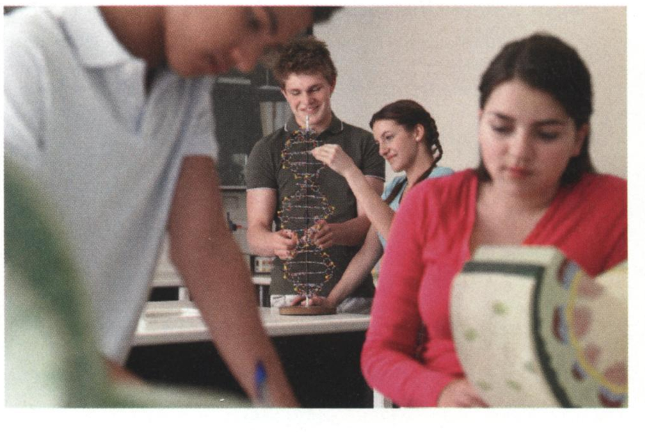
Myth #3: Teaching science through inquiry is chaotic

Some teachers are concerned that teaching science through inquiry is chaotic and leads to classroom management issues (Llewellyn 2002). Effectively teaching science through inquiry does demand more attention to students' work and thinking, as well as extensive interactions with students described earlier. Thus, the environment is structured in the sense that students understand what they are trying to achieve, the teacher sets clear expectations for on-task behavior, and the teacher extensively monitors students and provides scaffolding assistance where needed. However, the investigative processes students employ, the meaning they make from data, and other science practices are far less structured. When teachers effectively create this environment, students are mentally and physically engaged and thus classroom management issues are often less prevalent than in more typical science classrooms.

Myth #4: Teaching science through inquiry is not an efficient use of time

Teaching science through inquiry does take more time than traditional science teaching. However, evidence supports that students taught science through inquiry have greater understanding and retention of content (Chang and Mao 1999; Hake 1998; Minner, Levy, and Century 2010; Schroeder et al. 2007; Wise and Okey 1983; Anderson 2002). This is because highly directive instruction (e.g., textbook reading, lecture, prescriptive labs) does not as effectively promote the critical thinking, self-regulation, reflective thought, or elaboration (Schraw, Crippen, and Hartley 2006) needed for developing deep understanding.

Science teachers want their students to deeply understand and meaningfully apply science content. This goal is thwarted when attention is directed at covering content rather than teaching for conceptual understanding. Thus, we waste both our time and students' time merely covering content. However, when students have extensive experiences with phenomena, actively wrestle with ideas being investigated, provide evidence for why ideas work or do not work, and apply what they know in multiple ways, they more deeply



understand and retain both science content and practices. They also have more positive attitudes toward science (Chang and Mao 1999; Sungur and Tekkaya 2006). When considering the time required for teaching science through inquiry, teachers should consider the following:

"Efficiency is a measure of accomplishment per time. Yet, if accomplishment is defined as deep, applicable, and transferable conceptual understanding of science content, teaching science through inquiry *is* more efficient than traditional science teaching practices" (Clough and Kruse 2010, p. 3).

The additional time required to teach science through inquiry is worth the investment.

Myth #5: Teaching science through inquiry is only for some students

Teaching science through inquiry is for all students. However, it must be done in developmentally appropriate contexts. When the content is beyond students' zone of proximal development, they cannot be assisted in deeply understanding the content and processes addressed. This well-substantiated idea applies to all students. Students who struggle in science are in even greater need of the concrete experiences, extensive mental engagement, and teacher interaction that effectively teaching science through inquiry entails. These experiences help all students, including those with learning and language barriers, better understand abstract concepts (Bransford, Brown, and Cocking 2000). When teachers situate the teaching of science through inquiry in developmentally appropriate contexts, struggling students can engage in scientific practices and are often far more motivated to do so.

Teaching science through inquiry is also for advanced students. Advanced Placement courses have long been criticized for promoting superficial memorization of science content. A 2002 report by the National Research Council argued that advanced placement courses should place less emphasis on comprehensive coverage and memorization of factual detail and more on understanding of fundamental concepts, the process of science, and interdisciplinary connections through more student-centered activities such as problem solving, inquiry-based laboratories, and active learning in the classroom (Wood 2009).

These changes are reflected in the College Board's *Inquiry Instruction in the AP Science Classroom* (College Board 2013a) and *AP Biology Course and Exam Description* (College Board 2013b, p. 121). The latter states:

"Teachers are expected to devote 25 percent of instructional time to lab investigations and conduct at least two investigations per big idea. In conducting lab investigations, students will be encouraged to engage in the following:

- Generate questions for investigation
- Choose which variables to investigate
- Design and conduct experiments
- Design their own experimental procedures
- Collect, analyze, interpret, and display data
- Determine how to present their conclusions."

Clearly, teaching science through inquiry is for all students.

Myth #6: Teaching science through inquiry can't be used to teach advanced science concepts

This myth questions whether teaching science through inquiry may be accomplished with a wide range of content (Llewellyn 2002). Figure 2 cites examples of articles describing difficult science concepts taught through inquiry. Each article illustrates that the key to effectively teaching any science idea through inquiry, including advanced science concepts, is the teachers' role in carefully scaffolding students' thinking.

Myth #7: Teaching science through inquiry does not promote college and career readiness

A commonly expressed view is that because students must be prepared for college and careers, time doesn't allow for

FIGURE 2

Difficult science concepts taught through inquiry (with article citations).

- Chemical bonding and polarity (Kruse 2005)
- Temperature and thermal energy (McLaughlin and Bajpai 2009)
- Determining mass percent of water in a crystal (Clark, Clough, and Berg 2000)
- Mendelian genetics (Robinson 2006)
- Circular motion (McLaughlin 2006)
- Electron mass (Hingstrum, Pleasants, and McLaughlin 2011)

teaching science through inquiry. However, college and career readiness are central to the purpose of the *NGSS* and the science practices students are expected to engage in. Appendix C of the *NGSS* states:

"The last decade has seen an emerging consensus that effective preparation for student success in postsecondary education and careers includes a strong background in science. In particular, the best science education seems to be one based on integrating rigorous content with the practices that scientists and engineers routinely use in their work... Traditional instruction has emphasized lectures, note-taking, reading, and assessment that tested recall, offering little opportunity for in-depth study or research (NRC 2007)... Laboratory activities, when offered, generally consisted of cookbook or confirmatory experiences. ... thereby making it difficult for students to connect learning about science content with learning the processes of science (NRC 2005)" (NGSS Lead States 2013, vol. 2, p. 1–2).

Moreover, university science faculty generally regard understanding scientific practices as an important prerequisite for success in college science courses (ACT 2013) and often lament that students enter college unprepared for the mental demands and practices that scientific inquiry entails. Furthermore, the laboratory component of post-secondary introductory science courses is increasingly being taught through inquiry (Weaver, Russell, and Wink 2008; Lopatto 2004). Both college and career readiness demand that teaching promote deep understanding of fundamental science ideas and engagement in science practices.

Conclusion

Like all deeply held misconceptions, many of the myths above are linked and may coalesce to form a fortress that interferes with understanding and implementing science teaching through inquiry. So how may science teachers accurately assess whether their teaching shares characteristics associated with teaching science through inquiry? Below are some self-reflection questions we have found useful:

- What decisions can students make?
- To what extent is the teacher doing the thinking for students that with appropriately scaffolded questions the students could do themselves?
- In what ways are students encouraged to explore their thinking?
- To what extent are the inquiry experiences eliciting and confronting student misconceptions?
- To what extent are students making more meaningful cognitive decisions now than they were at the beginning of the year/unit?
- To what extent must the students draw from previously addressed science content and practices?
- To what extent does the teacher's interactions with students promote critical thinking, creativity, self-reflection, decision making, problem solving, and deep conceptual understanding?
- How well are experiences moving from concrete to abstract?
- How much do students really have to think (as opposed to merely following directions or protocols)?
- To what extent is the teacher answering questions rather than responding with questions to help students arrive at the answer to their questions?

Answering these questions requires teachers to deeply reflect on pedagogical teaching decisions. Learning to accurately assess our decision making and interaction with students improves teaching practice.

To ensure accurate self-assessment, audio and video recording one's teaching, and then carefully listening and noting what is said and done are indispensable for gaining a more accurate response to the questions above. Collaborating with a colleague by observing each other teach is another important way to accurately access and progressively move our teaching practices forward.

However, efforts to improve practice first require addressing the myths about teaching science through inquiry. Just as students hold misconceptions that hinder their learning and development, the myths above can hinder teachers' learning and their development and enactment of inquiry-based instruction (Clough and Kruse 2010). As with all conceptual change, the first step is making overt prior knowledge, acknowledging that it may be mistaken, and then working to establish a more accurate understanding. As Mark Twain supposedly said: "It ain't what you don't know that gets you into trouble. It's what you know for sure that just ain't so." ■

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