

A Science Education that Promotes the Characteristics of Science and Scientists: Features of Science Teacher Preparation

MICHAEL P. CLOUGH

Center for Excellence in Science, Mathematics & Engineering Education
Iowa State University, Ames, IA 50011 USA
E-mail: mclough@iastate.edu

Editor note: This is the fourth in a series of four articles regarding the nature of science, and how it relates to STEM education.

Effective science teaching is highly complex and counter-intuitive

The three prior articles in this series have addressed teaching students in a manner that instills in them habits of thinking and action that reflect the characteristics of science and scientists. Achieving this is an essential part of STEM education efforts and demands overt attention to goals like those appearing in Table 1. As has been made clear in the previous two articles in this series (Clough 2015 a & b), much is known about teaching that effectively promotes these goals. For instance, Minner, Levy and Century (2010) synthesized relevant research reported between 1984 and 2002 to determine what impact, if any, inquiry science instruction has on K-12 learning. They concluded that:

Various findings across 138 analyzed studies indicate a clear, positive trend favoring inquiry-based instructional practices, particularly instruction that emphasizes student active thinking and drawing conclusions from data. Teaching strategies that actively engage students in the learning process through scientific investigations are more likely to increase conceptual understanding than are strategies that rely on more passive techniques...

This and other research coalesce to describe a consistent picture of science teaching practices that advance the goals listed in Table 1 (Clough et al., 2009).

Table 1. Goals for science education

- Demonstrate deep robust understanding of fundamental science concepts.
 - Exhibit an accurate understanding of the nature of science.
 - Exhibit an accurate understanding of the nature of technology and engineering.
 - Identify and solve problems effectively.
 - Be creative and curious.
 - Use critical thinking skills.
 - Use communication and cooperative skills effectively.
 - Actively participate in working towards solutions to local, national, and global problems.
 - Set goals, make decisions, and accurately self-evaluate.
 - Access, retrieve, and use existing scientific knowledge in the process of investigating phenomena.
 - Convey self-confidence and a positive self-image.
 - Demonstrate an awareness of the importance of science in STEM and STEM-related careers.
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That said, those science teaching practices that would accurately promote deep conceptual science content understanding and characteristics common to science and scientists are too infrequent in science education (Weiss, 1993; Weiss, Pasley, Smith, Banilower & Heck, 2003; Banilower, Smith, Weiss, Malzahn, Campbell & Weiss, 2013). Science teaching that engenders high mental engagement aligned with the goals appearing in Table 1 (as inquiry teaching does) is far more complex and demanding than traditional science teaching practices commonly found in schools. The dynamic and at times unpredictable nature of classrooms exacerbates this complexity.

Making matters worse, as Lakin and Wellington (1994) noted almost two decades ago, efforts to accurately convey what science is, how it works, and the characteristics of scientists appear to be contrary to “expectations held of science and science teaching in schools, not only by teachers and pupils but also those perceived as being held by parents and society” (p. 186). Intuitive notions of how we learn and how science should be taught are developed and reinforced during the many years spent as students in science classrooms and then, in the case of experienced teachers, further engrained through years honing time-honored science teaching practices.

Not surprisingly, as research regarding conceptual change makes clear, changing strongly held ideas is difficult and defies merely providing new information. Driver (1997), writing about learning more generally, stated:

Some of the more complicated learning we have to do in life, and a lot of science is like this, involves not adding new information to what we already know, but changing the way we think about the information we already have. It means developing new ways of seeing things.

Modifying or giving up on strongly-held ideas that are situated in extensive experience is cognitively challenging, but also often results in strong emotional responses.

We know that changing the way you think about things can often be not just difficult, but emotionally taxing because it means giving something up. It means letting go of some knowledge that you have used in the past. It means letting go of something while you are still unsure about what it is you are grasping after in terms of a new way of seeing things (Driver, 1997).

Understandably, all professionals, including science teachers, struggle with changing their long-held beliefs and practices. Presenting science via lecture, textbook readings, worksheets, mathematical algorithms, and cookbook activities has been, and largely still is, the standard in science education. Moving toward teaching science through and as inquiry is difficult, sometimes frightening, and often frustrating. Clough and Kruse (2010) write that “Even when [teachers] genuinely want to change [their] pedagogical practices, because [their] past experiences are so often dissonant with inquiry-based teaching, [they] struggle to actually implement such practices – tripping over questions, giving in to student resistance, or genuinely not knowing how to scaffold students from their mistaken or initial ideas to accepted science thinking.” Again, in the words of Driver (1997):

Teaching is a very complicated job. Teachers need to carry a lot of information in their minds at once — there are many planes at which they are thinking. Overall general lesson strategies, what they want to happen at particular times. The minute-to-minute eye that they’re keeping on different children in terms of their behavior and whether they are on task. Now if you ask teachers to change their strategies from tried and tested strategies they’ve developed over the years, it de-skills them to begin with. All this complicated behavior that they’ve developed a way of managing, they start having to rethinking it again. It’s like riding a bicycle—if you start thinking about what you’re doing, that’s when you fall off.

Helping preservice and experienced teachers promote the goals appearing in Table 1 demands giving up simplistic notions of teacher preparation and professional development. Much time and effort is required to support teachers as they work to (a) replace simplistic notions of how people learn (e.g., learning styles – see Olson, 2006 and Pashler, McDaniel & Bjork, 2008) in favor of more fruitful conceptions (Bransford, Brown & Cocking, 2000; National Research Council, 2005); (b) reassess their views of time-honored approaches to teaching science; (c) understand and value inquiry science teaching; (d) comprehend and put into practice the pedagogical decision-making and teacher behaviors crucial for highly engaging and successful science teaching; and (e) cope with the setbacks and frustrations

that will occur as they transition from time-honored teaching practices to those that will promote the characteristics of science and scientists.

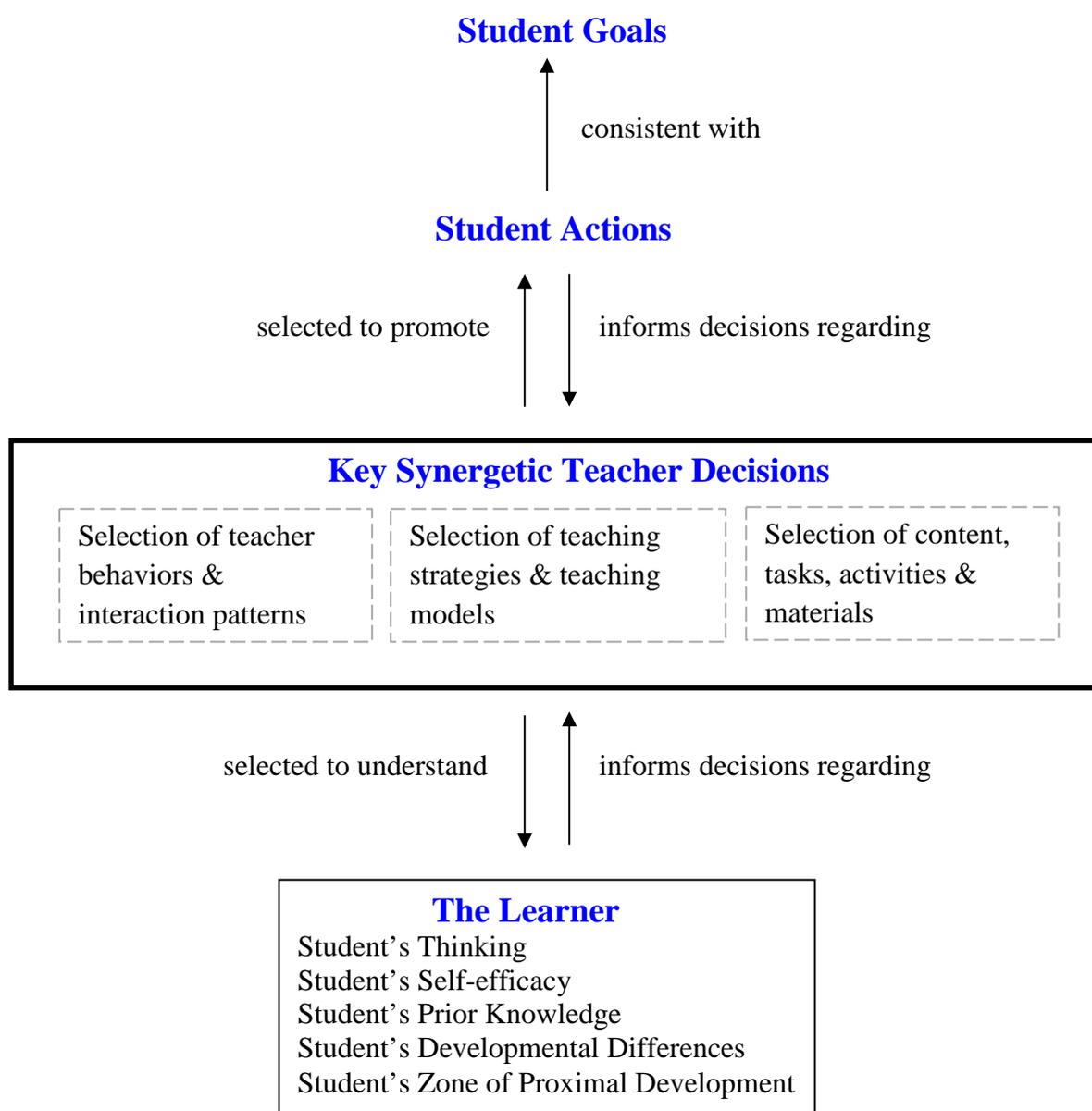
Effective science teaching is highly complex and counter-intuitive

Preparing teachers to make well-informed pedagogical decisions first demands that they know what those decisions are and on what basis they are to be made. Figure 1 presents a decision-making framework to help teachers make sense of education research, come to understand crucial teacher decisions, and how those decisions interact to affect student learning. This framework summarizes crucial teacher decisions regarding the selection of science content, tasks, activities, materials, models, strategies, and teacher behaviors and how they should be carefully and consciously made in light of desired goals for students and how students learn. Clough et al. (2009) explain how the decision-making framework may be used in preservice and professional development programs to:

- Illustrate how pedagogical research best informs practice as a coherent package;
- Resolve perceived contradictions and dilemmas in education research;
- Effectively plan science lessons;
- Make explicit the crucial role of the teacher and teacher behaviors in effectively teaching science;
- Promote more thorough and accurate teacher self-reflection and supervision;
- Help science teachers adequately explain to policymakers, administrators, colleagues, parents and students their professional expertise and research-based decision-making;
- Assist in avoiding fads and policies that are put forward as solutions to effective teaching; and
- Structure professional development, science teacher education programs and science methods courses.

The framework promotes research-based decision-making rather than narrow and inflexible prescriptive approaches and policies. Efforts to assist teachers to deeply understand research-based decision-making appearing in Figure 1 reflects teacher education as opposed to teacher training. Teacher education embraces educators as professionals who have an obligation to understand and use well-established education research in making decisions like those appearing in Figure 1. This perspective acknowledges that much of what goes on in school science is problematic, but that effective teaching is far too complex to establish rigid prescriptions and policies regarding how to teach. Teachers' decision-making ought to be guided by well-established research, but teaching and learning, like conducting science research, defies rigid prescriptive techniques.

Figure 1. Framework Illustrating Teacher Decisions and their Interactions (Clough *et al.*, 2009)



Features of effective science teacher education programs

Understanding all that appears in Figure 1, developing the necessary decision-making capabilities, and becoming proficient with research-based teaching behaviors takes much time. Preparing science teachers to effectively implement teaching practices promoting goals like those in Table 1 that will result in habits of mind and action consistent with the characteristics of science and scientists requires highly coordinated and demanding preservice programs and professional development efforts. Single methods courses, like short-term professional development experiences, cannot effectively challenge time-honored views of teaching and how people learn, and move individuals to an accurate understanding and sophisticated implementation of key teacher decisions that promote desired student goals.

The Salish Project (1997) and IMPPACT Project (Tillotson & Young, 2013) are perhaps the most extensive efforts to investigate the impact of science teacher education efforts on teacher beliefs and practices. Salient findings from these studies include the following:

- The duration of preservice programs, the number of science methods courses, and completing the program as a cohort group all impacted graduates' pedagogical beliefs and practices (IMPPACT);
- Graduates of programs consisting of three science methods courses taken over a two-year period were more likely to hold reform-based beliefs about science teaching than were graduates of programs of shorter duration and fewer science methods courses (IMPPACT);
- Graduates of programs having a cohort model reported that feature positively impacted their beliefs and classroom practices and wanted even more emphasis on that aspect of their program (IMPPACT);
- Graduates of programs having a cohort model for two full years were far more likely to continue collaborations with that peer group while in and after having graduated from their program (IMPPACT);
- Graduates of programs where field-based cooperating teachers' practices were consistent with the university-based teacher education program research-based approach to teaching science were more likely to implement reform-based science instruction (IMPPACT);
- Graduates expressing student-centered beliefs completed programs that included at least nine semester hours of subject-specific methods courses (SALISH);
- Student-centered beliefs of graduates were associated with programs that had subject-specific methods courses, were completed as a cohort group, utilized cooperative learning, fostered strong and close relationships between faculty and students (SALISH); and
- Student-centered beliefs were associated with more extensive field-based experiences (SALISH).

Reflecting this research and the structure of other successful teacher education programs (e.g., Krajcik & Penick, 1989; Penick & Yager, 1989), colleagues and I restructured the science education component of the secondary science teacher education program at our university. The required science education course work includes multiple science methods courses, a nature of science and science education course, and extensive field-based experiences (see Table 2). Science education faculty model research-based decision-making and teaching behaviors and draw teachers' attention to their teaching. Students are expected to closely observe how the science education courses are taught and the teaching behaviors of faculty. Prospective teachers are placed with cooperating teachers, many who graduated from the program, who themselves overtly draw students attention to their research-based decision-making and teacher behaviors. These required courses and field-based experiences push students to understand all that the decision-making framework in Figure 1 entails and change their habits of mind and action so they promote the goals appearing in Table 1. Research following graduates of our program during their first five years of teaching provides ample evidence of its success (Bergman, 2007; Herman, 2010; Herman, Clough & Olson, 2011; Ihrig, 2014). Since 2007, ten former preservice teachers have received the National Science Teachers Association (NSTA) Maitland P. Simmons Memorial Award for New Teachers, six have been recognized for exemplary science teaching, and more than fifty have published articles and presented papers at conferences on their success at teaching science in a manner that accurately promotes the goals in Table 1.

Table 2. Science teacher education program structure, sequence, credits and contact hours

Undergraduate Science Teacher Education Program

Sophomore Year	Junior Year		Senior Year
Spring Semester	Fall Semester	Spring Semester	Fall or Spring Semester
<ul style="list-style-type: none"> Introduction to the complexities of learning and teaching science (2 cr) 20 contact hours 20+ observation hours 	<ul style="list-style-type: none"> Science Methods 1 (3 cr, 50 contact hours) School Internship (2 cr, 60+ hours) Nature of Science and Science Education (3 cr, 45 contact hours) 	<ul style="list-style-type: none"> Science. Methods II (3 cr, 50 contact hours) School Internship (2 cr, 60+ hours) 	<ul style="list-style-type: none"> Student Teaching (14 cr, 14 weeks)

Graduate Science Teacher Education Program (Master of Arts in Teaching)

Summer 1 Semester	Fall Semester	Spring Semester	Summer 2 Semester
<ul style="list-style-type: none"> Introduction to the complexities of learning and teaching science (2 cr) 20 contact hours 20+ observation hours 	<ul style="list-style-type: none"> Science Methods 1 (3 cr, 50 contact hours) School Internship (2 cr, 60+ hours) Nature of Science and Science Education (3 cr, 45 contact hours) 	<ul style="list-style-type: none"> Science. Methods II (3 cr, 50 contact hours) School Internship (2 cr, 60+ hours) Student Teaching (14 cr, 14 weeks) 	<ul style="list-style-type: none"> Advanced Science Pedagogy (3 cr, 45 contact hours)

Most students also complete an elective three credit “Restructuring Science Activities” course the summer after completing Science Methods II.

The above is the science education specific course work preservice teachers must complete. Other education courses (e.g. Education Psychology, Multicultural Education, etc.) must also be completed.

Teacher education efforts, when they are structured and taught well, are crucial in preparing teachers to promote desired student goals congruent with the characteristics of science and scientists. If policymakers are serious about promoting STEM education, then much must be done to ensure preservice and inservice teachers receive extensive professional development aligned with desired goals for students.

Policies are at cross-purposes with preparing and nurturing highly effective teachers

However, secondary science teacher education programs like that described in Table 2 are uncommon (Olson, Tippett, Milford, Ohana & Clough, 2015). Most teacher education programs have only one science methods courses and some only a general methods course. And while understanding the characteristics of science and scientists are in every science education reform document, Backhus & Thompson (2006) report that "...the majority of institutions (more than two-thirds) do not have a nature of science course of any variety and... at most perhaps 6% of preservice 9-12 science teachers will have taken such a course as a requirement." In many countries, policymakers have established alternative routes for teacher licensure that require little meaningful preparation for the complexities of effective science teaching. In the U.S., many states have reduced the science content requirements for teachers to levels that make effective science teaching problematic and place students at risk. For example, in my state an "All Science" endorsement consisting of 24 credits in one science area and 9 credits in each of three other areas permits teaching any secondary school science subject. Thus, a person teaching chemistry may have as little as 9 credits of chemistry course work which is merely one year of introductory chemistry. The same issue exists for STEM teaching endorsements where the content requirements in each of the STEM areas are too often woefully low.

Moreover, the current high-stakes standardized-assessment environment is largely at odds with promoting highly engaging teaching strategies and behaviors (Minner et al., 2010) and the goals list in Table 1. Administrators and teachers feel pressure to teach to tests requiring little that is congruent with the goals appearing in Table 1. Looking for simplistic solutions to complex problems, naive "What Works" approaches (Marzano, Gaddy, & Dean, 2000) are too often thoughtlessly mandated, robbing teachers of making more appropriate research-based decisions. More troubling still, those who attempt to implement teaching practices that promote the characteristics of science and scientists often receive little support for doing so, and may face fierce attacks for deviating from time-honored science teaching practices that are ubiquitous in schools (Ihrig, 2014).

More troubling still, those who attempt to implement teaching practices that promote the characteristics of science and scientists often receive little support for doing so, and may face fierce attacks for deviating from time-honored science teaching practices (e.g., lecture, cookbook labs, worksheets, multiple-choice assessments) that are ubiquitous in schools.

Thus, promoting the characteristics of science and scientists in school science faces an uncertain future. Lederman (2006) writes:

Although the words of various reforms are different, the message remains quite familiar. Just as familiar is the lack of progress toward the all too familiar goals of reform efforts. ...There is not, and there has not been, a concerted professional development effort to clearly communicate, first, what is meant by "[nature of science]" and scientific inquiry and second, how a functional understanding of these valued aspects of science can be communicated to K-12 students. (pp. 301 & 302)

The same can be said for effective science teaching in general. Sadly, what results is a serious, and in some sense cruel, mismatch between what policymakers and science educators *claim* they desire from school science education and their actions that undermine effective science teacher education and professional development.

So while the problems with science education have been well documented for decades, and the virtues of teaching science through and as inquiry well established, secondary science teacher education programs and policies regarding the preparation of secondary science teachers largely ignore what is required to prepare science teachers who will effectively teach science, and accurately promote the characteristics of science and scientists.



Michael P. Clough is a professor of science education at Iowa State University where he teaches The Nature of Science and Science Education, Secondary Science Methods I, Secondary Science Methods II, and Restructuring Science Activities. He is the recipient of several awards for his teaching (at both the university and secondary school level), scholarship and service. His scholarship is directed at the nature of science and its implications for science learning, teaching, and teacher education; and the synthesis, criticism, and clarification of extant knowledge and research in science education. He currently serves as past-president of the International History, Philosophy and Science Teaching (IHPST) organization.

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