2011

Scientific inquiry in the genetics laboratory: Biologists and university science teacher educators collaborating to increase engagements in science processes.

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Scientific Inquiry in the Genetics Laboratory: Biologists and University Science Teacher Educators Collaborating to Increase Engagement in Science Processes

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The importance of engaging students in undergraduate science courses in scientific inquiry is well understood. K–12 standards documents and undergraduate science education literature both support the central role of engagement in science processes in the course of science education. However, most scientists and educators have experienced science education without engagement in science processes as a focus. Thus, the importance of this engagement as an instructional strategy and goal is minimized at best. This article details how collaboration among the authors—science teacher educators and scientists—was forged and the benefits that have emerged. These benefits include documentation of "reformed teaching" and significant gains in pre- and poststudent reports of experiences engaging in scientific inquiry. The structure of the synergistic collaborations shared in this article offers one possible mechanism for organizing collaborations among science teacher educators and scientists as well as future collaborations among these two groups and other disciplinary experts.

The following excerpt was taken from a grant proposal by one of the biologist authors of this paper (the third author), in which he makes reference to scientific teaching—teaching that "involves active learning strategies to engage students in the process of science, and teaching methods that have been systematically tested and shown to reach diverse students" (Handelsman et al., 2004, p. 521)—as one area he prioritizes and seeks to improve in his instruction:

> Teaching and research are parts of an integrated educational mission. My research requires appropriate teaching and mentoring; my formal teaching duties incorporate aspects of scientific research in ways that align with scientific teaching (Handelsman, Miller, & Pfund, 2007). Through this approach, I strive to foster higher-order thinking, creativity, and rigor couched in experimentation (Handelsman et al., 2004). My goal is to help students learn science as a process.

This excerpt presents a rationale for teaching and learning in an undergraduate science course that aligns with science education standards documents framing K–12 science teaching, namely "teaching should be consistent with the nature of scientific inquiry" (American Association for the Advancement of Science [AAAS], 1989, p. 147). From extensive contact with undergraduates over the years, this same author realized that although many biology undergraduate students have a good grasp of scientific information, few have a good grasp of the way science is actually done because of their lack of experiences engaging in scientific inquiry. This experience mirrors what others have reported regarding students' lack of experience engaging in scientific inquiry (Campbell & Bohn, 2008); National Research Council [NRC], 2005; O'Sullivan & Weiss, 1999; Windschitl, 2003).

Just as there are extensive calls for increased attention to the quality of science education experiences at the K–12 level (NRC, 1996; NRC, 2007), these same concerns can be found at the undergraduate level (Dehaan, 2005; Handelsman et al., 2007). One central concern for science educators at the K–12 level is moving beyond science education focused solely on content and instead heeding recent calls (NRC, 2007; NRC, 2008) for a focus on four strands of scientific learning that include (1) science conceptual understanding, (2) science process, (3) the nature of science, and (4) communication in science. These same strands of learning can also be found in documents targeting undergraduate-level science education improvements (Handelsman et al., 2007).

The collaboration serving as a context for this article partnered science teacher educators and scientists. This was seen as a fitting partnership because the science teacher educators and scientists work closely with many of the same students (i.e., all students in the genetics course were biology majors, and many were secondary biology teaching majors). The collaboration was initially sought with the scientists because the science teacher educator realized that although gains could be made in facilitating preservice teacher growth as science teachers comfortable and capable of facilitating scientific inquiry, these gains would be more pronounced, informed, and likely to take hold better if the preservice teachers encountered content area coursework in biology in a manner that allowed them to experience science as inquiry as they themselves learned science. Both the science teacher educators and scientists quickly realized the potential benefit that could come if both the conceptual biological expertise of the scientists and the pedagogical expertise of the science teacher educators were leveraged to consider improvements in the genetics laboratory course taught by the scientists.

Context and approach to improving a course

This collaboration was focused on improving an undergraduate Genetics Laboratory course during fall 2009. The course is offered every other year and serves as a capstone course for all undergraduate biology majors, including those in a composite teaching–biology program. Two sections of the laboratory course were offered during fall 2009 and the biologist (third author) and a teaching assistant/biologist (second author) cotaught both sections. The laboratory course met weekly for one three-hour session.

The collaborators first completed a half-day Reformed Teaching Observation Protocol (RTOP; Piburn et al., 2000) training session prior to the semester. The RTOP is an observational instrument designed to measure reformed teaching (Piburn et al., 2000), in which reformed teaching is defined for the purposes of this manuscript as teaching that is framed by constructivism. Constructivism focuses on instructional strategies through which teachers engage learners actively in creating, interpreting, and reorganizing or synthesizing knowledge (Gordon, 2008). In reformed teaching, student learning is seen as an active process of students working to develop meanings that align with their current understandings, environment, and social settings. According to the National Science Education Standards (NRC, 1996, p. 32), teachers should

- focus and support inquiries while interacting with students;
- orchestrate discourse among students about scientific ideas;
- challenge students to accept and share responsibility for their own learning;
- recognize and respond to student diversity; and
- encourage and model the skills of scientific inquiry as well as the curiosity, openness to new ideas and data, and skepticism that characterize science.

The RTOP is adept at measuring reformed teaching because it is an instrument that was developed in alignment with national standards documents (AAAS, 1989; National Council of Teachers of Mathematics [NCTM], 2000; NRC, 1996). During this training session, the collaborators became familiar with the RTOP by rating online training videos found at *http://physicsed.buffalostate.edu/AZTEC/RTOP/RTOP_full/*. This was seen as a productive starting point for the collaboration because it facilitated initial discussions about teaching and learning in science classrooms. For example, we considered in-depth descriptors from the RTOP found in the training manual, such as the following:

> *This lesson encouraged students to seek and value alternative modes of investigation or of problem solving.* Divergent thinking is an important part of . . . scientific reasoning. A lesson that meets this criterion would not insist on only one method of experimentation . . . A teacher who valued alternative modes of thinking would respect and actively solicit a variety of approaches, and understand that there may be more than one answer to a question. (Piburn et al., 2000, p. 35)

The biologist in our group understood the value of divergent modes of thinking, but we found that attempts by the biologists to cultivate scientific reasoning were not as explicit as those strategies proposed by the science teacher educators. They recognized the importance of engaging students in developing scientific processes but had not previously considered the value of making students explicitly cognizant of the processes and of helping them to articulate nuances of scientific processes that they were beginning to understand through their experiences. The science teacher educators then explained that it is not enough to engage students in the process of science. Rather, it is also important to engage them in metacognitive discussion about science (Abd-El-Khalick, Bell, & Lederman, 1998; Ackerson, Abd-El-Khalick, & Lederman, 2000). Collaborations between scientists and science teacher educators are at the heart of what we think is so important about our engagement outlined in this article. As this exemplar highlights, the biologists bring cutting-edge research methodology, years of experience facilitating genetics instruction, and cultural capital founded on their research and publication in biological journals. Likewise, the science teacher educators bring expertise to this collaboration that is founded on connections and contributions to science education literature focused on teaching and learning in science classrooms. Coupling these two areas of expertise enhances the experiences of undergraduates in science courses, but it also enhances the professional growth of the biologists and science teacher educators.

The training session with the RTOP videos allowed the collaborators to establish interrater agreement at or greater than .80 with each other as well as the expert ratings at the website. The RTOP served as a laboratory observation tool for documenting the extent to which observed instruction was aligned with national reform documents, but it was also used as a reflective anchor in pre- and postobservational meetings, providing tangible criteria for focusing discussion and reflection. In the preobservational meetings, the RTOP was used to shape needed changes. As an example, RTOP indicator 12 (students made predictions, estimations, and/or hypothesis and devised means for testing them) provided specific criteria for assessment of the planned session. Thus in the past, when hypotheses might have been devised for the students as well as mechanisms for testing them, these plans were changed as a result of the preobservational meetings to intentionally engage students in developing and testing their own hypothesis.

Fogarty and Pete (2009/2010) outlined anchors that can have a lasting impact for engaging adult learners. These anchors situate learning as “sustained, job embedded, collegial, interactive, integrative, practical, and results-oriented” (Fogarty & Pete, 2009/2010, p. 32). To varying degrees, these anchors capture the collaborative approach described in this article, in which the adult learners were the science educators and scientists. The collaboration was “sustained” in that it started prior to the fall 2009 semester at the half-day RTOP training session and continued until the end of the course. The RTOP served as an observational instrument to assess instruction in the course and as a foundation for discussion and collaboration for four different genetics laboratory observations strategically planned throughout the semester. The science teacher educators were invited to observe these four laboratory sessions. Initially only postobservation meetings were planned, but after the second observation was completed, preobservation coplanning sessions were initiated for the third and fourth observation because the science teacher educators felt they were not contributing prior to the observation and instead that they were “judging” the scientists instead of working with them. This change was initiated because it was believed that even more benefit could emerge, as the preobservation served as a lesson study for the group of collaborators. Lesson study is aptly described by Carlone and Webb (2006) as follows: “[t]he format involves teachers collaboratively planning, teaching, observing, reflecting on, and revising lessons focused on specific learning goals” (pp. 563–564). This shift from only postobservations meetings to pre-/postobservation meetings allowed the science teacher educators involved to engage more in coplanning laboratory sessions and iterative work on multiday lab sessions on the basis of students’ responses to the laboratories as they were enacted.

In addition to being sustained, the collaboration was also collegial, interactive, integrative, and practical as the scientists and science educators “put their heads” together to negotiate improvements for the course. The value of this was captured at the end of the semester, when one of the collaborators (first author) shared the following:

> Going into this collaboration, I believed that I had much to offer, but also saw the other collaborators had equally as much experience and expertise to offer so that each of us could gain from our involvement . . . [in the end] I was very excited about what I think we were able to accomplish as a group. We saw many future teachers engaging in reformed teaching

in this course in a way that would support, in a positive way, teachers teaching how they are taught.

And finally, the collaboration described here was results oriented. This anchor for fostering lasting impact was described by Fogarty and Pete (2009/2010) as the need to focus on measurable outcomes; they declared that "professional learning, at its best, is data driven" (p. 34). Both laboratory observations using the RTOP and pre-/poststudent surveys were completed to investigate the impact of this collaboration and to inform directions for the collaboration into the future in subsequent semesters.

Example of laboratory planning and revision

The Revised Bioinformatics Laboratory (RBL) exemplifies how collaboration and the use of "reformed teaching" enhance student experiences. This RBL was the focus of the third planned observation. In years past, students were given detailed step-by-step instructions, guiding them through the use of online databases (e.g., Genbank) and web tools (e.g., Blast, bl2seq, and NEBcutter) for biological sequence analysis. Students were asked questions about their results at each step to check their comprehension but were not challenged to develop their own investigations, nor to collaborate with each other in solving a scientific problem of their design (see internet resources for databases and web tools at end of article).

As a result of this collaboration, the scientists were particularly interested in realigning this bioinformatics lab exercise with reformed teaching practices to enhance student exposure to the nature and process of science in addition to specific instruction in the mechanics and tools used in bioinformatic sequence analysis. To better accomplish these objectives, the science teacher educators and scientists met prior to the scheduled laboratory session to discuss and plan effective reformed teaching strategies in the context of this particular lesson.

In the RBL, the scientists briefly demonstrated several bioinformatic resources and tools available to students and then presented the class with a sample data set constructed in the context of earlier molecular biology labs. This data set consisted of an unknown plant gene sequence and a set of reference sequences that could be used to place the unknown sequence in an evolutionary context. Students were asked to form small groups to brainstorm and discuss possible questions and hypotheses related to the sample data set. The class was then brought back together to list some of the students' ideas on the board. The scientists highlighted one of these questions and led the students through the use of several web tools to test hypotheses related to the question. Students then returned to the small groups to help each other identify a question of interest to them (not limited to those applicable to the sample data), generate relevant hypotheses, and work out a protocol to address their hypotheses. The scientists visited each group to provide advice and direction to ensure each student could begin his or her analyses. Once each student in a group had identified an individual or partnered project, the students began collecting any additional data needed from online data banks and started to use the bioinformatic tools to address their questions. The scientists provided assistance in using the tools as each student began working on their problem.

Because students were not restricted to using the sample data provided, many students identified a problem relevant to other classes, work experiences, or their independent interests. Among these were projects investigating protein structural differences between species, the evolution of the H1N1 influenza genome in the context of archived sequences for the standard flu and previous pandemic strains, population-level variation in a wild plant species, and the evolution of a body-size gene in canids using data from wolves and various domesticated dog breeds.

Because there seemed to be substantial variation among students with respect to making progress on their projects, an additional class period was devoted to helping students work out problems encountered during the intervening week and to make sure they could communicate their project and results in a formal lab report. The conceptual space was left open for students to pursue something of interest to them, but this was very challenging to many students as they had not been asked to do this in their previous science classes. Additionally, many students faced challenges in seeing their projects to a satisfying conclusion (e.g., negative results or coming to a "dead end" in the project because of an incorrect assumption implicit in their hypotheses). Students were divided into small groups again during the second laboratory session so they could help each other work out the specific challenges they each faced in their individual projects. The second lab follow-up period presented an opportunity to get students on the right track and to instruct them in the way real scientific research often progresses: that regardless of the outcome of an experiment, investigators often learn something about the system they are studying and can then revise hypotheses on the basis of this new information.

This laboratory, which lasted for two sessions, did not come without problems, but even these problems were seen as opportune times for learning as instructors and for making revisions to attain the instructional objectives. An example of this occurred when a decision was made to have students present their results to solicit feedback from peers during the follow-up lab. One student in the class presented her well-conceived project with very clean results. This presentation intimidated other students, to the point at which discussion from other students was shut down. Because of this unintended outcome, the scientist shifted tactics and divided the students up into small groups so they could help each other in a less intimidating atmosphere. During this time, the scientists circulated around to the groups and helped troubleshoot specific challenges individually. This midstream instructional adjustment helped ensure that students received the original feedback intended.

Although the same breadth of description is not offered for the other three laboratory sessions in which focused collaboration occurred, a brief description of the reformed teaching in laboratory sessions is provided in Table 1 to offer additional information about the changes aligned with the reformed teaching occurring in these sessions.

Benefits of collaboration and evidence of improvements

Two particular measures that were used to investigate and document the benefits emerging from this collaboration were (1) RTOP (Piburn et al., 2000) ratings throughout the semester and (2) Principles of Scientific Inquiry–Student (PSI-S) surveys completed by students (Campbell, Abd-Hamid, & Chapman, 2010).

As mentioned earlier, the RTOP served as a reflective anchor for

TABLE 1

Reformed teaching in laboratory sessions.

Laboratory sessions	Focus of session	Examples of Reformed Teaching Observed (from RTOP Indicators)
Week 2	Drosophila experiments: Developing questions and hypothesis for testing as part of semester-long projects and discussing population genetics sampling and conservation genetics	• The teacher's questions triggered divergent modes of thinking. • The teacher acted as a resource person, working to support and enhance student investigations.
Week 6	Molecular genetics: DNA extraction from plants	• The lesson involved fundamental concepts of the subject. • Students were involved in the communication of their ideas to others using a variety of means and media.
Week 10	Revised Bioinformatics Laboratory	• Students were encouraged to generate conjectures, alternative solution strategies, and ways of interpreting evidence. • There was a high proportion of student talk and a significant amount of it occurred between and among students.
Week 13	Forensic genetics-plasmid isolation, restriction digest, agarose gel, forensic analysis	• Student questions and comments often determined the focus and direction of classroom discourse. • This lesson encouraged students to seek and value alternative modes of investigation or of problem solving.

Note: RTOP = Reformed Teaching Observation Protocol.

discussing and planning laboratory sessions as well as an observational measure for detecting the level of reformed teaching enacted in the genetics laboratory. During the semester, the RTOP ratings were completed four times by the science teacher educator (first author; see Table 2) who had earlier established interrater agreement with the other collaborators (second, third, and fourth authors) and an expert. Although only one collaborator completed the RTOP ratings throughout the semester, the credibility of this process was established by (1) establishing of interrater agreement between this researcher, the other collaborators, and an expert and (2) consistent evidence of reformed teaching also found emerging from the PSI-S surveys in ways aligned with previous research (Campbell, Abd-Hamid, & Chapman, 2010).

As can be seen in Table 2, the RTOP ratings for observations 1, 3, and 4 were very high. MacIsaac and Falconer (2002) declared that "[a]ny RTOP score greater than 50 indicates considerable presence of 'reformed teaching' in a lesson" (p. 19). The rating for the second observation was at the "considerable presence of 'reformed teaching'" level, but it is important to note that this observation was the point in the collaboration at which a decision was made to initiate preobservational planning sessions. So, observations occurring after observation 2 represented the stage in the collaboration at which preobservations were instituted so that the science teacher educators felt more like collaborators where formative RTOP reflective collaborations anchored by the tangible criteria found in RTOP indicators were likely responsible for the higher summative RTOP ratings found during observations 3 and 4. These RTOP ratings provide evidence that instruction occurring throughout the semester was aligned with reformed teaching, instruction that has proven effective for increasing student achievement as measured by science conceptual understanding, science process/reasoning, attitudinal, and nature of science learning (Adamson et al., 2003).

In addition to RTOP ratings, students in the genetics lab were asked to complete the PSI-S at two times during the semester, during the first and final laboratory sessions (pre-/poststudent surveys). The PSI-S instrument was created to "investigate the extent to which students are engaged in scientific inquiry" (Campbell et al., 2010, p. 13). It is a self-reporting survey. The presurvey was administered during the first laboratory session of the semester during week 1 as students were asked to consider all of their undergraduate biology classes to date to offer responses to the PSI-S reflecting a summary of these experiences. Subsequently, the PSI-S was administered again during week 16 of the semester, but this time students were asked to consider only their experiences in the genetics laboratory course to offer responses to the PSI-S reflecting a summary of only these experiences. On the basis of these instructions, findings that emerged from the PSI-S pre-/postsurveys were used to compare students' inquiry experiences in this genetics laboratory course with experiences that they had before this course. The PSI-S instrument is divided into the following categories:

- asking questions/framing research questions,
- designing investigations,
- conducting investigations,
- collecting data, and
- drawing conclusions.

TABLE 2

Reformed Teaching Observation Protocol ratings.

Observation week during the semester	Rating
Week 2	94
Week 6	45
Week 10	89
Week 13	90

Descriptive statistics from the pre-/postsurveys as well as the results of *t*-tests comparing average scores for each category of the PSI-S can be found in Table 3. One limitation of the PSI-S data that is openly revealed is the drop in students completing the post-PSI-S compared with those taking the pre-PSI-S. A few students dropped the course, but this drop in post-PSI-S mainly occurred because it was administered during the last class session at a time when several students for various reasons missed the class session (e.g., final-examination scheduling conflicts, unavoidable travel conflicts). This limitation should be considered as the findings from the PSI-S are discussed, but it was still believed that much could be gained from these surveys, as those completing the post-PSI-S were considered representative of the student population in the course.

We found that significant improvement occurred with respect to the extent to which students were able to engage in inquiry when comparing experiences students had during this genetics laboratory course with experiences they had across the rest of their undergraduate biology coursework. This occurred on all facets of inquiry outlined in the NRC's America's Lab Report: Investigations in High School Science (NRC, 2005), the document used to shape the PSI-S instrument. On the basis of the RTOP observations and PSI-S surveys, there is evidence to suggest that this course aligns better with reformed teaching and provides an experience for science students that is more "consistent with the nature of scientific inquiry" (AAAS, 1989, p. 147).

Conclusion

We believe that our collaboration exemplifies the learning communities that Senge (1990) described as "where people continually expand their capacity to create the results they truly desire, where new and expansive patterns of thinking are nurtured, where collective aspiration is set free, and where people are continually learning how to learn together" (p. 3). This was even more evident as the biologist (third author) shared the following:

> I have always struggled with the problem of knowing that there is a better way to teach science than how I have been . . . I am trained as a scientist, not as a teacher . . . The meat of the science is designing experiments to test hypotheses. The satisfaction of progress comes usually from successfully rejecting hypotheses. The discovery is often not in finding out something about nature itself, but the realization that I had overlooked an important assumption . . . But the way science is taught often revolves around being "right": getting the correct answer on an exam or the correct answer in a teaching lab "experiment." Although I have been trying to reconcile this paradox for years, I did not make significant progress until I established collaboration with science educators who understood more about the science of teaching.

In summary, although there are collaborations occurring between science and science education faculty members nationally and internationally to improve undergraduate student learning, these partnerships are not yet the norm and, on the basis of early RTOP and PSI-S data collected in this specific project, suggest that the experiences encountered by undergraduate students represent a new and innovative approach. Through the collaboration described in this article and similarly shaped ones involving scientists and university science teacher educators, we see undergraduate science courses continually improved in ways that will foster science majors' understanding in all four strands of science learning outlined in recent national academies documents (NRC, 2007, 2008). Additionally, we see this as one mechanism for fostering scientists' and science teacher educators' professional growth as teachers. ■

TABLE 3

Pre/post PSI-S descriptive statistics and comparative results.

PSI-S category	Pre (average/SD) (*N* = 32)	Post (average/SD) (*N* = 20)	*t*-statistic
Asking questions/ framing research questions	6.97 (4.02)	12.55 (2.42)	6.25**
Designing investigations	5.59 (2.92)	10.75 (2.83)	6.28**
Conducting investigations	9.94 (3.22)	12.15 (2.80)	2.53*
Collecting data	8.41 (3.75)	12.00 (2.45)	4.19**
Drawing conclusions	9.94 (3.79)	12.90 (2.17)	3.18**
Total	40.84 (13.90)	60.35 (10.54)	5.38**

Note: Twelve students originally surveyed during week 1 were not surveyed in week 16 because they either dropped the course or did not attend the final session of the laboratory of the semester. PSI-S = Principles of Scientific Inquiry–Student.
*Significant at .05 **Significant at .01

Internet resources

Blast—*http://blast.ncbi.nlm.nih.gov/Blast.cgi*
bl2seq—*http://1usa.gov/bCd07h*
Genbank—*http://www.ncbi.nlm.nih.gov/genbank/*
NEBcutter—*http://tools.neb.com/NEBcutter2/index.php*

References

Abd-El-Khalick, F., Bell, R. L., & Lederman, N. G. (1998). The nature of science and instructional practice: Making the unnatural natural. *Science Education*, *82,* 417–436.

Ackerson, V. L., Abd-El-Khalick, F., & Lederman, N. G. (2000). Influence of a reflective explicit activity-based approach on elementary teachers' conceptions of nature of science. *Journal of Research in Science Teaching*, *37,* 295–317.

Adamson, A. E., Banks, D., Burtch, M., Cox III, F., Judson, E., Turley, J. B., . . . Lawson, A. E. (2003).

Reformed undergraduate instruction and its subsequent impact on secondary school teaching practice and student achievement. *Journal of Research in Science Teaching*, *40,* 939–958.
American Association for the Advancement of Science. (1989). *Science for all Americans*. New York, NY: Oxford University Press.
Campbell, T., Abd-Hamid, N., & Chapman, H. (2010). Development of instruments to assess teacher and student perceptions of inquiry experiences in science classrooms. *Journal of Science Teacher Education*, *21,* 13–30.
Campbell, T., & Bohn, C. (2008). Science laboratory experiences of high school students across one state in the U.S.: Descriptive research from the classroom. *Science Educator, 17,* 36–48.
Carlone, H., & Webb, S. (2006). On (not) overcoming our history of hierarchy: Complexities of university/school collaboration. *Science Education*, *90,* 544–568.
Dehaan, R. L. (2005). The impending revolution in undergraduate science education. *Journal of Science Education and Technology*, *14,* 253–269.
Fogarty, R., & Pete, B. (2009/2010). Professional learning 101: A syllabus of seven protocols. *Phi Delta Kappan, 91,* 32–34.
Gordon, M. (2008). Between constructivism and connectedness. *Journal of Teacher Education*, *59,* 322–331.
Handelsman, J., Ebert-May, D., Beichner, R., Bruns, P., Change, A., DeHaan, R., . . . Wood, W. (2004). Scientific teaching. *Science*, *304,* 521–522.
Handelsman, J., Miller, S., & Pfund, C. (2007). *Scientific teaching*. New York, NY: Freeman.
MacIsaac, D., & Falconer, K. (2002). Reforming physics instruction via RTOP. *The Physics Teacher*, *40,* 479–485.
National Council of Teachers of Mathematics. (2000). *Principles and standards for school mathematics.* Reston, VA: Author.
National Research Council. (1996). National science education standards. Washington, DC: National Academies Press.
National Research Council. (2005). *America's lab report: Investigations in high school science*. Washington, DC: National Academies Press.
National Research Council. (2007). *Taking science to school; Learning and teaching science in grades K–8*. Washington DC: National Academies Press.
National Research Council. (2008). *Ready, set, science: Putting research to work in K–8 science classrooms*. Washington, DC: National Academies Press.
O'Sullivan, C. Y., & Weiss, A. R. (1999). *Student work and teacher practices in science* (NCES 1999-455). Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement, National Center for Education Statistics.
Piburn, M., Sawada, D., Turley, J., Falconer, K., Benford, R., Bloom, I., & Judson, E. (2000). *Reformed teaching observation protocol (RTOP): Reference manual* (ACEPT Technical Report No. INOO-3). Tempe, AZ: Arizona Collaborative for Excellence in the Preparation of Teachers.
Senge, P. (1990). *The fifth discipline: The art and practice of the learning organization.* New York, NY: Currency Doubleday.
Windschitl, M. (2003). Inquiry projects in science teacher education: What can investigative experiences reveal about teacher thinking and eventual classroom practice? *Science Education*, *87,* 112–143.

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