

Agriscience Student Engagement in Scientific Inquiry: Representations of Scientific Processes and Nature of Science

Julie R. Grady, Assistant Professor
Arkansas State University

Erin L. Dolan, Associate Professor

George E. Glasson, Associate Professor
Virginia Polytechnic Institute and State University

Students' experiences with science integrated into agriscience courses contribute to their developing epistemologies of science. The purpose of this case study was to gain insight into the implementation of scientific inquiry in an agriscience classroom. Also of interest was how the tenets of the nature of science were reflected in the students' experiments. Participants included an agriscience teacher and her fifteen students who were conducting plant experiments to gain insight into the role of a gene disabled by scientists. Data sources included classroom observations, conversations with students, face-to-face interviews with the teacher, and students' work. Analysis of the data indicated that the teacher viewed scientific inquiry as a mechanical process with little emphasis on the reasoning that typifies scientific inquiry. Students' participation in their experiments also centered on the procedural aspects of inquiry with little attention to scientific reasoning. There was no explicit attention to the nature of science during the experiments, but the practice implied correct, incorrect, and underdeveloped conceptions of the nature of science. Evidence from the study suggests a need for collaboration between agriscience and science teacher educators to design and conduct professional development focused on scientific inquiry and nature of science for preservice and practicing teachers.

Keywords: scientific inquiry, scientific methods, nature of science

Introduction/Theoretical Framework

Educators have long been engaged in conversations about the connections between agriculture and science. The National Research Council (1988) emphasized these connections by recommending that “ongoing efforts should be expanded to upgrade the scientific and technical content of vocational agriculture courses” (p. 35). This interdependence of agriculture and science is further evidenced in Buriak’s (1992) definition of agriscience: “Instruction in agriculture emphasizing the principles, concepts, and laws of science and their mathematical relationships supporting, describing, and explaining agriculture” (p. 4). Interest in the integration of agriculture and science is reflected in contemporary formal agriscience classroom

curricula (e.g., *Agriscience Exploration*, 3rd edition, 2004) as well as extra-curricular agricultural learning programs (e.g., the National FFA Organization annual Agriscience Fair). In addition to understanding and applying science concepts, formal and informal agriscience education emphasizes learning about the processes and nature of science. These ideas are similarly emphasized in national science education policy documents (e.g., American Association for the Advancement of Science, AAAS, 1993; National Research Council, NRC, 1996). As a result, agriculture and science educators have become partners in their commitment to educating scientifically literate citizens who have a basic understanding of the principles of science and how to think scientifically in their everyday lives.

All students, including those in agriculture classes, have preconceived notions about science and how scientists conduct their work (NRC, 2005). Students' epistemologies of science, or assumptions of what science is and how scientific knowledge is generated and modified, can be shaped by their experiences in science and agriculture courses. Classroom and laboratory experiences can contribute unintentionally to student epistemologies that are antithetical to that of genuine science by separating science from authentic contexts; focusing on physical methods of completing a lab lesson; and failing to engage students in reasoning about the design, conduct, and outcomes of laboratory activities (Carey & Smith, 1993; Chinn & Malhotra, 2002; Desautels, & Larochelle, 1998; Driver, Newton, & Osborne, 2000; Jimenez-Aleixandre, Bugallo Rodriguez, & Duschl, 2000; Moss, Abrams, & Kull, 1998; Osborne, 2002; Smith, Maclin, Houghton, & Hennessey, 2000; Watson, Swain, & McRobbie, 2004). Recent agriculture education research has expanded to include investigating the integration of scientific reasoning and skills into agriculture laboratory experiences (Johnson, 1996; Myers & Dyer, 2006; Myers, Washburn, & Dyer, 2004; Osborne, 2000; Parr & Edwards, 2004). Yet, the agriculture classroom has remained largely unexamined as a venue for learning about how the processes and nature of science are represented during inquiry.

Scientific Inquiry and Nature of Science

The *Benchmarks for Scientific Literacy* (AAAS, 1993) emphasizes student engagement in scientific inquiry to help meet the goals of educating scientifically literate citizens who have a basic understanding of the principles of science and how to use scientific thinking in their everyday lives. The National Research Council (1996) further underscored the importance of scientific inquiry (SI) and described it as "the diverse ways in which scientists study the natural world and propose explanations based on evidence derived from their work" (p. 23). The NRC explains SI with the following description:

Inquiry is a multifaceted activity that involves making observations; posing

questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations. (p. 23)

Frequently, SI is incorrectly referred to as the scientific method by teachers and students; however, there is not one, recipe-like method that scientists follow to investigate the natural world (Bauer, 1994).

Distinctly unique, but inextricable from SI, the nature of science (NOS) has been of significant import during the last several decades (Lederman, 2007). Often mistaken as being the same as SI, the NOS refers to "the epistemology and sociology of science, science as a way of knowing, or the values and beliefs inherent to scientific knowledge and its development" (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002, p. 498). The tenets of NOS that are of interest for this study and are generally accepted as relevant to K-12 science education include: (a) Scientific knowledge can be generated through empirical practices. Scientists use their senses and instruments to observe the natural world, and these observations are influenced by instruments, as well as assumptions made about the instruments; (b) Scientific knowledge is theory-laden and subjective because scientists' decisions about their research are influenced by professional and personal prior knowledge, experiences, background, and expectations; and (c) Scientific knowledge is socially and culturally embedded because there are established norms for scientific work. Additional norms result from political, economic, philosophical, social, and religious influences from the society within which science operates (Lederman et al., 2002).

Purpose and Objectives

Here we present the findings of an exploratory case study that examines the practice of SI in an agriscience classroom, including how the process and NOS are

represented, by addressing the following research questions: (1) What is the agriscience teacher's understanding of SI? (2) How do the students participate in SI? (3) How is the NOS represented during the inquiries?

Methods and Procedures

The purpose of this qualitative case study was to investigate in-depth how SI and NOS were shaped in an agriscience classroom, and thus present a comprehensive picture to interested agriculture educators to inform their own teaching and research (Merriam, 1998).

Experiments supported by the Partnership for Research and Education in Plants (PREP) provided a context for the study of agriculture students' engagement in SI. PREP involves students in a study of *Arabidopsis thaliana* plants from which scientists have disabled genes of unknown functions (Dolan, Lally, Brooks, & Tax, 2008; Lally, Brooks, Tax, & Dolan, 2007). With mentorship from their teachers and scientists, students design and conduct original experiments in their classrooms to gain insight into the disabled gene's role in the plant's response to a variety of environmental conditions. In the classroom under study, the plant experiments began with a kick-off session led by a PREP staff member who discussed the benefits of plant research, the role genes play in determining characteristics of plants, and how scientists experimentally determine a gene's function. Plant scientists and online materials about the plant experiments were available to the teacher and students if they had questions or sought additional information.

Sara and her agriscience class were identified for the study through purposeful sampling (Patton, 1990). Sara was completing her first year teaching and had implemented PREP during the previous semester. Sara's formal education included a bachelor's degree in Animal Science and a master's degree in Agriculture Education. Her school was located in a rural community in a Mid-mid-Atlantic state. Fifteen students in grades 8–10 were enrolled in her class, including three Caucasian females, one African American male, and 11 Caucasian males. Some students in the class intended to join the workforce upon high school graduation while others planned to attend college. Several students in the class received

special education services. The PREP experiments closely aligned with the agriscience course curriculum and state competencies, complimenting Sara's unit on plants.

Data sources included classroom observations, in-class conversations with students, face-to-face interviews with Sara, and students' work (Denzin & Lincoln, 1994; Merriam, 1998). Sara was interviewed six times using a semi-structured format. The purpose of the interviews was to learn more about Sara's background, her students, her understanding of scientific inquiry and the nature of science, and the school environment, and to gain insight into classroom goings-on on days the class was not observed.

In her role of participant-observer, the first author observed ten class sessions and recorded field notes on her observations of the general practice of SI, class discussions during the investigations and unrelated lessons, and the actions and interactions of the teacher and students (Gold, 1958; Merriam, 1998). After several class observations, the first author conversed informally with students while they worked on their experiments. During these conversations, she asked students questions such as: "How did you decide on an experimental treatment?" and "How did you decide what features of the plant to observe and measure?" Finally, documents collected for analysis included students' plans for the experiments, their data tables, and the lab reports.

For the data analysis, code categories were pre-established and based on research questions and literature concerning SI and the NOS. Field notes and student work were analyzed to identify implied or explicit references to the following tenets of the NOS: (a) Scientific knowledge can be generated through empirical practices, (b) Scientific knowledge is socially and culturally embedded, and (c) Scientific knowledge is theory-laden and subjective (Lederman et al., 2002). These features of NOS were chosen because they are most compatible with the context of PREP (i.e., cause-and-effect, quantitative experiment format, and potential for agricultural applications) and cognitively appropriate at the high school level. To identify Sara's understandings of SI, interviews, classroom observations/field notes, and student work during their experiments were analyzed. Sara's understanding of SI and the classroom

practice was coded according to the features of SI:

making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is known in light of experimental evidence; using tools to gather, analyze, and interpret data, proposing answers, explanations and predictions; and communicating the results.... identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations. (NRC, 1996, p. 23)

LeCompte (1987) located sources of subjectivity and bias in professional training and personal experiences and urged researchers to reflect on and identify their own individual sources to improve their research. The primary researcher's extensive experiences engaging her own secondary science students in SI, as well as her prior experiences researching SI in high school science and agriculture classrooms, invariably influenced this study. The primary researcher identified other key factors that could have impacted the study: the lenses, influenced by her class, race, age, and gender, through which she interpreted the interviews and activities in the classroom; prior work with PREP; and the researcher's presence in the classroom during the experiments. In light of the bias ever present in educational research, the following strategies were employed to strengthen the trustworthiness of the findings: The first author (a) was in the classroom as often as was possible, and particularly when the students completed their experimental work, (b) collaborated with experienced qualitative researchers and involved them in reviewing the methods and analysis, (c) collected evidence from different data sources, (d) kept good records of process and decisions, and (e) reflected on her own biases or limitations that may have influenced the study (Ary, Jacobs, & Razavieh, 2002; Denzin, 1994; Denzin & Lincoln, 1994; Guba & Lincoln, 1994; Merriam, 1998).

Results and Findings

Question 1: Teacher's Understanding of Scientific Inquiry

The first research question focused on the teacher's understanding of SI because this understanding will likely influence the practice of inquiry in the classroom (Crawford, 2007). In general, Sara demonstrated the view of SI as a mechanical process. For example, Sara explained during the first interview: "The research process...the different variables, and keeping recording data, and then making a chart of something out of it and then having a conclusion; 'This is how a affected b.'" When asked to elaborate about the meaning of inquiry, she added that students are "just, just trying to find an answer to a question." Sara's description of the research process and inquiry encompassed several key mechanical features of inquiry (e.g., recording data, writing a conclusion, making a data chart). She did not, however, mention any of the complex cognitive processes of SI, including posing questions, designing experiments, interpreting data, presenting explanations and predictions, or communicating findings. Her classroom actions were consistent with her focus on the mechanics of SI. Her directions and discussions centered on the routine rather than the reasoning involved in experimentation.

Question 2: Students' Participation in Scientific Inquiry

The second research question focused on the actual practice of SI during the students' experiments in the agriscience classroom. The students' participation in their experiments primarily consisted of treating their plants with various metal solutions, watering the plants, making measurements (e.g., plant height), and recording data. Students did not turn to other sources of information to gather basic information about the plants, what metal solutions to use on the plants, or how the metal solutions could impact plant growth and health. While the students did choose which treatment solution to use and which plant feature to observe from short lists provided by Sara, the planning for the experiments had been done in advance by Sara. Students engaged in a few, very brief teacher-led discussions about their experiments primarily addressing logistics or

methods (e.g., how to water and treat the plants, label equipment, conduct measurements, and fill in the data tables). In addition, even though students worked in teams to conduct their experiments, they typically did not discuss their experiments with their teammates or other students in the class. Because student talking was discouraged, students did not have opportunities to explain or defend their actions or thinking as they conducted their experiments. On the final day of the experiments, Sara quickly summarized the purpose of the experiments and the meaning of the students' observations. Sara dictated a fill-in-the-blank, pre-formatted paragraph for the final project report in which the students inserted information relevant to their own experiments. There were no class discussions about experimental evidence or explanations and conclusions based on the evidence.

Question 3: The Representations of the Nature of Science during the Scientific Inquiry

The final research question sought to understand how the NOS was reflected in the students' plant experiments. There was no evidence from the interviews or observations that explicit attention was drawn to NOS during the experiments (Schwartz, Lederman, & Crawford, 2004). Implicitly, the students' inquiries reinforced a combination of accepted, underdeveloped, and incorrect conceptions of NOS.

Tenet 1: Scientific knowledge can be generated through empirical practices.

Because of the purpose of the PREP experiments, students' work aligned with the assumption that scientists engage in empirical practices that may lead to the generation of scientific knowledge. In addition, students made direct observations of the plant features and these observations were enhanced by the use of simple equipment such as rulers and magnifying glasses. However, the students' experiments also reinforced contradictions to scientists' empirical practices. For example, implied by the students' inquiries was that scientists' observations are nonproblematic with regard to equipment use and that scientists do not make inferences about what they cannot observe. The intentional cause-and-effect, controlled quantitative design of PREP experiments and the linear format of

the students' final reports supported the notion that there is a single, lock-step procedure by which scientists conduct their work.

Tenet 2: Scientific work is socially and culturally embedded.

Students working in teams reflected the normative practice of scientists collaborating with each other rather than working isolated in laboratories. However, student talking was discouraged, thus limiting the discourse associated with SI. Students did not base their experiments on previous efforts of scientists or students or use conventional formats for sharing their findings and conclusions. Students recorded their data in a traditionally structured data table provided by Sara, but they did not analyze their data or represent it in ways that indicate the meaning of their results (e.g., graphs or diagrams). Connections between the practice of science and the political, economical, philosophical, social, and religious influences from the society within which science operates were limited to the visiting PREP scientist's brief discussion of the medical benefits of plant research. Implied in the students' practice of SI was that science and the culture within which scientists work are disconnected.

Tenet 3: Scientific knowledge is theory-laden and subjective.

During the experiments, students' decisions about which treatment to use and which features of the plants to observe were made superficially rather than being based on students' prior experiences, knowledge, training, values, and beliefs. For example, when students were asked how they decided which treatment solution to use on their plants, the students responded: "I picked it from the list" and "We just picked it." Implied in their practice was that scientists' decision-making is based on a choice with no necessary influence from previous experience, knowledge, or training. Students did not address the inherent subjective NOS. Instead, Sara stressed that students needed to be objective: "You are going to observe two things...These can be number of leaves or height of plants. We want to do objective observations, not subjective." There was no follow-up discussion about the fundamental subjectivity of scientists' research and the ways in which students may have introduced bias into their work.

Conclusions

The analysis of the student engagement in the experiments indicates that the students attended to the procedural steps of inquiry and were minimally engaged in scientific tasks that involved reasoning or discourse characteristic of SI. In addition, the inquiries lacked attention to assumptions aligning with current conceptions of NOS. These findings agree with previous research conducted in science classrooms indicating that students may attend to the mechanical and practical aspects of laboratory experiences, focus on the completion of their experiments, or discuss procedures and facts instead of engaging in the complex reasoning and the substantive discourse that define SI (Carey & Smith, 1993; Chinn & Malhotra, 2002; Dolan & Grady, 2009; Driver, Newton, & Osborne, 2000; Hofstein & Lunetta, 2004; Jimenez-Aleixandre et al., 2000; Moss et al., 1998; Osborne, 2002; Watson et al., 2004).

Several factors likely influenced the representation of SI and NOS in this classroom. Sara's prior preservice and inservice teacher education experiences related to SI and NOS fell short of providing her with opportunities to build a thorough understanding of and experience with the nature and processes of science, and the relevant science and pedagogy content knowledge needed to support student learning about NOS and participating in SI. Sara reported that her agriscience class was treated as a "back-up plan" for students who were not planning to go to college and that many of her students had behavior problems, learning disabilities, or attention-deficit/hyperactivity disorder. During the study, Sara was concluding her first year teaching, and she reported that she was still learning about how to manage these students effectively. Struggling with classroom management, an issue cited by other beginning agriculture educators (Myers, Dyer, & Washburn, 2005), likely contributed to Sara's reluctance to relinquish the responsibility and control necessary to make the transition from a traditionally structured, ordered, and controlled classroom to more free-form, small group experiences that depend upon extensive student and student-teacher discussions as does SI. Her beliefs about her students, teaching, and learning, as well as her reconciliation of these beliefs with school culture, may have influenced

the practice of inquiry in her classroom (Crawford, 1999; Llewellyn, 2005; Roehrig & Luft, 2004). In addition, her students were likely unfamiliar and even uncomfortable with the atypical roles students are required to assume in SI (e.g., collaborators, leaders, apprentices, planners). Instead, they held on to the established expectations of the teacher and student roles and discourse structures (Crawford, 2000; Yerrick, 2000).

Chinn and Malhotra (2002) proposed that participating in simple inquiry activities in science classrooms, may actually contribute to students developing a nonscientific epistemology as opposed to an epistemology of authentic SI. Because the practice of inquiry in this agriscience classroom emphasized the mechanical processes of inquiry, the tenets of the NOS, as well as opportunities for reasoning and discourse, were minimized. It is likely that the students' inquiry experience contributed little, if any, to the development of students' informed conceptual understanding of the NOS and scientific processes.

Recommendations

The authors believe that conducting the plant experiments in this agriscience classroom could have nurtured students' epistemologies of science and more closely reflected the authentic practice of scientists had Sara been supported with professional development related to SI and NOS. Because of the current professional interest in engaging agriscience students in classroom experiments and FFA projects, the authors urge agriculture and science teacher educators to design and implement preservice and inservice professional development collaboratively to help teachers prepare for and conduct SI in their classrooms. Specifically, these experiences should engage teachers in their own authentic inquiries, preferably grounded in the context they will use in their classes, that promote learning about the NOS and scientific reasoning strategies, as well as how to promote NOS in the classroom. Such opportunities would support teachers with learning and practicing new roles as guide, motivator, learner, modeler, and co-researcher and new instructional strategies such as modeling, coaching, and scaffolding, as well as providing other instructional support for

implementing inquiry (Crawford, 1999, 2000, 2007; Magnusson, Palincsar, & Templin, 2006; Roehrig & Luft, 2004; Smith et al., 2000).

Teacher education programs in science and agriculture can support teachers by providing materials and guides and ongoing mentoring support and opportunities to interact with other teachers while they implement the inquiries in their classrooms (Akerson & Abd-El-Khalick, 2003; Edelson, 1998). Also, teachers must be supported as they attempt to move the thinking and practice in their classrooms beyond the traditionally accepted classroom practices and discourse for students of lower abilities and motivation or in lower track classrooms (Roehrig & Luft, 2004; Kang & Wallace, 2004; Yerrick, 2000). Finally, to be better prepared to provide effective SI and NOS instruction and support for their preservice and inservice teachers, it may be necessary for teacher educators to participate in SI and NOS professional development.

In light of these case study findings, the authors recommend that science and agriculture educators continue with their commitment to research the integration of science and agriculture. In particular, the authors suggest that research be expanded to examine (a) the practice of SI facilitated by veteran teachers who have participated in SI and NOS professional

development, (b) the practice of SI in additional agriscience classrooms and how this agriculture context and inquiry practice contribute to students' developing views of NOS, (c) the factors that promote and inhibit SI in agriscience classrooms, and (d) how university science and agriculture teacher educators can collaborate to prepare and support preservice and practicing teachers for successful inquiry experiences in their classrooms that promote students' developing understanding of the NOS.

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References

- Akerson, V. L., & Abd-El-Khalick, F. (2003). Teaching elements of nature of science: A year-long case study of a fourth-grade teacher. *Journal of Research in Science Teaching*, 40, 1025-1049. doi: [10.1002/tea.10119](https://doi.org/10.1002/tea.10119)
- American Association for the Advancement of Science. (1993). *Benchmarks of scientific literacy: A Project 2061 report*. New York, NY: Oxford University Press.
- Ary, D., Jacobs, L. C., & Razavieh, A. (2002). *Introduction to research in education* (6th ed.). Belmont, CA: Wadsworth/Thomson Learning.
- Bauer, H. H. (1994). *Scientific literacy and the myth of the scientific method*. Champaign, IL: University of Illinois Press.
- Buriak, P. (1992). Filling the gap in agriculture. *The Agricultural Education Magazine*, 64(9), 4, 23.
- Carey, S., & Smith, D. (1993). On understanding the nature of scientific knowledge. *Educational Psychologist*, 28(3), 235-251.
- Chinn, C. A., & Malhotra, B. A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science Education*, 86, 175-218. doi: [10.1002/sce.10001](https://doi.org/10.1002/sce.10001)

- Crawford, B. A. (1999). Is it realistic to expect a preservice teacher to create an inquiry-based classroom? *Journal of Science Teacher Education*, 10(3), 175–194. doi: [10.1023/A:1009422728845](https://doi.org/10.1023/A:1009422728845)
- Crawford, B. A. (2000). Embracing the essence of inquiry: New roles for science teachers. *Journal of Research in Science Teaching*, 37, 916–937. doi: [10.1002/1098-2736\(200011\)37:9<916::AID-TEA4>3.0.CO;2-2](https://doi.org/10.1002/1098-2736(200011)37:9<916::AID-TEA4>3.0.CO;2-2)
- Crawford, B. A. (2007). Learning to teach science as inquiry in the rough and tumble of practice. *Journal of Research in Science Teaching*, 44(4), 613–642. doi: [10.1002/tea.20157](https://doi.org/10.1002/tea.20157)
- Denzin, N. K. (1994). The art and politics of interpretation. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (pp. 500–515). Thousand Oaks, CA: Sage Publications.
- Denzin, N. K., & Lincoln, Y. S. (Eds.). (1994). *Handbook of qualitative research*. Thousand Oaks, CA: Sage Publications.
- Desautels, J., & Laroche, M. (1998). The epistemology of students: The ‘thingified’ nature of scientific knowledge. In B. J. Fraser and K. G. Tobin (Eds.), *International handbook of science education* (pp. 115–126). London: Kluwer Academic Publishers.
- Dolan, E. L., & Grady, J. R. (2010). Recognizing students' scientific reasoning: A tool for categorizing complexity of reasoning during teaching by inquiry. *Journal of Science Teacher Education*, 21(1), 31–55. doi: [10.1007/s10972-009-9154-7](https://doi.org/10.1007/s10972-009-9154-7)
- Dolan, E. L., Lally, D. J., Brooks, E., & Tax, F. E. (2008). PREPping students for authentic science. *The Science Teacher*, 75(7), 38–43.
- Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education*, 84, 287–312. doi: [10.1002/\(SICI\)1098-237X\(200005\)84:3<287::AID-SCE1>3.0.CO;2-A](https://doi.org/10.1002/(SICI)1098-237X(200005)84:3<287::AID-SCE1>3.0.CO;2-A)
- Edelson, D. C. (1998). Realizing authentic science learning through the adaption of scientific practice. In B. J. Fraser and K. G. Tobin (Eds.), *International handbook of science education* (pp. 317–331). London: Kluwer Academic Publishers.
- Gold, R. L. (1958). Roles in sociological field observations. *Social forces*, 36(3), 217–223.
- Guba, E. G., & Lincoln, Y. S. (1994). Competing paradigms in qualitative research. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (pp. 105–117). Thousand Oaks, CA: Sage Publications.
- Hofstein, A., & Lunetta, V. N. (2004). The laboratory in science education. Foundations for the twenty-first century. *Science Education*, 88(1), 28–54. doi: [10.1002/sce.10106](https://doi.org/10.1002/sce.10106)
- Jimenez-Aleixandre, M. P., Rodriguez, A. B., & Duschl, R. A. (2000). “Doing the lesson” or “Doing science”: Argument in high school genetics. *Science Education*, 84, 757–792. doi: [10.1002/1098-237X\(200011\)84:6<757::AID-SCE5>3.0.CO;2-F](https://doi.org/10.1002/1098-237X(200011)84:6<757::AID-SCE5>3.0.CO;2-F)
- Johnson, D. (1996). Science credit for agriculture: Perceived support, preferred implementation methods and teacher science course work. *Journal of Agricultural Education*, 37(1), 22–30. doi: [10.5032/jae.1996.01022](https://doi.org/10.5032/jae.1996.01022)

- Kang, N., & Wallace, C. S. (2004). Secondary science teachers' use of laboratory activities: Linking epistemological beliefs, goals, and practices. *Science Education*, 89, 140–165. doi: [10.1002/sce.2001](https://doi.org/10.1002/sce.2001)
- Lally, D., Brooks, E., Tax, F. E., & Dolan, E. L. (2007). Sowing the seeds of dialogue: Public engagement through plant science. *Plant Cell*, 19, 2311–2319.
- LeCompte, M. D. (1987). Bias in biography: Bias and subjectivity in ethnographic research. *Anthropology & Education Quarterly*, 18(1), 43–52.
- Lederman, N. G. (2007). Nature of science: Past, present, and future. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 831–880). Mahwah, NJ: Lawrence Erlbaum Associates.
- Lederman, N., Abd-El-Khalick, F., Bell, R., & Schwartz, R. (2002). Views of nature of science questionnaire: Toward valid and meaningful assessment of learners' conceptions of nature of science. *Journal of Research in Science Teaching*, 39(6), 497–521. doi: [10.1002/tea.10034](https://doi.org/10.1002/tea.10034)
- Llewellyn, D. (2005). *Teaching high school science through inquiry: A case study approach*. Thousand Oaks, CA: Corwin Press & NSTA Press.
- Magnusson, S. J., Palincsar, A., & Templin, M. (2006). Community, culture, and conversation in inquiry-based science instruction. In L. B. Flick & N. G. Lederman (Eds.), *Scientific inquiry and nature of science* (pp. 131–155). Dordrecht, Netherlands: Springer.
- Merriam, S. B. (1998). *Qualitative research and case study applications in education*. San Francisco, CA: Jossey-Bass Publications.
- Moss, D. M., Abrams, E. D., & Kull, J. A. (1998). Can we be scientists, too? Secondary students' perceptions of scientific research from a project-based classroom. *Journal of Science Education and Technology*, 7(2), 149–161.
- Myers, B. E., & Dyer, J. E. (2006). Effects of investigative laboratory instruction on content knowledge and science process skill achievement across learning styles. *Journal of Agricultural Education*, 47(4), 52–63. doi: [10.5032/jae.2006.04052](https://doi.org/10.5032/jae.2006.04052)
- Myers, B. E., Dyer, J. E., & Washburn, S. G. (2005). Problems facing beginning agriculture teachers. *Journal of Agricultural Education*, 46(3), 47–55. doi: [10.5032/jae.2005.03047](https://doi.org/10.5032/jae.2005.03047)
- Myers, B. E., Washburn, S. G., & Dyer, J. E. (2004). Assessing agriculture teachers' capacity for teaching science integrated process skills. *Journal of Southern Agricultural Education Research*, 54(1), 74–85.
- National Research Council. (1988). *Understanding agriculture: New directions for education*. [Electronic Version]. Committee on Agricultural Education in Secondary Schools, Board on Agriculture, and the National Research Council. Retrieved from National Academies Press. Retrieved from http://www.nap.edu/catalog.php?record_id=766
- National Research Council. (1996). *National science education standards*. Washington, DC: National Academy Press.

- National Research Council. (2005). *How students learn: Science in the classroom*. Committee on *How People Learn, A targeted report for teachers*, M.S. Donovan and J.D. Bransford (Eds.), Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.
- Osborne, E. W. (2000). Effects of level of openness in agriscience experiments on student achievement and science process skill development. *Journal of Southern Agricultural Education Research*, 50(1), 69–75.
- Osborne, J. (2002). Science without literacy: A ship without a sail? *Cambridge Journal of Education*, 32(2), 203–218. doi: [10.1080/03057640220147559](https://doi.org/10.1080/03057640220147559)
- Parr, B. A., & Edwards, M. C. (2004). Inquiry-based instruction in secondary agricultural education: Problem solving—An old friend revisited. *Journal of Agricultural Education*, 45(4), 106–117. doi: [10.5032/jae.2004.04106](https://doi.org/10.5032/jae.2004.04106)
- Patton, M. Q. (1990). *Qualitative evaluation methods*. Thousand Oaks, CA: Sage Publications.
- Roehrig, G. H., & Luft, J. A. (2004). Constraints experienced by beginning secondary science teachers in implementing scientific inquiry lessons. *International Journal of Science Education*, 26(1), 3–24. doi: [10.1080/0950069032000070261](https://doi.org/10.1080/0950069032000070261)
- Schwartz, R. S., Lederman, N. G., & Crawford, B. A. (2004). Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry. *Science Education*, 88, 610–645. doi: [10.1002/sce.10128](https://doi.org/10.1002/sce.10128)
- Smith, C., Maclin, D., Houghton, C., & Hennessey, M. G. (2000). Sixth-grade students' epistemologies of science: The impact of school science experiences on epistemological development. *Cognition and Instruction*, 18(3), 349–422.
- Watson, J. R., Swain, J. R. L., & McRobbie, C. (2004). Students' discussions in practical scientific inquires. *International Journal of Science Education*, 26(1), 25–45. doi: [10.1080/0950069032000072764](https://doi.org/10.1080/0950069032000072764)
- Yerrick, R. K. (2000). Lower track science students' argumentation and open inquiry instruction. *Journal of Research in Science Teaching*, 37, 980–988. doi: [10.1002/1098-2736\(200010\)37:8<807::AID-TEA4>3.0.CO;2-7](https://doi.org/10.1002/1098-2736(200010)37:8<807::AID-TEA4>3.0.CO;2-7)

JULIE R. GRADY is an Assistant Professor of Curriculum in the Department of Educational Leadership, Curriculum, and Special Education at Arkansas State University, P.O. Box 1450, State University, AR 72467, jgrady@astate.edu

ERIN L. DOLAN is an Associate Professor in the Department of Biochemistry at Virginia Polytechnic Institute and State University, Fralin Life Science Institute, West Campus Drive MC 0346, Blacksburg, VA, 24061, edolan@vt.edu.

GEORGE E GLASSON is an Associate Professor in the Department of Teaching and Learning at Virginia Polytechnic Institute and State University, 319 War Memorial Hall, Blacksburg, VA 24061, glassong@vt.edu