

Friedrichsen, P., Munford, D., & Zembal-Saul, C. (2003). Using inquiry empowering technologies to support prospective teachers' scientific inquiry and science learning. *Contemporary Issues in Technology and Teacher Education*, 3(2), 223-239.

Using Inquiry Empowering Technologies to Support Prospective Teachers' Scientific Inquiry and Science Learning

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The Inquiry Empowering Technologies for Supporting Scientific Inquiry course was designed to engage prospective teachers, as science learners, in developing their understandings about and abilities to do scientific inquiry. The design of the course was informed by three central goals: (a) engage prospective science teachers in authentic science experiences in a technology-rich environment designed to promote and support scientific inquiry; (b) situate science learning within a social context; and (c) promote reflection on learning. Pedagogical approaches used in the course are described in detail within the context of a life science module. Throughout the course, prospective teachers reflected on their own experiences as learners of science; these learning experiences appear to serve as powerful referents for novice teachers as they learn to teach science through the use of inquiry empowering technologies.

The notion of scientific inquiry is at the core of reform views of science teaching and learning (National Research Council [NRC], 1996, 2000). Consequently, teachers are being asked to teach science in ways that differ

from their own past experiences as learners of science (Putnam & Borko, 1997). To prepare future science teachers to meet the vision proposed in reform documents, prospective teachers need to have experiences engaging in scientific inquiry as learners. The purpose of this paper is to describe the design of an innovative, technology-rich, inquiry-based science course, *Inquiry Empowering Technologies for Supporting Scientific Inquiry*. In this course, prospective secondary science teachers engaged, as science learners, in authentic science investigations using inquiry empowering technologies and reflected on these experiences to reconsider their roles as science teachers. In this paper, the rationale for the course and theoretical underpinnings will be followed by a discussion of the course goals. This one semester course consisted of three instructional units, referred to as modules – one each in life, physical, and earth science. For the purposes of this paper, pedagogical approaches for meeting the course goals will be illustrated with examples from the life science module. We conclude with a brief discussion of research implications within the context of the course.

COURSE RATIONALE AND THEORETICAL UNDERPINNINGS

Scientific Inquiry

In the *National Science Education Standards* (NRC, 1996), two elements of scientific inquiry *for science learners* have been emphasized: abilities to do scientific inquiry and understandings about scientific inquiry. Engaging in scientific inquiry involves focusing on scientifically oriented questions, giving priority to evidence in responding to questions, formulating explanations from evidence, connecting explanations to scientific knowledge, and communicating and justifying explanations (NRC, 2000, p. 29). This definition of engaging in scientific inquiry represents a shift in the focus of teaching: less emphasis on “science as exploration and experiment” (or hands-on activities), and increasing emphasis on “science as argument and explanation” (or minds-on activities) (Abell, Anderson, & Chezem, 2000; Kuhn, 1993; NRC, 1996).

The notion that *learning science* also means learning *a way of thinking* about nature underlies the other major dimension of scientific inquiry for learners, that is, that they should develop understandings about scientific inquiry. Scientific inquiry from a reform-oriented perspective implies that through school science, students should learn *how* to “engage in a dialogue with the material world” (Wheeler, 2000). Moreover, in order to understand how scientific knowledge is constructed, it is not enough to understand

scientists' practices. Rather, it is fundamental that science is understood in a cultural and social context (Abd-El-Khalick & Lederman, 2000). Science educators have referred to this broader construct as the "nature of science" (NOS). Unfortunately, NOS aspects of scientific inquiry, in particular, have been overlooked in school science (Bybee, 2000).

How do we achieve a more encompassing understanding of scientific inquiry in school science so that learners develop both understandings about and abilities to do scientific inquiry? Teachers need to create opportunities for students to engage in inquiry-based investigations, in conjunction with helping students reflect on those experiences to develop *understandings* of scientific inquiry. To meet this challenge, teachers need to have a thorough understanding of scientific inquiry (in addition to having robust understandings of subject matter and inquiry-oriented teaching strategies; Bybee (2000). Unfortunately, many prospective teachers have not learned science in this way and know little about scientific inquiry. How, then, can they realize the vision of science education reform in their classrooms? It is the responsibility of teacher educators to provide support in this area. The course described here, Inquiry Empowering Technologies for Supporting Scientific Inquiry, was designed to support prospective teachers in developing their own abilities and understandings of scientific inquiry.

Status of Teacher Education Preparation in Technology

"Most preservice teachers know very little about effective use of technology in education and leaders believe there is a pressing need to increase substantially the amount and quality of instruction teachers receive about technology," stated Willis and Mehlinger (1996, p. 978) in their review of the literature on information technology and teacher education. In addition, The United States Office of Technology Assessment (U.S. Congress, 1995), in assessing preservice teacher education, found that technology was not a central component of teacher preparation programs in most colleges of education. A summary of the report's key findings stated, "Most technology instruction in colleges of education is teaching about technology as a separate subject, not teaching with technology across the curriculum" (p. 165). The Web-Based Education Commission (2000) summarized the inherent problem in offering a separate course in information technology: "But providing a stand-alone course about technology is not

the same as ensuring that courses in teaching methods integrate technology as a way of building understanding or assessing learning” (p. 31).

In response to the current status of teacher preparation, the Association for the Education of Teachers in Science (AETS) has proposed the following guidelines for using technology in the preparation of science teachers:

- Technology should be introduced in the context of science content.
- Technology should address worthwhile science with appropriate technology.
- Technology instruction in science should take advantage of the unique features of technology.
- Technology should make scientific views more accessible.
- Technology instruction should develop students’ understanding of the relationship between technology and science. (Flick & Bell, 2000, p. 40)

In this paper, we describe an innovative course that attempts to meet the guidelines proposed by AETS. Although taught in the College of Education, Inquiry Empowering Technologies for Supporting Scientific Inquiry is a science content course with the focus on science learning, rather than a science “methods” course. The instructional team selected science topics in which alternative conceptions abound. The computer-based tools selected for use in the course, referred to as “inquiry empowering technologies” (Zemba-Saul, 2002; Zemba-Saul, Munford, & Friedrichsen, 2002), were specially designed to support scientific inquiry by providing access to complex databases and powerful tools for organizing and analyzing data, visualizing complex scientific phenomena, and constructing evidence-based arguments (Krajcik, Blumenfeld, Marx, & Soloway, 2000; Reiser, Tabak, & Sandoval, 2001). The use of electronic journals and the development of web-based science teaching and learning philosophies were essential components of the course, allowing students’ views to be made public. Through public sharing of ideas, students were able to compare and contrast their views with those of the scientific community. Additionally, the web-based philosophies and class discussions were designed to support the students’ developing understandings of the relationship between technology and science.

THE CONTEXT OF THE SECONDARY SCIENCE TEACHER EDUCATION PROGRAM

The course, Inquiry Empowering Technologies for Supporting Scientific Inquiry, is the first course in a three-semester sequence of science teaching and learning courses. This first course is designed to provide reform-oriented science learning experiences early in the program. The second and third courses in the sequence focus on science *teaching* (i.e., methods courses). At the end of the third course, prospective teachers enroll in a 5-week practicum in which they observe and teach in secondary schools. As part of this practicum experience, prospective teachers design and teach an inquiry-based science unit. After the completion of these three courses and practicum experience, prospective secondary science teachers enter their student teaching semester.

DESCRIPTION OF THE COURSE

Course Goals

The design of the course was informed by three central goals: (a) engage prospective science teachers (PSTs) in authentic science experiences in a technology-rich environment designed to promote and support scientific inquiry; (b) situate science learning within a social context; and (c) promote reflection on learning. In reference to “authentic” science experiences, the instructional team wanted prospective teachers to *participate* in practices and discourses that parallel those taking place in “formal science” (Brown, Collins, & Duiguid, 1989). For instance, an essential aspect of scientists’ work involves investigation in a rich and complex context to reach conclusions based on evidence (Hogan & Maglienti, 2001). By engaging students in authentic science experiences, the intent was to promote a shift from a discourse centered in authority to a discourse centered on interpretation of evidence (Osborne, Erduran, Simon, & Monk, 2000). In addition, the instructional team selected a set of inquiry empowering technologies as an essential component of creating authentic science experiences. “The successful adaptation of scientific practice for learning will place the tools and techniques of scientists into the hands of students in a context that reflects the characteristics of science practice” (Edelson, 1998, p. 319). Furthermore, by engaging students in authentic science experiences, the

instructional team expected that prospective teachers' knowledge about the natural world would become less inert and could be used by these learners in realistic situations (Edelson, 2001).

The second goal was to challenge traditional conceptions of science learning, which are centered on factual information and individualistic sense-making (Driver, Leach, Millar, & Scott, 1996). The instructional team's goal was to promote a notion of scientific knowledge as socially constructed, an idea that has become increasingly prevalent in science education and teacher education literature (e.g., Putnam & Borko, 1997; Roth, 1995). Thus, in this course, the instructional team designed opportunities for students to work collaboratively to construct scientific understanding. The third goal was to promote PSTs' reflection on their science learning experiences. This goal derives from the perspective that the learner is the one who actively constructs knowledge, instead of being a passive receptor of information. Thus, opportunities for PSTs to reflect on their experiences and construct new understandings included peer review sessions, class discussions, and the ongoing development of a web-based philosophy of science teaching and learning.

Course Structure: Three Discipline-Specific Modules

The instructional team, consisting of a professor and three graduate students, worked collaboratively to design, implement, and revise the course. Each of the graduate students served as the lead instructor for a module, drawing on their expertise as former secondary science teachers. The 15-week course was comprised of three modules, with each module focusing on a different science discipline: life, physical, and earth science. The course was designed to engage learners in multiple science disciplines for several reasons. First, the instructional team wanted the prospective teachers to experience at least one of the modules as learners. Secondary science teachers major in a specific science discipline, and the instructional team expected that the prospective teachers would have more content knowledge in some modules (those most closely connected to their major) and less in other modules. Findings from a pilot study indicated that some prospective teachers resisted engaging as learners in a module in their content area, in an attempt to avoid opening themselves up to the possibility of revealing a lack of robust subject matter knowledge (Zemba-Saul,

Munford, Crawford, Friedrichsen, & Land, 2001). By designing the course with modules in multiple disciplines, the instructional team's intent was to engage the prospective teachers as science learners, rather than perceived content experts.

Second, by representing multiple disciplines in the course, the instructional team's intent was to address an aspect of the nature of science frequently neglected in school science – the common misconception of a single scientific method. This misconception is rarely challenged in classrooms (Driver et al., 1996; Rudolph & Stewart, 1998), despite the extensive evidence derived from science studies (Hess, 1997). For example, in the life science module, students analyzed a dataset of observational field data, whereas in the physical science module, students collected and analyzed experimental data. The course design reflected the instructors' goal of challenging PSTs' preconceived notions of a single scientific method.

Module Structure: Pedagogical Approaches Illustrated with the Life Science Module

Consistent pedagogical approaches were used across the three modules (see Table 1). Within each module, a problem context and a driving question were used to focus the students' inquiry. Evolutionary biology was the focus of the life science module. At the beginning of each module, students' prior knowledge was assessed. Throughout the module, students used inquiry empowering technologies to build evidence-based arguments. The students engaged in peer review, and class presentations and electronic journals were used for assessment purposes. At the end of each module, students revised their web-based science teaching and learning philosophies. In the following sections, these pedagogical approaches are elaborated and illustrated with examples from the life science module.

Table 1
Overview of Modules

Module:	Driving Question	Inquiring-Empowering	Unique Module
Problem Context		Technology	Features
Life Science: Evolutionary Biology	Why did the finches die in 1977? Why did some finches survive?	<ul style="list-style-type: none"> Galapagos Finches software (Reiser et al., 1998-1999) 	Analyzed a dataset of observational field data, role of theory emphasized
Physical Science: Optics	What happens when light leaves its source? Why do we see what we see?	<ul style="list-style-type: none"> Progress Portfolio (Gomez et al., 1996- 1999) Light Probes 	Collected & analyzed experimental data
Earth Science: Global Climate Change	Are global temperatures increasing? What is causing changes in global temperatures?	<ul style="list-style-type: none"> Worldwatcher (Edelson & Gordin, 1998) Temperature Probe Progress Portfolio software 	Analyzed empirical data and established datasets, Complex scientific representations through visualization, socio-cultural aspects of nature of science

Using an Authentic Problem Context with Driving Questions

Each module was centered within a problem context focused by a driving question. In the life science module, prospective teachers worked in pairs to investigate an authentic problem, one that Rosalyn and Peter Grant encountered in the Galapagos Islands during the 1970s (Grant, 1986; Weiner, 1994). The student pairs were required to explain the drastic decrease in the

population of ground finches in 1977, as well as determine why some birds were able to survive. To do this, they used the *Galapagos Finches* software to study a rich dataset from the island Daphne Major. We intentionally selected the *Galapagos Finches* software and the supporting curriculum, *Struggle for Survival*, because of the focus on creating a context for scientific inquiry and supporting the construction of evidence-based arguments. The software and curriculum are part of the *Biology Guided Inquiry Learning Environment* (BGuILE) project directed by Brian Reiser at Northwestern University (see <http://www.letus.org/bguile>) and supported by LeTUS (Learning Technologies in Urban Schools; see <http://www.letus.org>). Scientists have reached some consensus regarding what caused the death of so many birds, while there are still uncertainties regarding how some birds managed to survive (Grant & Grant, 1989). In other words, the task did not involve simply confirming something that had been extensively corroborated by scientists. In that sense, the students engaged in an authentic scientific problem.

Eliciting Students' Prior Knowledge

Students' prior conceptions were elicited at the beginning of each module. In the life science module, a portion of Bishop and Anderson's (1990) paper and pencil questionnaire was used. The questionnaire is designed to elicit common alternative conceptions regarding natural selection and its role in evolution. As an out-of-class assignment, students read the Bishop and Anderson (1990) article, which contrasts common alternative conceptions of biologists' conceptions of evolution by natural selection. In a follow-up whole class discussion, the students explored possible sources of their alternative conceptions.

Constructing Evidence-based Arguments

Within each module, a driving question focused the students' inquiry. In response to the driving question, students built arguments consisting of claims, evidence, and justifications. Claims were defined as assertions grounded in data/evidence that were intended to account for the phenomena under investigation. Evidence was drawn directly from the investigation and

assumed multiple forms (e.g., graphs, numerical data, field notes). Finally, justification provided an explicit rationale indicating how/why a particular piece of evidence was appropriate for supporting a claim. Working in pairs, the PSTs sorted through the data, examined the data set for patterns, and collected evidence for their arguments. Electronic journals were used to aid students in this process (see Figure 1). In the life science module, the students used *Explanation Constructor*, which is part of The Galapagos Finches software. An important feature of the *Explanation Constructor* was the linking feature, which allowed students easily to connect specific pieces of evidence to the claims that they supported (Reiser et al., 2001; Sandoval & Reiser, 1997).

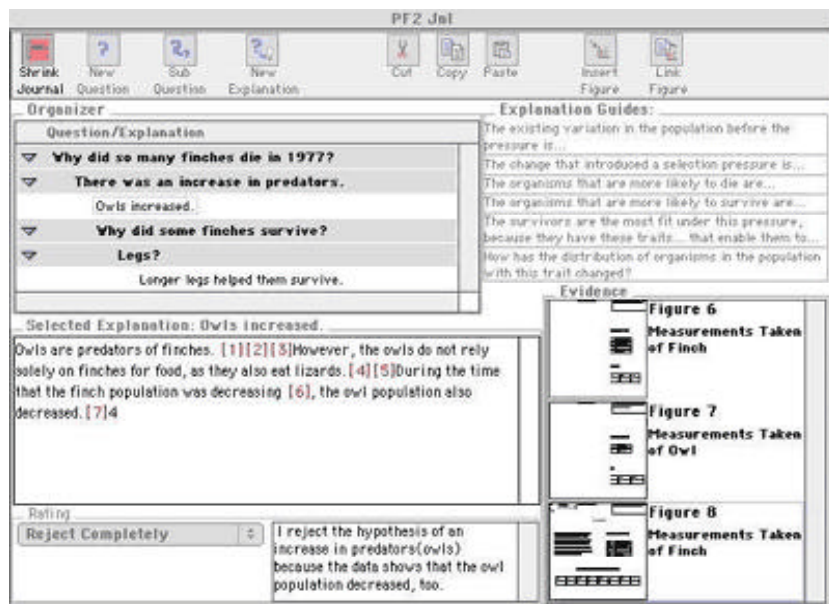


Figure 1. Screen shot of electronic journal.

Peer Reviews

As part of creating authentic science experiences, peer review was incorporated into each module. Using a peer review assessment sheet (see [appendix](#)) as a guide, each pair of students reviewed another pair's electronic journal. After completing the assessment sheets, the two pairs met for face-to-face discussions. During this time, the PSTs shared their critique of the argument, reviewing each claim and the strength of the evidence used. Students were encouraged to use multiple pieces of evidence to support each claim, as well as to consider alternative explanations. After the peer review, the students were given additional class time to revise their arguments based on peer feedback.

Students' Presentations

As a summative assessment task, students created PowerPoint™ presentations ([PowerPoint 1](#)) of their arguments. In creating their presentations, students were asked to outline their arguments, selecting only the most powerful pieces of evidence to support their claims. Students also included alternative arguments they had explored. Each student analyzed the same dataset, so they were able to ask critical questions during the class presentations. Afterwards, the students were given the opportunity to revise their

Developing Web-based Science Teaching and Learning Philosophies

Throughout the course, the students worked on creating their individual web-based science teaching and learning philosophy (Avraamidou & Zembal-Saul, 2002). The web-based philosophies were designed around three main questions: (a) What is the nature of science and scientific inquiry? (b) What does it mean to learn science in meaningful and authentic ways? and (c) How can technology support meaningful science learning? At the end of the evolutionary biology module, the students generated claims for each of the three guiding questions. The claims needed to be supported with evidence from their experiences in the evolutionary biology module (see student example of Version 1 at <http://www.missouri.edu/~pfxcf/Conrad/>)

[version2.html](#)). At the completion of each module, students added to and revised their claims using additional evidence from the new module (see student example Version 2 at <http://www.missouri.edu/~pfxcf/Conrad/wbp4.html>). Construction of the web-based science teaching and learning philosophy required the students to reflect on their own science learning, using the format of an evidence-based argument.

Making Connections to Teaching

Although the primary focus of the course was on science learning, each module had explicit pedagogical connections. In the evolutionary biology module, the students examined the *Atlas of Science Literacy's* K-12 conceptual strand maps for evolution and natural selection (American Association for the Advancement of Science [AAAS], 2001). The maps illustrate the sequence of concepts, as well as the relationships between concepts, needed to develop a robust understanding of evolution and natural selection (AAAS, 2001, pp. 80-83). Prospective secondary science teachers, particularly those seeking certification in earth science, were able to see how concepts in their discipline connected to the teaching of evolution. Using the conceptual strand maps as a guide, PSTs selected National Science Teacher Association journal articles related to the teaching of evolution. In a written assignment, students made connections to the module and discussed how the NSTA journal article informed their future teaching practices.

CONCLUSIONS AND RESEARCH IMPLICATIONS

The Inquiry Empowering Technologies for Supporting Scientific Inquiry course was designed to engage prospective science teachers, as science learners, in authentic science investigations. The students constructed evidence-based arguments with the support of inquiry empowering technologies. The science experiences were situated within social contexts, and reflection on learning was a critical component of the course. Within each of the three discipline-specific modules, the following pedagogical approaches were used: (a) an authentic problem context with a driving question; (b) elicitation of students' prior knowledge; (c) evidence-based argument

construction (d) peer reviews; (e) development of web-based science teaching and learning philosophies; and (f) connections to teaching. Through the course design, our goal was to help prospective teachers develop both *understandings* about and *abilities* to do scientific inquiry.

The Inquiry Empowering Technologies for Supporting Scientific Inquiry course has provided a rich context for research. In a phenomenological study, the second and third authors explored the PSTs' lived experiences as they participated in the course, focusing on individual students' understandings of science as argumentation (Munford, 2002). The results of the study indicated that, from PSTs' perspectives, the learning experiences in this course were complex and contextualized. Multiple factors interplayed to define these experiences, namely perceptions about science, learning and school. Technological tools had the potential to challenge or reinforce these perceptions, indirectly raising questions about what it means to learn science, what science is, and what characterizes school science. In the context of this course, PSTs had the opportunity to consider these questions in light of their own experiences as learners of science.

Additionally, as researchers, we are interested in the transformation of subject matter knowledge for teaching – a domain referred to as pedagogical content knowledge (PCK) (Shulman, 1986). How do PSTs, as learners, translate their experiences in this course into *teaching* science as argumentation? Currently, in a longitudinal study, we are continuing to work with former students as they enter practice and student teaching experiences. Initial findings indicate that previous experiences in this course (and meanings constructed from these experiences) appear to serve as powerful referents for novice teachers as they learn to teach science as argumentation through the use of inquiry empowering technologies.

References

- Abd-El-Khalick, F., & Lederman, N. (2000). Improving science teachers' conceptions of nature of science: A critical review of the literature. *International Journal of Science Education, 22*(7), 665-701.
- Abell, S. K., Anderson, G., & Chezem, J. (2000). Science as argument and explanation: Exploring concepts of sound in third grade. In J. Minstrell & E. H. van Zee (Eds.), *Inquiry into inquiry learning and teaching in science*

- (pp. 100-119). Washington: American Association for the Advancement of Science.
- American Association for the Advancement of Science, Project 2061. (2001). *Atlas of science literacy*. Washington: Author and National Science Teachers Association.
- Avraamidou, L., & Zembal-Saul, C. (2002). Using a web-based task to make prospective elementary teachers' personal theorizing about science teaching explicit. In P. Rubba, J. Rye, W. DiBiase, & B. Crawford (Eds.), *Proceedings of the 2002 Annual International Conference of the Association for the Education of Teachers in Science*. (ERIC Document Reproduction Service No. 465 602)
- Bishop, B. A., & Anderson, C. W. (1990). Student conceptions of natural selection and its role in evolution. *Journal of Research in Science Teaching, 27(5)*, 415-427.
- Brown, J. S., Collins, A., & Duiguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18(1)*, 32-42.
- Bybee, R. W. (2000). Teaching science as inquiry. In J. Minstrell & E. H. van Zee (Eds.), *Inquiry into inquiry learning and teaching in science* (pp. 20-46). Washington: American Association for the Advancement of Science.
- Driver, R., Leach, J., Millar, R., & Scott, P. (1996). *Young's people's images of science*. Buckingham: Open University Press.
- Edelson, D. (1998). Realising authentic science learning through the adaptation of scientific practice. In B.J. Fraser & K.G. Tobin (Eds.), *International handbook of science education* (pp. 317-331). Great Britain: Kluwer.
- Edelson, D. C. (2001). Learning-for-Use: A framework for the design of technology-supported inquiry activities. *Journal of Research in Science Teaching, 38(3)*, 355-385.
- Edelson, D., & Gordin, D.N. (1998). Visualization for learners: A framework for adapting scientists' tools. *Computers and Geosciences, 24(7)*, 607-616.
- Flick, L., & Bell, R. (2000) Preparing tomorrow's science teachers to use technology: Guidelines for science educators. *Contemporary Issues in Technology and Teacher Education, 1(1)*, 39-60.
- Gomez, L., Edelson, D., Pea, R., Reiser, B., Loh, B., Randisnky, J., & Russell, E. (1996-1999). *Progress portfolio* (Version 2.2b5) [Computer Software]. Chicago: Northwestern University.
- Grant, P.R. (1986) *Ecology and evolution of Darwin's finches*. Princeton: Princeton University Press.
- Grant, B. R., & Grant, P. R. (1989). *Evolutionary dynamics of a natural population: The large cactus finch of the Galápagos*. Chicago: The University of Chicago Press.
- Hess, D. J. (1997). *Science studies: An advanced introduction*. New York: New York University Press.
- Hogan, K., & Maglienti, M. (2001). Comparing the epistemological underpinnings of students' and scientists' reasoning about conclusions. *Journal of Research in Science Teaching, 18(6)*, 663-687.

- Krajcik, J., Blumenfeld, P., Marx, R., & Soloway, E. (2000). Instructional, curricular, and technological supports for inquiry in science classrooms. In J. Minstrell & E. H. van Zee (Eds.), *Inquiring into inquiry learning and teaching in science* (pp. 283-315). Washington: American Association for the Advancement of Science.
- Kuhn, D. (1993). Science as argument: Implications for teaching and learning scientific thinking. *Science Education, 77*(3), 319-337.
- Munford, D. (2002). Situated argumentation, learning and science education: A case study of prospective teachers' experiences in an innovative science course (Doctoral dissertation, The Pennsylvania State University). *Dissertation Abstracts International, 63*(07), 2497. (UMI No. AAT 3060025)
- National Research Council. (1996). *National science education standards*. Washington: National Academy Press.
- National Research Council. (2000). *Inquiry and the National Science Standards: A guide for teaching and learning*. Washington: National Academy Press.
- Osborne, J., Erduran, S., Simon, S., & Monk, M. (2000). Enhancing the quality of argument in school science. *School Science Review, 82*(301), 63-70.
- Putnam, R. T., & Borko, H. (1997). Teacher learning: Implications of new views of cognition. In B. J. Biddle (Ed.), *International handbook of teachers and teaching* (pp. 1223-1296). Boston: Kluwer Academic Publishers.
- Reiser, B., Tabak, I., & Sandoval, W. (2001). BGuILE: Strategic and conceptual scaffolds for scientific inquiry. In S. M. Carver & D. Klahr (Eds.), *Cognition and instruction: Twenty-five years of progress* (pp. 263-305) Mahwah: Erlbaum.
- Reiser, B., Tabak, I., Sandoval, B., Steinmuller, F., Leone, T.J., Leider, R., Hudson., & Massey, T., (1998-1999). *The Galapagos finches* (Version 2.0) [Computer Software]. Chicago: Northwestern University.
- Roth, W. M. (1995). *Authentic school science: Knowing and learning in open-inquiry science laboratories*. Dordrecht: Kluwer Academic Publishers.
- Rudolph, J. L., & Stewart, J. (1998). Evolution and the nature of science: On the historical discord and its implications for education. *Journal of Research in Science Teaching, 35*(10), 1069-1089.
- Sandoval, W. A., & Reiser, B. J. (1997, April). *Evolving explanations in high school biology*. A paper presented at the Annual Meeting of the American Educational Research Association, Chicago.
- Shulman, L.S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher 15*(2), 4-14.
- U.S. Congress. Office of Technology Assessment. (1995). *Teachers and technology: making the connections* (GPO #052-003-01409-2). Washington: U.S. Government Printing Office.
- Web-Based Education Commission. (2000). *The power of the Internet for learning: Final report of the web-based education commission*. Retrieved April 25, 2003, from http://interact.hpcnet.org/webcommission/Professional_Development.htm

- Weiner, J. (1994). *The beak of the finch: A story of evolution in our time*. New York: Alfred A. Knopf.
- Wheeler, G. F. (2000). The three faces of inquiry. In J. Minstrell & E. H. van Zee (Eds.), *Inquiry into inquiry learning and teaching in science* (pp. 14-19). Washington: American Association for the Advancement of Science.
- Willis, J.W., & Mehlinger, H.D. (1996). Information technology and teacher education. In J. Sikula, T. Buttery & E. Guyton (Eds.). *Handbook of research on teacher education* (2nd ed., pp. 978-1029). New York: Simon and Shuster.
- Zemal-Saul, C. (2002, April). Toward science as argument and explanation. Invited paper presented in V.N. Lunetta & A. Hofstein, *The laboratory in science education: Foundations for the 21st century* (Symposium) at the annual meeting of the National Association for Research in Science Teaching, New Orleans, LA.
- Zemal-Saul, C., Munford, D., Crawford, B., Friedrichsen, P., & Land, S. (2001, March). *Examining the role of software scaffolds in the development of prospective science teachers' explanations in biology*. A paper presented at the annual meeting of the National Association for Research in Science Teaching, St. Louis, MO.
- Zemal-Saul, C., Munford, D., & Friedrichsen, P. (2002). Technology tools for supporting scientific inquiry: A preservice science education course. In P. Rubba, J. Rye, W. DiBiase & B. Crawford (Eds.), *Proceedings of the 2002 Annual International Conference of the Association for the Education of Teachers of Science*. (ERIC Document Reproduction Service No. 465 602)

Author Notes

This material is based upon work supported by the National Science Foundation (NSF REC 9980055). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

An earlier version of this paper was presented at the Association for the Education of Teachers of Science Annual Meeting, Charlotte, NC, January 2002.

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