Centering a Professional Learning Community on a Learning Progression for Natural Selection: Transforming Community, Language, and Instructional Practice

Erin Marie Furtak, Deborah Morrison, and Kathleen Henson
University of Colorado at Boulder, School of Education, UCB 249, Boulder, CO 80309
erin.furtak@colorado.edu, deb.morrison@colorado.edu, kathleen.henson@colorado.edu

In this study we examine the development of a professional learning community (PLC) centered on the practice of understanding student learning of natural selection. Eight biology teachers engaged with researchers to use an educative learning progression (LP) empirically developed from student work as a tool for exploring prior ideas and sharing potential instructional strategies to move students towards scientific understandings of natural selection. The PLC involved iterative cycles of development and reflection of the LP, formative assessments and feedback strategies. Three primary results are reported in this paper with respect to the PLC's development associated with the LP: transformation of interactions within the PLC, changes in the language teachers used to describe student thinking, and modifications in the ways instructional practices were shared. These changes demonstrate the potential for a PLC when used in conjunction with a LP to encourage meaningful changes in classroom practice.

Theoretical Background

The *National Science Education Standards [NSES]* (National Research Council, 1996) defined the knowledge and practices students are expected to learn, but were never intended as a 'how-to' document for teachers (Collins, 1998). To supplement the NSES, science education researchers are currently creating Learning Progressions (LPs), which are empirically-based sequences of conceptual understandings and scientific skills intended as guides for teaching and learning. LPs map "the successively more sophisticated ways of thinking about a topic that can follow and build on one another as children learn about and investigate a topic over a broad span of time" (National Research Council, 2007, p. 213).

At least two approaches have emerged for the construction of LPs. The first approach consists of a progression of *correct* ideas based on standards documents or consultations with scientists, articulated across grade spans (American Association for the Advancement of Science, 2001; Catley, Lehrer, & Reiser, 2005). This kind of LP tends to be created by exhaustive conceptual analyses of how scientifically accurate student ideas should develop during instruction; examples have been created in the domain of evolution (Catley et al., 2005) and modern genetics (Duncan, Rogat, & Yarden, 2009). These LPs are being developed as guides for curriculum and large-scale assessments. A second approach to LPs entails the creation of maps of concepts anchored on one end by naïve ideas about the natural world and on the other end by scientifically accepted explanations. The middle is occupied by increasingly sophisticated intermediate understandings. A key feature of this second type of learning progression is that they are anchored at the lower end by students' common prior ideas and misunderstandings (Briggs, Alonzo, Schwab, & Wilson, 2006; Wilson, 2005).

Toward Learning Progressions as Teacher Development Tools

Given the aforementioned challenges presented by previous studies employing LPs in the classroom, it follows that LPs could be complimented with additional information to make them not only maps of how student knowledge develops through instruction, but also maps of the instructional strategies that will help teachers more effectively teach a given concept. Knowing the means by which students learn concepts is important, but without the tools to help teachers recognize and act upon those ideas, the means by which the information LPs contain will be translated into practice is unclear. LPs need to be developed that will scaffold the development of the knowledge and practices that teachers need for effective science instruction.

The science education community, after several years of developing LPs, is now emphasizing the need for empirical explorations of the impact of LPs on teacher practice and student learning (Shavelson, 2009). According to the Center on Continuous Instructional Improvement's recent report on LPs, the field needs "continuing effort, and funding, to refine and test the progressions that now are under development, including making a concerted effort to demonstrate the effects on instruction and improved student outcomes when teaching and assessment are aligned with well tested progressions - to provide a kind of "existence proof" that further investment in developing progressions would be justified." (Corcoran et al., 2009, p. 9).

Educative Learning Progressions

Although the primary purpose of LPs as currently conceived is to sequentially map the knowledge and practices students are expected to learn, LPs have great potential to be invaluable tools for teacher development. LPs could serve as the foundation for what Davis & Krajcik (2005) called 'educative curriculum materials' with the dual potential of scaffolding not only student learning, but also teacher learning in a conceptual domain. This kind of LP – which will henceforth be referred to as an educative LP - contains information regarding knowledge of common student ideas and alternative conceptions, suggestions for strategies or actions to help students learn, and a model for teacher development in relation to the LP. An educative LP is thus a suite of tools that may work synergistically to support improvement in teacher practice and student learning.

In the inquiry-based learning environments currently emphasized in science education reforms (National Research Council, 1996, 2001, 2007) the ideas that students develop are often undifferentiated, poorly stated, and inconsistent with standards-style statements of idealized student understanding (e.g. Driver, Guesne, & Tiberghien, 1985). In order for teachers to navigate these ideas and move students toward learning goals, they must have deep content knowledge, as well as knowledge of students' understandings and misconceptions (Duschl, 2003; Gess-Newsome, 1999; Shulman, 1986). Since teachers' content knowledge is not always interconnected or easily translated into reform-based classroom practice, the ideas students present in inquiry-based activities pose a particular challenge (Luft & Roehrig, 2007; Windschitl, 2004).

Educative LPs could serve as scaffolds for teachers in inquiry-based settings by helping them to anticipate not only the ideas students might share, but also to suggest instructional strategies tailored to these ideas. In order to serve that purpose, however, LPs need to include examples of student responses for each level, as well as instructional strategies, feedback suggestions to help students proceed up the LP, and professional development to support changes in practice. Educative LPs should thus contain the preceding five elements; the first four are features of the educative LP itself, and the fifth emphasizes the importance of sustained professional development within a community of practice to support teachers' adoption of new instructional strategies based on the educative LP (Lave & Wenger, 1991). Sustained professional development centered on an educative LP and its accompanying tools could help teachers learn the structure and relationship of students' understandings about a particular concept, teaching strategies to elicit student thinking, likely student responses, and targeted feedback for students. In this way, educative LPs can act as a guide for teachers, showing them potential steps to take in order to help students move along the learning progression, thereby meeting increasingly challenging learning goals (Sadler, 1989) and positively impacting student learning (Black, 1998). To explore the potential influence of an educative LP on a PLC, this paper responds to the following research question: How does sustained, ongoing professional development in a PLC centered on the LP transform the community, language and practice?

Context: Natural Selection and the Daphne Project

Charles Darwin's theory of evolution through the process of natural selection is the unifying framework for Biology (Dobzhansky, 1973); nevertheless, students often have a difficult time understanding it (Bishop & Anderson, 1990; Ferrari & Chi, 1998). Studies indicate evolution instruction in high school has been "absent, cursory, or fraught with misinformation" (Rutledge & Mitchell, 2002, p. 21), and students commonly have misconceptions about how populations change over time (Anderson, Fisher, & Norman, 2002; Rudolph & Stewart, 1998; Shtulman, 2006).

The Daphne Project is a design-based research study located at the intersection of the new theory of LPs and classroom practice (Brown, 1992; Sandoval & Bell, 2004; Sloan 2009). The goal of the Daphne Project was to collaborate with a department of biology teachers to explore and refine a hypothesized LP. It was hypothesized at the outset of the study that engaging in the process of developing this LP would help teachers be better prepared to recognize and act upon student thinking, which in turn would impact student learning by closing what has been called a 'feedback loop' in the formative assessment process (Black & Wiliam, 1998; National Research Council, 2001).

The educative LP created in the Daphne Project combines features of LPs designed as frameworks for curriculum with lower anchors serving as foundational *correct* understandings (Catley et al., 2005) and those anchored by students' common prior ideas as suggested by Shepard (2009) and Wilson (2009). In this way, the LP has as its foundation both an overarching framework to inform scope and sequence as well as information mapping students' complex thinking that can often obfuscate the path forward for teachers. The educative LP is not a curriculum in itself, but is intended as a framework to guide teachers' enactment of a curriculum by representing a sequence of correct ideas as well as a categorization of the common misunderstandings students may have regarding those ideas. The educative LP is shown in Figure 1; the horizontal sequence of correct ideas is taken directly from Mayr (1997), and the two vertical sequences (*Origin and Inheritance of Traits* and *Selective Force* constructs) were identified through analyses of student responses to the assessments in the Daphne Project. The educative LP is paired with accompanying tools intended to scaffold instruction, as well as a professional development model to support teachers in changing their practice. The educative LP for natural selection includes a set of formative assessment prompts designed to be embedded in the curriculum to provide opportunities for teachers to elicit student thinking and map it to the progression. It also includes common student responses to each assessment at each level and suggested feedback strategies for students with different ideas.

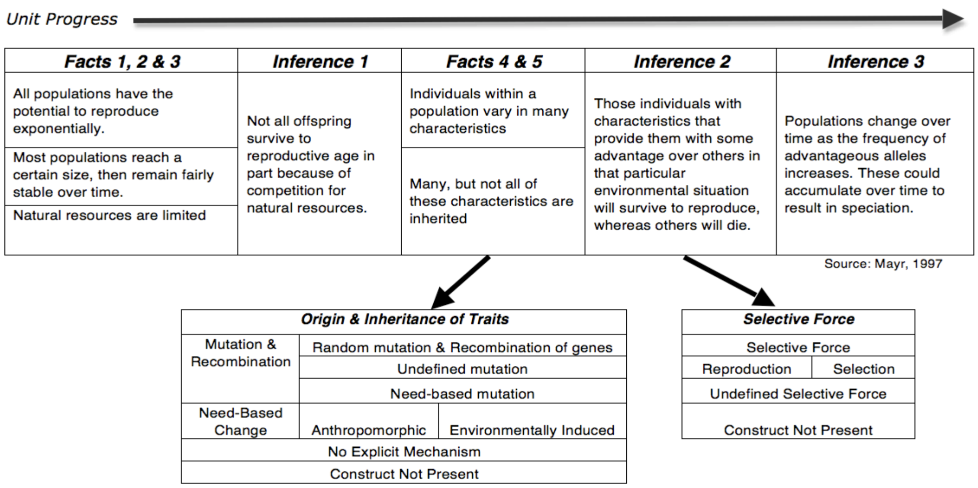

Figure 1. Learning Progression for Natural Selection

A suite of tools including a series of formative assessment prompts, sample student responses, and feedback ideas were developed and piloted across the three years of the Daphne Project. The result was a set of formative assessments that targeted different ideas on the *Origin of New Traits* and *Selective Force* constructs, including a constructed-response prompt of "How do species change over time?", a multiple-choice plus-justification prompt, an evaluation of Peter and Rosemary Grant's data on Darwin's finches in the Galapagos Islands, and interpretation of real-life scenarios (Figure 2). and analysis of these prompts being implemented led to collection of student responses for each level of the LP, as well as suggested feedback strategies (Table 1).

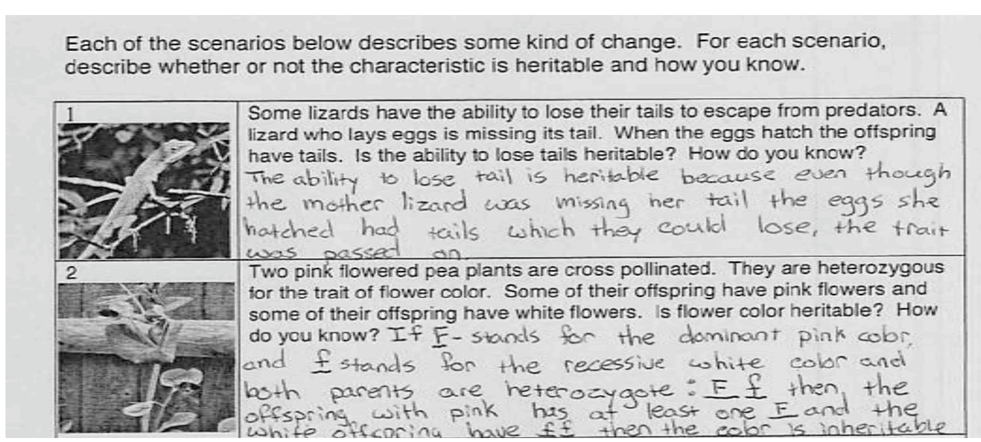

Figure 2. Sample formative assessment activity

Table 1. Sample student responses, and feedback strategies linked to the need-based conceptions on the *Origin and Inheritance of Traits* construct.

Description	Example Student Responses	Suggested Feedback
Anthropomorphic: Changes arise from deliberate acts by the parent organism or the species as a whole	"The moths become darker because of bark." "The moths would change their color to a darker color to blend in with the dark bark."	Examine evidence collected in class activities and focus upon where variation originated Explore Lamarck's idea of descent with modification, and compare to modern ideas about genetic inheritance
Environmentally Induced: Changes emerge because of environmental conditions; i.e., the environment causes changes in organisms to occur	"When food and other resources become scarce, the finches develop over a period of time different beaks to eat the hard seeds that seem to be abundant." "Animals mutate to fit in with their natural surroundings. So becoming darker helps to keep them in camouflage."	Explore differences between mutations in an individual and population changes Discuss instances in which individuals change in response to the environment (e.g. arctic hares), and how this differs from changes in the proportion of genes in a population

Sustained Professional Development

Since the LP and the tools themselves do not represent a sufficient intervention to help teachers develop their own practices, a central component of the Daphne Project was the development of a PLC consisting of the authors and seven biology teacher participants, with a biologist providing content-specific guidance when necessary. These multiple stakeholders brought myriad perspectives to the PLC, allowing for the active exchange of ideas based on the participants' diverse expertise. The PLC met monthly during the school year for the duration of years two and three of the project. According to DuFour (2004), three components of successful PLCs in schools are (1) a focus on student learning, (2) a culture of collaboration and (3) a focus on results. Each of these components was undertaken within the Daphne Project work as the activities of the PLC were modeled on problem-solving and assessment development cycles from mathematics education (Borko, 2004; Webb, Romberg, Burrill, & Ford, 2005) to facilitate teachers' reflection on their current practices and adoption of new practices supported by the educative LP.

The Daphne Project PLC is modeled on an iterative four-step process. At each step in this process student learning was central in teachers' collaboration around specific instruction and feedback necessary to move students with specific prior ideas forward to correct understandings. The first step is for teachers to **Reflect** upon their current practice, sharing instructional strategies and materials with each other and discussing their advantages and disadvantages (Loughran, Mulhall, & Berry, 2004). In the second step, teachers **Explore** student thinking in their classes and compare those ideas with the LP. In this step, a particular focus is placed upon deepening teachers' content knowledge, as well as understanding students' common misunderstandings and alternative conceptions and the sources of those ideas. In the third step, teachers **Practice** using the associated tools and formative assessments, categorizing samples of student work, anticipating feedback, and discussing video cases. At this stage, encouraging teachers to discuss not only the identification of student ideas is essential, but also anticipating the kinds of feedback students within each category of student thinking would need. The fourth step has the teachers **Enact** their natural selection units with the tools contained in the educative LP, after which the teachers continue the cycle by reflecting upon their enactment and **Revising** their plans for next time.

Method

Participants

Eight biology teachers at Springfield High School participated. Springfield, considered among the top high schools in the state, is an ethnically and socioeconomically diverse school near a large city in the western US. The teachers represented a wide range of backgrounds and experience, ranging from a second-career student teacher to a 29-year veteran Biology teacher. Students in the participating teachers' classes were enrolled in four levels of biology: 9th grade pre-International Baccalaureate Biology, 10th grade General Biology, 10th grade English Language Learner (ELL) Biology, and 11th grade Advanced Placement Biology.

Learning Progression and Professional Learning Community

On the basis of the student ideas about natural selection identified above, a draft LP was developed, piloted, and revised based upon analyses of student work (Furtak, 2009). By organizing students' ideas in a linear fashion, progressing from simple to complex, moving away from the ideas of Lamarck toward those of Darwin. As described above, the LP was accompanied by formative assessments designed to elicit student thinking, along with sample student responses and feedback strategies that were updated and extended by the reseachers and teachers through the course of the study.

Prior to the beginning of the study, the biology teachers at Springfield High did not have common planning time, and other than using the same textbook at each level of biology instruction, did not have a common curriculum. The teachers and the lead researcher participated in meetings every two to three weeks during the 2008-2009. Sessions involved discussing approaches to teaching evolution, predicting and exploring students' ideas about natural selection, categorizing student work, and discussing different instructional approaches given student ideas represented in the LPs.

Sources of Data

Videotapes made of PLC meetings spanning the 2008-2009 and 2009-2010 academic years are the primary source of data for this study. Complimenting these videotapes are field notes kept by the authors of the study during each meeting, reflective notes made immediately followign each meeting, artifacts from the meetings, and content logs made of each videotape.

Data Analysis

Through the course of the study, the authors kept ongoing notes based upond emergent themes they noticed during the PLC meetings. Reflection and discussion of these notes within research group meetings revealed converging themes centered on three shifts that occurred across the course of the academic year: shifts in the community interactions, shifts in the language teachers used to characterize student thinking, and shifts in practice.

The authors independently viewed videos supplemented by the artifacts described above and noted instances of interest in the PLC videos related to these three themes. Observations were categorized according to their relationship to the three elements of focus in this study: community, language, and instrucitonal practice. Then propositions were made on the basis of what each researcher viewed as the nature of the interactions in that video. The three researchers then met and came to a consensus about the nature of the three categories in each video. Longitudinal comparisons were then made across the set of PLC videos.

Table 2: Sample categories

Categories	Questions to frame analysis
Community	How do teachers interact within the PLC community? Who allies with whom? What are the issues of status that arise? Who is speaking, and who is listening? How do they listen to and respond to each other?
Language	How do teachers characterize student ideas? What kinds of ideas do they mention, and what words are they using to describe them? How do these relate/not to the learning progression? Issues of creationism and intelligent design versus misconceptions?
Instructional Practices	What kinds of instructional practices are discussed? What are the rationales for using these teaching practices? How are learning experiences sequenced? How do these teaching practices relate to those represented in the learning progression?

Results

Results of our analyses of the multiple sources of data collected around the PLC meetings indicate that the PLC became more empathetic and communicative, respecting and exchanging ideas in a way that did not happen at the beginning of the study. In addition, teachers moved away from describing student beliefs in general terms and migrated toward description of the student ideas represented in the learning progression, using the common language present in the LP to describe and label these ideas. Finally, teachers' discussion of their instructional practices moved away from simple discussion of what their favorite activites were to more targeted description of which practices were better suited to the ideas represented in the LP. In the full paper, we will describe and illustrate how these changes occurred over the course of the study, describing in detail important events in this transformation process; however, for the purposes of the proposal, we summarize our results briefly below.

Shifts in Community Dynamics
Early in the study, teachers took oppositional stances about practices in individual classrooms, without strong sense of a need for collaboration. For example, In the first PLC meeting, Lisa stated that that she was not trying to change student beliefs about evolution while Rachel stated that she didn't feel like she needed to respect non-scientific student ideas. Over time, however, the conversation in the PLC shifted almost completely away from oppositional stances and toward teachers expressing mutual respect for each other's aprpoaches to teaching the strategies common to the LP, sharing strategies and their effectiveness at addressing particular student ideas, and taking up each other's ideas. For example, Rachel moved away from her oppositional stance later in the study, responding to a video of a colleague teaching with the statement, "I just really like that last bit of questioning she did…who would be the only predator…what would happen? So she, like, took it to be predictive and extended the idea." This comment highlights the development of mutual respect within the group. In addition, the balance of contribution to the PLC shifted away from its initial status, in which Rachel and Chris, the teachers most confident in their content knowledge, dominated the discussion at the expense of other teachers who were less confident, toward a more even balance of contribution. We argue that this shift took place not only because the previously dominant teachers gained a new respect for the practices of their colleagues, but also because the previously non-dominant teachers gained confidence in content knowledge through the PLC and therefore had more to contribute.

Shifts in Language to Describe Student Ideas
Early in the study, teachers were not able to differentiate between different kinds of student ideas about natural selection. In early meetings, they spoke extensively either about students' rejection of evolution and natural selection or, when pushed to speak about common student understandings, teachers stated their impression of student ideas in general terms. This general stance is reflected in a statement by Alison, who said, "I just feel like yeah they're confused about all parts of natural selection so I'll just go from there." Later in the study, conversation about evolution all but disappeared in favor of explicit description of student ideas using the categories from the LP; for example, distinguishing between various categories of what we came to call 'need-based change' in the forms of students arguing that the environment induces changes in organisms, or that organisms mutate to fit their surroundings. In addition, teachers cited Mayr's facts and inferences when talking about the 'big ideas' students were expected to come to know. In fact, Chris and Lisa - teachers who previously had not worked collaboratively - met independently of the scheduled PLC meetings and categorized preassessments according to the categories in the LP.

Shifts in Descriptions of Instructional Practices
We found that early in the study, teachers described which activities they liked to use to teach particular concepts, but did not have common activities that would facilitate their sharing of strategies across the group. Much of early discussion in the PLC was therefore focused on the teachers coming to an understanding of exactly what they were doing in their classrooms. However, as the study progressed, teachers agreed to use a common set of formative assessments in all of their classrooms as a basis for a discussion about their relative effectiveness in eliciting student ideas along the LP. In addition, teachers' conversations about the source of common student misunderstandings served as an impetus to create new formative assessments to which each teacher contributed, and which each teacher then used in her or her own classroom. In addition to these common activities that were a part of the educative LP, teachers came to discuss more explicitly which of the student ideas represented on the LP necessitated use of different activities in the classroom. Early in the development of the PLC teachers expressed hesitation to solicit student ideas about evolution. This hesitation appeared to be driven by a fear of creating conflict in the classroom. Later, this hesitation disappeared and teachers not only were interested in soliciting student ideas but also the sources of those ideas. We suggest that the confidence to tackle student ideas grew out of the stronger content knowledge and instructional strategies developed in the PLC.

In addition to these common formative assessments, teachers also came to share the different variations of common class activities that they were using in their natural selection units. For example, several teachers used some version of the Biological Sciences Curriculum Study's (2006) activity in which students pick up colored dots from patterend cloth, discovering over multiple iteractions of the activity that the harder-to-see dots were less likely to be picked up from the cloth. During the course of the study, all teachers decided to use some form of this activity, some using physical materials and others using an online applet to model the same phenomenon. Teachers then came together later in the study and discussed the relative effectiveness of the activity, weighing trade-offs such as time spent on the activity and depth of student understanding.

Another change in the discussion of instructional practices within the PLC was a change in focus from talking about activities to specifically identifying and addressing student misconceptions, and targeting which instructional examples, analogies, and activities would best address them. In addition, teachers reflected on the fact that students reverted back to their naïve ideas when presented with novel scenarios in class. This highlights the fact that these teachers, in addition to developing more advance strategies for eliciting and identifying student ideas, are also reflecting upon the process of conceptual change in a more sophisticated manner than at the beginning of the study (Smith, diSessa, & Roschelle, 1993).

.

Educational Importance

Thte preceding data indicate that the PLC centered on the educative LP provided teachers an opportunity to reconnect and develop a common language around a single conceptual domain, enriching their own content knowledge while they simultaneously built a new community in their department. We found that repeated meetings centered on the educative LP helped to refocus teachers from defensive stances regarding the teaching of evolution to the smaller instrucitonal issue of natural selection, to enrich teachers' common language regarding student ideas, and inform their discussion and selection of instructional strategies targeted at student thinking.

The present research also illustrates the importance of involving the 'user' audience in the development of LPs and their accompanying tools.

Given the current level of interest in the development and study of LPs in science education, the present analysis is of critical importance to inform educational researchers and professional developers of the utility of these tools not only in guiding assessment and curriculum development, but also in developing the content knowledge of practicing science teachers and building community around a common content area.

References

American Association for the Advancement of Science. (2001). *Atlas of Science LIteracy*. Washington, D.C.: National Academies Press.

Anderson, D. L., Fisher, K. M., & Norman, G. J. (2002). Development and Evaluation of the Conceptual Inventory of Natural Selection. *Journal of Research in Science Teaching, 39*(10), 952-978.

Biological Sciences Curriculum Study. (2006). *BSCS Biology: An Ecological Approach* (10th ed.). Dubuque, Iowa: Kendall/Hunt.

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.

Black, P. (1998). Assessment by Teachers and the Improvement of Students' Learning. In B. J. Fraser & K. G. Tobin (Eds.), *International Handbook of Science Education* (pp. 811-822). Dordrecht, Netherlands: Kluwer Academic Publishers.

Brown, A. 1992. Design Experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. The Journal of the Learning Sciences, v.2, n.2, p.141-178.

Borko, H. (2004). Professional Development and Teacher Learning: Mapping the Terrain. *Educational Researcher, 33*(8), 3-15.

Briggs, D. C., Alonzo, A. C., Schwab, C., & Wilson, M. (2006). Diagnostic Assessment with Multiple-Choice Items. *Educational Assessment, 11*(1), 33-63.

Catley, K., Lehrer, R., & Reiser, B. (2005). *Tracing a Prospective Learning Progression for Developing Understanding of Evolution*: Paper Commissioned by the National Academies Committee on Test Design for K-12 Science Achievemento. Document Number)

Collins, A. (1998). National Science Education Standards: A political document. *Journal of Research in Science Teaching, 35*(7), 711-727.

Davis, E. A., & Krajcik, J. (2005). Designing Educative Curriculum Materials to Support Teacher Learning. *Educational Researcher, 34*(3), 4-14.

Dobzhansky, T. (1973). Nothing in biology makes sense except in the light of evolution. *The American Biology Teacher, 35*, 125-129.

Driver, R., Guesne, E., & Tiberghien, A. (1985). *Children's Ideas in Science*. Philadelphia: Open University Press.

DuFour, R. (2004). What is a "Professional Learning Community"? *Educational Leadership*, 61(8), p. 6-11.

Duncan, R. G., Rogat, A., & Yarden, A. (2009). A learning progression for deepening students' understanding of modern genetics across the 5th-12th grades. . *Journal of Research in Science Teaching, 46*(6), 655-674.

Duschl, R. A. (2003). Assessment of Inquiry. In J. M. Atkin & J. Coffey (Eds.), *Everyday Assessment in the Science Classroom* (pp. 41-59). Arlington, VA: NSTA Press.

Ferrari, M., & Chi, M. T. H. (1998). The nature of naive explanations of natural selection. *International Journal of Science Education, 20*(10), 1231-1256.

Furtak, E. M. (2009). *Toward Learning Progressions as Teacher Development Tools*. Paper presented at the Learning Progressions in Science Conference, Iowa City, IA.

Gess-Newsome, J. (1999). Secondary Science Teachers' Knowledge and Beliefs about Subject Matter and Their Impact on Instruction. In J. Gess-Newsome & N. G. Lederman (Eds.), *Pedagogical Content Knowledge and Science Education* (pp. 51-94). The Netherlands: Kluwer Academic Publishers.

Lieberman, A, and Miller, L. (2008). "Balancing content and process: Facing challenges." In Lieberman, A. and Miller, L. (eds.), *Teachers in Professional Communities*. New York: Teachers College Press, p.29-38.

Loughran, J., Mulhall, P., & Berry, A. (2004). In Search of Pedagogical Content Knowledge in Science: Developing Ways of Articulating and Documenting Professional Practice. *Journal of Research in Science Teaching, 41*(4), 370-391.

Luft, J. A., & Roehrig, G. H. (2007). Capturing Science Teachers' Epistemological Beliefs: The Development of the Teacher Beliefs Interview. *Electronic Journal of Science Education, 11*(2), 38-63.

Mayr, E. (1997). *This is Biology*. Cambridge, MA: Harvard University Press.

McLaughlin, M. & Talbert, J. (2006). Building school-based teacher learning communities: professional strategies to improve student achievement. New York: Teachers College Press.

National Research Council. (1996). *National Science Education Standards*. Washington, D.C.: National Academy Press.

National Research Council. (2001). *Classroom Assessment and the National Science Education Standards*. Washington, D.C.: National Academy Press.

National Research Council. (2007). *Taking Science to School: Learning and Teaching Science in Grades K-8.* Washington, D.C.: National Academies Press.

Rudolph, J. L., & Stewart, J. (1998). Evolution and the Nature of Science: On the historical discord and its implications for science education. *Journal of Research in Science Teaching, 35*(10), 1069-1089.

Rutledge, M. L., & Mitchell, M. A. (2002). High School Biology Teachers' Knowledge Structure, Acceptance, and Teaching of Evolution. *The American Biology Teacher, 64*(1), 21-28.

Sadler, D. R. (1989). Formative Assessment and the Design of Instructional Systems. *Instructional Science, 18*, 119-144.

Sandoval, W. & Bell, P. (2004). Design-based research methods for studying learning context: introduction. Educational Psychologist, v.39, n.4, p.199-201.

Shavelson, R. J. (2009). *Reflections on Learning Progressions*. Paper presented at the Learning Progressions in Science Conference.

Shepard, L. (2009). *From Advocacy to Adoption: Getting Formative Assessment into More Classrooms. Discussant Remarks*. Paper presented at the American Educational Research Association Annual Meeting.

Shtulman, A. (2006). Qualitative differences between naive and scientific theories of evolution. *Cognitive Psychology, 52*, 170-194.

Shulman, L. S. (1986). Those Who Understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4-14.

Sloane, F. (2009). Randomized trials in mathematics education: recalibrating the proposed high watermark. *Educational Researcher,* 37(9), p.624-630.

Smith, J. P., DiSessa, A. A., & Roschelle, J. (1993). Misconceptions Reconceived: A Constructivist Analysis of Knowledge in Transition. *The Journal of the Learning Sciences, 3*(2), 115-163.

Webb, D. C., Romberg, T. A., Burrill, J., & Ford, M. J. (2005). Teacher Collaboration: Focusing on Problems of Practice. In T. A. Romberg & T. P. Carpenter (Eds.), *Understanding Math and Science Matters* (pp. 231-251). Mahwah. NJ: Lawrence Erlbaum Associates.

Lave, J., & Wenger, E. (1991). *Situated Learning: Legitimate Peripheral Participation*. Cambridge: University of Cambridge Press.

Wilson, M. (2005). *Constructing Measures: An Item Response Modeling Approach*. Mahwah, N.J.: Erlbaum.

Wilson, M. (2009). *Learning Progressions to Guide Systems of Formative and Summative Assessment*. Paper presented at the Annual Meeting of the American Educational Research Association.

Windschitl, M. (2004). Folk theories of "inquiry:" How preservice teachers reproduce the discourse and practices of an atheoretical scientific method. *Journal of Research in Science Teaching, 41*(5), 481-512.