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# Exploring the Influence of Learning Progressions in Two Teacher Communities

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Abstract: Learning progressions, or sequences of how ideas and practices develop within domains, are increasingly a focus of science education research. Recently, researchers have called for these progressions to be used as interpretive frameworks for teachers' instructional planning and assessment practices. In this study, we explore data from two high schools collected in two studies. In the first study, we engaged with teachers to develop and refine a learning progression for natural selection alongside formative assessments. In the second study, we took this learning progression to teachers at a different school, and used it to co-develop formative assessments and plan units. We adopt a communities of practice perspective to frame two case studies of these schools, taking the learning progression as a boundary object that not only maintained its meaning across the two different communities, but also took up different meanings within each community. We found that the learning community that helped to develop the learning progression used it as an opportunity to bring previously disparate units into sync, and to develop and enact a common sequence of formative assessments within their unit. In contrast, at the second school, teachers struggled to make sense of the learning progression within the accountability context of their school, as well as other tools provided them by the school and district. These results indicate that teachers could potentially benefit from the opportunity to co-develop learning progressions with researchers that capture their ideas that are shared within the community; however, if learning progressions are not in sync with other tools provided to teachers to structure their planning, they will not be taken up in the same way. © 2014 Wiley Periodicals, Inc. J Res Sci Teach

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The science education research community has recently devoted considerable effort to develop sequences of how students come to learn concepts and practices within a domain, also called learning progressions. Corcoran, Mosher, and Rogat (2009) defined learning progressions as "hypothesized descriptions of the successively more sophisticated ways student thinking about an important domain of knowledge or practice develops as children learn about and investigate that domain over an appropriate span of time" (p. 37). They represent some kind of developmental sequence that emphasizes the connectedness of concepts, practices, or the interrelationship of both within a domain (Songer, Kelcey, & Gotwals, 2009).

Given these characteristics, learning progressions are fundamentally different from representations of learning goals that teachers normally encounter in the course of their daily work. Tools more often provided to teachers to guide their planning include standards documents

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developed at the district or state level or assessment frameworks associated with an alphabet soup of state-level assessments. Schools and school districts may also rely upon pacing guides, which are "created by school district leaders to help teachers stay on track and to ensure curricular continuity across schools in the district" (David, 2008, p. 87).

The *Taking Science to School* report by the National Research Council argued that the *National Science Education Standards* (National Research Council, 1996) did not provide an adequate basis for designing effective curriculum sequences because they took in too much content, were phrased in simple declarative statements that were not grounded in the material world and reasoning practices, and did not reflect research into the development of student understanding (National Research Council, 2007). This report proposed "A sequencing that is more deeply informed by research on children's learning such that the sequences are grounded also in what we know about the ideas children bring to the classroom that can form the foundation for developing understanding of scientific ideas" (p. 216). They also stated, "At present, most decisions about instruction and curriculum sequences in science have not been guided by a long-term understanding of learning progressions that are grounded in the findings of contemporary cognitive, developmental, education, and science studies research" (p. 215). A movement is currently underway, supported by the *Next Generation Science Standards* (NGSS) (Achieve, Inc., 2013; BOSE, 2012), to base disciplinary core ideas and practices on underlying progressions and to connect those progressions within and across grade bands.

Some researchers have argued that learning progressions might serve as tools that can help teachers understand how knowledge and practices develop within a domain in ways that standards documents and pacing guides have not. This constitutes what the National Research Council (2007) framed as "a very different approach to describing learning sequences . . . that is more centrally grounded in building an understanding of conceptual frameworks" (p. 215). Heritage (2008) argued that learning progressions might be tools to support teachers' instructional planning, enabling them to "focus on important learning goals in the domain, centering their attention on what the student will learn rather that what the student will do (i.e., the learning activity)" (p. 5).

Heritage (2008) also argued that learning progressions could serve as tools to support teachers in conducting formative assessment; in fact, she stated that these tools were foundational to eliciting information about student learning, providing feedback, and involving students in classroom assessment.

Similarly, Bennett (2011) viewed learning progressions as helpful models for teachers in making inferences about what students know as part of the formative assessment process. Learning progressions could be used to "indicate steps toward mastery on key components of the cognitive-domain model, tasks to provide evidence about student standing with respect to those learning progressions, techniques fit to that substantive area, and a process for teachers to implement that is closely linked to the preceding materials and, therefore, to the domain in question" (p. 16). Furtak (2009) also argued that learning progressions could scaffold teachers' design and enactment of formative assessment tools.

However, little empirical research has been performed that explores the ways in which learning progressions might support instructional practices as these researchers suggest. While Furtak (2012) studied the ways that a learning progression helped teachers to notice and attend to student ideas about natural selection during conversations intended to elicit student thinking, little is still known about how learning progressions might support teachers in their instructional planning and assessment design. Indeed, Pellegrino (2012) recently argued that "there is much left to do in mapping out learning progressions for multiple areas of the science curriculum, most especially in ways that can effectively guide the design of instruction and assessment" (p. 835).

Furthermore, the ways that teachers balance the new information contained in learning progressions with other tools intended to support their planning has yet to be studied.

For a model of this type of analysis, we turn to Cobb, McClain, De Silva Lamberg, and Dean (2003), who explored how mathematics teachers were enlisted to assist in revising a district pacing guide, and how this process helped them to contribute to improvement of teaching in the district and broaden their purview beyond their individual classrooms. Cobb and colleagues argued that it is critical to explore tools and artifacts used by teachers in order to understand how they function within communities, and how those tools organize the activity of members of that community. They stated, "the use of tools and artifacts is a relatively inconspicuous, recurrent, and taken-for-granted aspect of school life that is underdeveloped in the research literature both on teacher professional development and on policy and educational leadership" (p. 14).

In this paper, we follow Cobb et al.'s framing as we explore how learning progressions served as tools to support the instructional planning and formative assessment of teachers in the work of two teacher learning communities in two separate studies.

## Theoretical Framing

In this analysis, we adopt a situated view of learning (Lave & Wenger, 1991) to explore how teachers from two different schools created and engaged with a learning progression intended to support their curriculum planning and everyday assessment practices. The situated perspective "focuses on properties of activity systems, specifically on principles of coordination between the various components of such systems—the participants, the technological tools in the environment, and the informational structures and practices of the participants in the subject-matter domain of their activities" (Greeno, 2006, p. 87). From this perspective, we characterize learning as changing participation in communities of practice and as inseparable from the contexts in which it occurs (Rogoff, 1995).

### *Communities of Practice*

According to Cobb et al. (2003), teaching is a distributed activity, and as such teachers' instructional practices are situated "within the institutional settings of the schools and school districts in which they work" (p. 13). Based on this view of teaching, Cobb et al. (2003) drew upon Lave and Wenger's (1991) communities of practice perspective as an analytic framing. Wenger (1998) identified three characteristics of the practices shared by members of a community: mutual engagement, joint enterprise, and a shared repertoire. Practices in themselves are not abstract, but exist in interactions individuals have with each other. Learning, then, includes "evolving forms of mutual engagement . . . understanding and tuning their enterprise . . . [and] developing their repertoire, styles, and discourses" (p. 95). This mutual engagement is carried out in service of a joint enterprise, or a shared goal or purpose to which the members of the community are mutually accountable. Finally, these practices involve a shared repertoire of "routines, words, tools, ways of doing things, stories, gestures, symbols, genres, actions, or concepts that the community has produced or adopted in the course of its existence, and which have become part of its practice." (p. 83).

As individuals negotiate meaning within their communities, their participation is coordinated and mediated through their shared repertoire. Members of communities come to create tools within their repertoires that capture and represent the knowledge and practices of those communities. Wenger (1998) termed this the process of reification, or "the process of giving form to our experience by producing objects that congeal this experience into "thingness." In so doing we create points of focus around which the negotiation of meaning becomes organized" (p. 58). As multiple communities interact, boundary objects, or objects that are incorporated into the

practices of two or more communities and maintain their meaning and coherence across those communities (Star, 2010; Star & Griesemer, 1989), are other important sites for participation and negotiation of meaning (Wenger, 1998).

### *Tools and Boundary Objects*

Tools intended to support instruction surround teachers, including district, state, and national standards, pacing guides, curriculum materials, nearly limitless lesson plans and activities available on the internet, and other resources located at the school. It becomes a great challenge for teachers working together or independently to make sense of these tools, evaluate them, and draw upon them in the course of their daily planning and assessment design.

The role that tools such as these play within communities and the way that those tools travel from place to place while maintaining their shape and meaning is a key piece of the communities of practice perspective. Huberman (1993) described teaching as a tool-centered profession and interactions among teachers in traditional collaborations as consisting primarily of exchanging activities and lessons in order for teachers to expand their instructional repertoires. Similarly, Cobb et al. (2003) described the "tool-mediated nature of both teaching and instructional leadership" (p. 22) and noted that organizing for teaching and learning is a central function of teaching, whereby teachers identify instructional goals and select and adapt instructional activities, assessments, and other resources with their colleagues.

Given the tool-mediated nature of teaching, it follows that studying how different tools are created, appropriated, and used within different communities would be an important focus of study. Indeed, Kazemi and Hubbard (2008) argued that analyses of professional development should focus on boundary objects, or artifacts that move between professional development meetings and teachers' classrooms. Following Star and Griesemer's (1989) framing, boundary objects "inhabit several intersecting social worlds . . . and satisfy the informational requirements of each of them" (p. 393). These artifacts are flexible enough to adapt to individual needs, and at the same time robust enough to keep a common meaning across sites. Star (2010) clarified that "boundary objects are at once temporal, based in action, subject to reflection and local tailoring, and distributed through all these dimensions" (p. 603). Boundary objects provide opportunities for learning through coordination when diverse practices cooperate even in the absence of consensus (Akkerman & Bakker, 2011; Star, 2010).

### *Learning Progressions: What Are They, and Who Are They For?*

Learning progressions are defined as "descriptions of the successively more sophisticated ways of thinking about a topic that can follow one another as children learn about and investigate a topic over a broad span of time" (NRC, 2007, p. 205). They are representations of hypotheses about the pathways that students are likely to follow as they learn about disciplinary core ideas and practices (Corcoran et al., 2009) and are anchored on one side by "what is known about the concepts and reasoning of students entering school" (NRC, 2007, p. 219) and at the other end by "societal expectations (values) about what society wants . . . students to understand about science" (p. 220). In the middle, learning progressions suggest intermediate understandings that are "reasonably coherent networks of ideas and practices and that contribute to building a more mature understanding. It is important to note that some of the important precursor ideas may not look like the later ideas, yet they crucially contribute to their construction" (p. 220). An important quality of learning progressions, therefore, is the way that they are not only logical analyses of ideas in a domain, but also represent how student ideas develop along the way to more sophisticated thinking.

Among the first published learning progressions are Catley, Lehrer, and Reiser's (2005) progression for evolution, and Smith, Wiser, Charles, and Krajcik's (2006) progression for matter and the atomic-molecular theory. Since then, a relative explosion of publications on learning progressions has occurred in top journals in science education (Duschl, Maeng, & Sezen, 2011). However, despite the profusion of learning progressions in the research literature, there is still not clear agreement within the community as to what constitutes a learning progression (e.g., Shavelson, 2009), or for whom learning progressions are intended. The preceding division suggests that learning progressions be used as *underlying frameworks* for curriculum materials to promote coherence and spiraling across the curriculum, or for assessments to improve their diagnostic function. However, a smaller subset of researchers is beginning to argue that learning progressions might also be provided to teachers to serve as models for how understanding develops in a domain (Bennett, 2011; Furtak, 2012; Heritage, 2008), and therefore may be ideally suited to support teachers in designing and enacting formative assessment in their classrooms. Since the ideas students share are often convoluted, rife with scientific misunderstandings and everyday ideas, and difficult to understand, teachers may benefit from a scaffold in the form of a learning progression to help them anticipate and interpret the ideas students share. In this sense, a learning progression is a kind of map that represents the complex terrain of student thinking within a domain.

### *Learning Progressions and Formative Assessment*

The process of attending and responding to student ideas in the course of instruction has been called formative assessment (Black & Wiliam, 1998). When teachers engage in formative assessment they set instructional goals for their students, measure their students' progress toward those goals, and take steps to support students in moving forward (Black & Wiliam, 2009). While prior definitions of formative assessment have delineated a series of steps in which a teacher elicits and responds to student thinking (e.g., NRC, 2001), we add participants to Bennett's (2011) framing of formative assessment as consisting of a network of practices and tools. As a *practice*, formative assessment consists of the actions in which students and teachers engage when ideas are made explicit, such as a teacher sharing criteria for quality work (Coffey, 2003; Sadler, 1989) or whereby a teacher notices student thinking, asks questions, responds to student ideas, and provides feedback to advance student learning. When viewed as *tools*, formative assessments are the objects that create opportunities for students to share their thinking with their teacher and peers. Finally, the *participants* in formative assessment are teachers and students, and formative assessment is most accurately conceived as requiring active participation of both.

Formative assessment has often been described as a domain-general practice; however, various authors have argued for the need for content-specific formative assessment practices (Bennett, 2011; Coffey, Hammer, Levin, & Grant, 2011). These authors have argued that teachers need content-specific understanding of both common student ideas within a domain, as well as ways that students develop understanding within that domain. Given that learning progressions are models for how students may develop understanding within particular content domains, they provide a model for teachers to understand their students' learning trajectories, as well as predict areas in which students commonly have problems and plan formative assessment to attend to those different ideas.

A number of studies have documented teachers' struggles in enacting formative assessment practices, and have identified the challenges teachers face in determining appropriate feedback moves (e.g., Furtak, 2012; Furtak et al., 2008; Heritage, Kim, Vendlinski, & Herman, 2009). In these studies, teachers are often provided with formative assessments and researchers explore the ways in which those assessments are enacted. A smaller subset of studies has explored the

process of teachers developing their own assessments as guides for their instruction, an approach that acknowledges the unique role teachers occupy in capturing and depicting what their students know and are able to do (Gardner, 2010). For instance, Atkin, Coffey, Moorthy, Sato, and Thibeault's (2005) CAPITAL project explored how researchers could support science teachers over long periods of time in developing formative assessments for a variety of instructional units. Results of this study indicated nonlinear changes in teachers' practices, influenced by their beliefs and values. Participation in the project enabled teachers to better listen to students, and to broaden their views of assessment (Coffey, Sato, & Thibeault, 2005), In addition, researchers at King's College London have established a variety of approaches to supporting teacher assessment (e.g., Black et al., 2004), and have identified improvements in teachers' practices and their views of student learning (Harrison, 2005). Other studies have similarly identified variability in the quality of teacher-designed assessment tasks and feedback (e.g., Beason, 1993; Clare et al., 2002), and benefits for teachers' understanding and enactment of formative assessment as well as student learning (Brookhart, Moss, & Long, 2010).

### *Learning Progressions as Tools for Teacher Learning Communities*

In our work we have used learning progressions as tools for teachers to plan formative assessments, to evaluate and categorize student ideas, and to provide feedback to students. We acknowledge that coming to understand how to use learning progressions, like other ambitious changes to teaching practice, takes time and ongoing support from colleagues. Prior studies have explored how sustained engagement in professional development can help teachers to increasingly attend to student thinking (e.g., Borko, Jacobs, Eiteljorg, & Pittman, 2008; Furtak, 2012). Given this framing, one might imagine that learning progressions could be used to structure learning and teaching in a variety of ways. For example, teachers could partner with researchers to develop learning progressions as embodiments of their own knowledge of the content and student thinking about it. Conversely, learning progressions might be provided to teachers in a format to inform teachers' instructional planning and everyday assessment practices.

We have employed learning progressions in both of these ways as the central tools around which we have built teacher learning communities. McLaughlin and Talbert's (2006) model of a teacher learning community builds on the situated perspective of learning (Rogoff, 1995) to describe contexts in which teachers work collaboratively to reflect on their own practice, examine evidence of student outcomes, and make proactive changes to improve the quality of teaching and learning at their school. This model posits that teachers' work will be best improved by working in single content areas (Loughran, Mulhall, & Berry, 2004). Doing so allows teachers to discover and remedy weaknesses in their content knowledge and share stories of enactment to gather 'existence proofs' of how new practices can work at their own school site (Wiliam & Thompson, 2007).

## Research Question

In the course of our research, we have conducted two distinct studies in which we have used a learning progression for natural selection to structure teachers' curriculum planning and formative assessment practices. In the first study, the Daphne Project, teachers iteratively developed and enacted formative assessments at the same time that they refined and developed a learning progression that captured the community's teaching and ideas about natural selection. In the second study, the Elevate Project, we took a revised version of the learning progression from the Daphne Project to teachers at a second school and used it to guide their instructional planning and formative assessment design and enactment.

In this paper, we view the learning progression as a boundary object that was created in one community of teachers and then revised and taken by the researchers into a different community of

teachers to support their everyday assessment practices. We will explore differences in how teachers described and used the learning progression, how this boundary object took on different meaning in the different communities, and the ways in which teachers were challenged in making sense of the learning progression as one of many tools they were dealing with in the course of their planning. Our intention is to use this framing to better understand the promise and potential challenges of learning progressions when used directly as tools to inform instructional planning and student assessment.

We explore the ways in which two different communities of teachers - each with different participants and located in different contexts - used the learning progression to develop and enact formative assessment and surrounding instructional units. Specifically, we respond to the following research question: *How did the learning progression act as a boundary object to coordinate the work of the two communities in making instructional plans, developing formative assessments, and interpreting student ideas?*

## Method

To respond to our research question, we employed a multiple case study approach (Merriam, 1998). We rely upon theoretical replication logic (Yin, 2003) by treating the two studies as independent cases with similar theoretical foundations and structures, but acknowledge that the cases will necessarily differ due to the different contexts of the participants and schools, as well as the role the learning progression played in the course of the work. To respond to the research question posed in this paper, we analyzed three sources of data: videotaped professional development meetings, interviews with teachers participating in the studies, and artifacts such as district pacing guides and learning progressions used by those teachers. We used these multiple sources of data to triangulate claims about the role the learning progression played within each community. In the following section, we will describe the two contexts of the studies, the sources of data we drew upon from each, and our analytic approach.

### *Participants*

The cases presented in this paper are drawn from two multiple-year research studies conducted over non-overlapping time periods. The first study, called the Daphne Project, was conducted from 2008 to 2010 at a single high school. The second study, called the Educative Learning Progressions as Tools for Teacher Development (Elevate) Project, took place at three high schools starting in 2010. Each project was conducted at a different school in the same large district located near a large city in the Western US: Springfield High School from the Daphne Project, and Monroe High School from the Elevate Project (all school and teacher names are pseudonyms). We will briefly describe each school before introducing the participating teachers and providing information about the district pacing guides in use at each school. Table 1 provides an overview of the demographics at each school.

*Springfield High School.* Springfield High School is located in the suburban center of the Harris County School District, and with about 2,000 students is one of the larger high schools in the district. The school has magnet programs that attract a large number of open-enrollment students from outside the school bounds and, as a result, students in the magnet programs are more likely to be open-enrolled from other schools in the district. Table 1 illustrates Springfield's high test scores and graduation rates, and shows that Springfield students are similar to the district proportions of free and reduced lunch and Hispanic students.

To cover the large number of biology courses taught in the normal and magnet tracks of the school, there were seven full-time science teachers who taught at least one section of a general

Table 1
*School and district demographics*

| Demographic | Springfield (2009–2010) (%) | Monroe (2010–2011) (%) | District (2010–2011) (%) |
|---|---|---|---|
| Racial composition | | | |
| Black | 2 | 4 | 1 |
| Hispanic | 21 | 80 | 24 |
| Asian | 6 | >1 | 3 |
| White | 68 | 13 | 68 |
| Free and reduced lunch | 28 | 87 | 33 |
| English language learner rate | 10 | 46 | 10 |
| Graduation rate | 88 | 62 | 79 |
| State test scores | | | |
| 10th grade reading (proficient or above) | 78 | 37 | 74 |
| 10th grade math (proficient or above) | 56 | 3 | 57 |
| 10th grade science (proficient or above) | 66 | 10 | 59 |

*Note*: Data obtained from school district for the years in which each study took place.

biology course to students in the 9th or 10th grade. During the first year of the study there were six full-time teachers and one student teacher in the study, and during the second year another teacher from the department—who had chosen not to participate the first year—joined the study, and a second, different student teacher participated in the spring term. These teachers participated in monthly professional development facilitated by two university researchers, one of whom is the first author of this paper. Table 2 summarizes characteristics of the participating teachers.

During the 2 years of the Daphne Study, the district provided teachers with a "Year at a Glance," a one-page-sheet that illustrated the sequence of units for the year of 10th grade biology, and how many weeks were to be spent on each. Units were roughly spaced on a calendar and generally aligned with major conceptual areas in biology, such as cell processes, cell reproduction, classification, and body systems. The pacing guide was accompanied what the district called the

Table 2
*Summary of teacher characteristics*

| Participant | Highest Degree Earned | Undergraduate Major | Years of Teaching at Time of Study |
|---|---|---|---|
| Springfield high school | | | |
| Robyn | MA/MS | Environmental biology | 8 |
| Chris | BS | Biology | 3 |
| Lisa | MA/MS | Biology | 8 |
| Theresa | MA/MS | Chemistry & zoology | 10 |
| Rachel | MA/MS | Biology | 11 |
| Alison | MA/MS | Biology | 13 |
| Megan | BS | Nutrition | 0 |
| Pat | BS | Biology | 29 |
| Nina | BA | Biology | 0 |
| Monroe HS | | | |
| Kim | MA | Biology | 9 |
| Donna | MA | Molecular biology | 10 |
| Mark | BA | Physical science education | 20 |

CAP-A document, a page-long explanation of goals, essential questions, and objectives for what students were expected to know and be able to do. Based on the CAP-A, teachers were expected to teach evolution for 4 weeks, starting at the beginning of the spring semester in January and carrying into the beginning of February.

*Monroe High School.* Atypical cases can fill in gaps about what is known about a phenomenon (Merriam, 1998); thus, we selected Monroe High School from the three Elevate schools as it presented the largest contrast with Springfield. Monroe is the smallest high school in the district and is closer to the large city that the school district borders. As Table 1 illustrates, Monroe has a greater population of students of color, English language learners, and students on free and reduced lunch as compared to Springfield High and the rest of the school district. Its test scores are also well below district averages.

Given Monroe's small size, there were only three teachers who taught biology to students in the 10th grade during the years of the study (see Table 2). At the behest of the school principal, and reflecting the school's emphasis on cross-departmental learning communities, the other two science teachers who covered chemistry, physics and environmental science classes, as well as an Assistant Principal, also attended the monthly professional development meetings. The monthly professional development was facilitated by the two university researchers who are the authors of this paper.

During the second year of the Elevate project, the district implemented a new version of the CAP document curriculum and pacing guide (CAP-B). The CAP-B re-sequenced the units over the course of the school year and reduced the amount of content required for teachers to cover. For example, CAP-A had nine units across the academic year and CAP-B reduced that to six units. CAP-A required teachers to teach evolution as the fourth unit of the year after the unit on genetics and before the ecology unit, whereas CAP-B moved evolution to the last unit of year following a unit on homeostasis. Furthermore, the CAP-A roughly corresponded with canonical units from biology (e.g., cell reproduction, genetics, classification, human body systems), whereas the CAP-B reorganized and renamed units (e.g., impact of humans on the environment, disruption to homeostasis).

### *Professional Development Approach*

The two studies shared a common professional development model and approach. In each study, university researchers met on-site with the department of biology teachers monthly to discuss the learning progression, the ideas it represented, and to use information from the learning progression to inform formative assessment design and enactment. Teachers' participation in the professional development meetings was guided by an iterative, five-step professional development cycle (Figure 1). The purpose of the cycle was to situate teachers' work in their own classrooms and to draw upon their own knowledge and experiences to develop, enact, and revise a set of common formative assessments (Furtak, 2009). Both studies started at the beginning of the school year with teachers *Exploring Student Ideas* as well their own understandings of the domain at hand by reviewing student response patterns to a diagnostic assessment administered at the beginning of the year, and by looking at samples of student work from other schools. In the second step, teachers *Developed Tools* designed to elicit more information about these student ideas during instruction. In the third step, teachers *Practiced Using the Tools* by rehearsing using the formative assessments together, categorizing samples of student work, and anticipating student responses and the feedback they might provide those students. The fourth step had the teachers *Enact the Tools* during their instructional units and collect student work. Finally, at the end of the

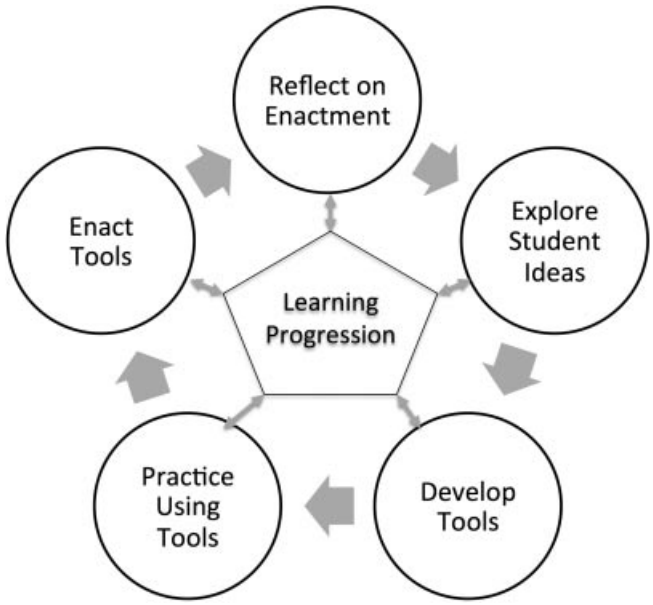


*Figure 1.* Professional development model.

school year, teachers *Reflected on Enactment* by exploring examples of student work and looking for patterns in student responses.

At the center of the professional development at each school was the learning progression, although its role in the intent of the professional development was different at each school. At Springfield, teachers were asked to draw upon their experiences in going through the cycle to inform construction of the learning progression; for example, by reflecting on their current instruction to identify organizing themes for the learning progression by creating a visual representation of the big ideas about natural selection and activities they used to teach it (Loughran et al., 2004). In this case, researchers brought their own representation of natural selection in the form of an initial, draft learning progression, as well as summaries of research into common student naïve ideas about natural selection. At the same time, the researchers encouraged teachers to reflect on their own understandings of natural selection at the outset of the study, and ended each year by determining if the learning progression captured the variation in student thinking they observed during instruction.

In contrast, at Monroe, researchers brought a completed learning progression to teachers and carefully presented the different ideas it contained, providing descriptions of the different categories of ideas and examples of student responses at the different levels. Teachers were also asked to compare these categories to their current understanding of natural selection and the way that they taught it. Then teachers were asked to use the learning progression as a tool to help identify areas in which formative assessments might be developed, to anticipate how students might respond to the assessments they developed, and to interpret student ideas shared in response to the formative assessments.

### *Sources of Data*

We draw upon parallel sources of data from each study. At Springfield, we met with teachers monthly for two academic years and use data from both of those years, beginning with the first

meeting in August 2008 and running through enactment of the natural selection unit in March of 2010. At Monroe, we draw upon data from the first two years of the Elevate project, a baseline year in which we conducted interviews with teachers (2010–2011) and a year in which we conducted monthly professional development meetings in which we introduced the learning progression to teachers and they used it to develop and enact formative assessments (2011–2012). We videotaped professional development meetings at both schools, collected artifacts and field notes around these meetings, and conducted interviews with teachers at the conclusion of the natural selection unit. The interview protocols from each study are included in Supporting Information Table 1 accompanying the online article. Table 3 summarizes the sources of data from each project.

To process the video data we collected across the two years at each participating school, we created content logs of each of the professional development meetings by writing descriptive accounts of the speakers, events, and artifacts used in one-minute intervals. Portions of the content logs of interest (e.g., places in which the learning progression was explicitly described, development of the formative assessments, descriptions of enactment, or expressions of the role of the learning progression during instruction) were then transcribed. Transcripts included speaker, descriptions of affect, and gestures referring to artifacts.

*Analytic Approach*

We uploaded content logs of professional development meetings and transcripts of interviews and artifacts into the Dedoose data analysis program for analysis. We then developed sets of *a priori* codes to apply to these sources of data (Miles & Huberman, 1994). The codes applied to the professional development videos and interviews are included in Supporting Information Tables 2 & 3 accompanying the online article. For the professional development meetings, these codes included when and how the learning progressions and CAP documents were brought up and used by the teachers to sequence instruction, design formative assessments, and interpret student thinking. For the interviews, we wanted to explore ways in which teachers reflected upon their experiences in the professional development meetings, and as such created codes to track statements referring to elements of their community, including the work in which they were mutually engaged and the tools that they used (e.g., the learning progression and the CAP documents). We applied these codes to the data iteratively, moving back and forth among the different sources of data within each school site, and then wrote numerous research memos focusing on how the learning progression organized the work of each community. When relevant,

Table 3
*Sources of data, by school*

| Data Source | Daphne Project Springfield HS | Elevate Project Monroe HS |
|---|---|---|
| Professional development videos | Monthly for timeframe during 2008–2009 and 2009–2010 academic years; both raw videotapes and 1-min logs | Monthly meetings from the 2011–2012 academic year; raw video and transcribed sections of video |
| Interviews | End-of-year semistructured interviews conducted with participant teachers in 2009 and 2010 | End-of-year semistructured interviews conducted with participants both prior to the intervention (2010) and after the first year of the intervention (2011) |
| Artifacts | District pacing guide version A (CAP-A), formative assessment copies, learning progression, fieldnotes from professional development meetings | District pacing guide version B (CAP-B), learning progression |

we created transcripts of certain excerpts of professional development meetings and then coded these transcripts to provide additional depth to our analysis.

Throughout this process, we triangulated each of our propositions with multiple sources of evidence (Yin, 2003). We wrote multiple research memos documenting these propositions and linking them to relevant coded evidence from the sources of data. We also created coding reports within Dedoose to facilitate looking across the data corpus at each site to identify patterns that emerged across the course of the study (Miles & Huberman, 1994). We then created and shared multiple interim case summaries for more critical and reflexive feedback, returning to the data to search for additional confirming and disconfirming evidence.

To ensure validity and reliability in this approach, we made explicit our theoretical assumptions, triangulated our claims from multiple sources of evidence, based our findings upon observation over many years at the partner school sites, and checked our claims with each other (Merriam, 1998). By operationalizing our steps in analysis and documenting our propositions at every step with research memos, we created a chain of multiple sources of evidence (Yin, 2003). Once we wrote up case reports, we invited a member of our research team who had worked on both studies but who had not been involved in the present analysis to read and provide feedback on our case reports. This researcher carefully evaluated our claims in light of the evidence we provided, as well as her own experiences at the school sites, and raised critical questions to which we then responded and, in some cases, returned to our data for further analyses to strengthen our case reports.

## Results

In this section, we will detail the two case studies, describe each version of the learning progression, and then will contrast the cases with each other. In each case study, we will tell the story of the learning progression as a boundary object and how it coordinated the work of each community. In the Springfield case, we will illustrate the ways in which the teacher and researcher members developed the learning progression in the community, and its role in organizing the ways that teachers made instructional plans, developed formative assessments, and identified and interpreted student ideas. We will then describe work that the research team performed to further develop the learning progression after it came out of the Springfield community. Then, in the Monroe case, we will illustrate how the learning progression, as a boundary object, informed the ways in which teachers made instructional plans, designed formative assessments, and interpreted the ideas students shared. Finally, in a section of cross-case analyses, we will reflect back upon the different ways in which the learning progression coordinated the work of each community.

### *Case 1: Springfield High School*

Prior to joining the research project, the teachers at Springfield High School did not plan their units together, nor did they have common planning time during the day. Each time they approached their principal to ask for planning time, the teachers would be told that, given the size of the high school and the number of teachers responsible for introductory biology courses, it was simply not logistically possible to have a period of the school day in which there were no biology courses being taught while teachers were planning together.

Consequently, at the beginning of the Daphne Project, teachers at Springfield did not teach their instructional units in the same sequence or with the same activities. This state of affairs existed despite the fact that the district's CAP-A document had been provided to them to help them align their instructional units with each other and with the goals of the district. Robyn reflected that teachers at Springfield had leeway to do as they wished without much oversight from the district:

> I think you can get away with a lot here, like not having to conform to the district's requirements or whatever just for the fact that our school does so well, and it's always nationally recognized, and all that kind of stuff, so a lot of the planning and whatnot we're supposed to be doing based on what the district is telling us doesn't actually go on.
> [Springfield High School, post-interview, April 2010]

Perhaps as a result of the lack of district enforcement, there was a great deal of variation at the beginning of the study in terms of what teachers included in their evolution units, and how long those units lasted.

To initiate a conversation about what teachers currently did in their instructional units, the research team began the study by creating, under the guidance of Erin, a university researcher who acted as facilitator, a conceptual representation (Loughran et al., 2008) that represented their own understanding of natural selection, and activities they used to teach it. Among the ideas that teachers identified about natural selection were that species change over time, and only those genetic changes that can be passed on from parents to offspring play a role in natural selection. Within each of these categories, teachers talked about the activities they used to teach these ideas, as well as the difficulties students had when learning them. Teachers noted that one of the biggest challenges facing their instruction was that students often thought that animals change because they want or need to, or that there were reasons for these changes. During this process, Rachel brought up Mayr's (1982) facts and inferences, a common framing for the different elements of natural selection. Rachel said that she structured her unit by teaching each individual facts and inference to build up to a complete explanation of natural selection.

*Informing Initial Versions of the Learning Progression.* At the next meeting, the researchers shared a rudimentary learning progression with teachers focused upon the big idea of natural selection as articulated in the *National Science Education Standards* (NRC, 1996). This draft or hypothesized learning progression had been developed by the research team on the basis of prior research into student ideas about natural selection (Bishop & Anderson, 1990; Dagher & Boujaoude, 2005; Ferrari & Chi, 1998; Geraedts & Boersma, 2006; Shtulman, 2006) as well as the only published learning progression about natural selection available at the time (Catley et al., 2005). In addition, researchers drew upon analyses of student responses to formative assessments and a pre-posttest collected as part of a pilot study (see Furtak, Morrison, Iverson, Ross, & Heredia, 2011). Analyses of student responses in the pilot study yielded a categorization of more and less sophisticated ideas about natural selection linked to categories identified in the literature cited above (Figure 2). This "map of student ideas," as it was called in the study, included four levels: unclear or undifferentiated ideas as its lower anchor, then the classic "misconceptions" about natural selection, a blending of these "misconceptions" with terms used to describe natural selection, and the classic "correct" understanding of natural selection as its upper anchor (Furtak, 2009). In addition to this list of four categories of student ideas, the map included example student responses collected during the pilot study, and feedback ideas brainstormed by the research team.

At the same time, and in response to Rachel's suggestion, the researchers also brought a listing of Mayr's facts and inferences as another way of representing the ways that the concept of natural selection could be disaggregated into separate learning goals. In this way, the two graphical representations that ultimately became the Daphne Learning Progression were introduced early in the study, one representation introduced by researchers, and the other suggested by the teachers (Figure 3).

As the work at Springfield continued through the study, researchers often encouraged teachers to repeatedly reflect back upon these two representations—the map of student ideas about natural

| Category | Description | Example Student Responses | Suggested Feedback |
|---|---|---|---|
| Natural Selection | Changes in populations and species occur gradually over time, due to the fact that all organisms produce more offspring than are able to survive. These offspring vary among themselves, and some of the variation can be passed on to the next generation. Thus, those offspring that are able to survive will happen to be those best suited their environments. Over many generations, accumulated changes will lead to changes in isolated populations and, in some cases, the generation of new species. | Natural selection occurs when the environment of the organism changes for whatever reason. The first graph shows that the length of the beaks of the birds were relatively spread out from 8-11.5 mm. However, the second graph shows a sharp increase in beaks that were about 10.1-10.7 mm long. Given the information about the drought, these graphs show that the birds with slightly larger beaks had a little bit more of an advantage over the other birds during the drought. This shows natural selection because it shows that those that had the ability to cope with the changing environment were more likely to successfully reproduce. | |
| Blended (Natural Selection and Need-based change) | Students base explanations on features of natural selection as well as need-based change; often include descriptions of the principles of 'survival of the fittest' and/or 'non-inheritance of acquired traits' in an otherwise non-selection description | The moth's predator would have killed the *Typica* and in order to survive the genes changed making it harder for the birds to see them.<br>The moth needs to survive and to do that it blends in with the bark. If the bark gets darker the moth needs to go through some genetic mutations to match the bark. You can't have a white moth on dark bark, it wouldn't survive. | Tell students that scientists have found that environments do not cause individuals to change, so then how does the variation come about? |
| Need-based change | *Anthropomorphic:* Changes arise from deliberate acts by the parent organism or the species as a whole<br>*Environment:* Changes emerge because of environmental conditions; i.e., the environment causes changes in organisms to occur | The moths become darker because of bark<br>The moths would change their color to a darker color to blend in with the dark bark.<br>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.<br>Animals mutate to fit in with their natural surroundings. So becoming darker helps to keep them in camouflage. | Ask students, 'How do changes in the environment cause changes in individuals?'<br>Ask students, 'How do mutations in an individual get passed on to their offspring?' |
| Unclear/ Other | Ideas that are confusing, ambiguous, or do not fall into other categories | When the world is evolving and changing populations can't stay the same because they won't be able to survive. So this is why species evolve as an environment changes species need to adapt to it.<br>Populations change over time because there has to be a balance between species. If there is no balance some species will over populate, which can cause problems to the whole world. If populations stay at a balance then everything is equal and everything will function right.<br>The cause of natural selection was an increase in population. Natural selection helps a species to adapt to obstacles and survive. | Get at what students think is the underlying mechanism for change by asking what students mean by 'adapt,' etc.<br>Ask students where changes in populations come from |

*Figure 2.* Map of student ideas about natural selection (originally presented in Furtak et al., 2012).

selection, and Mayr's facts and inferences—not only to design formative assessments, but to interpret the ideas students shared.

*Developing Formative Assessments.* The teachers then engaged in the process of developing formative assessments for their natural selection unit using these two representations as resources.

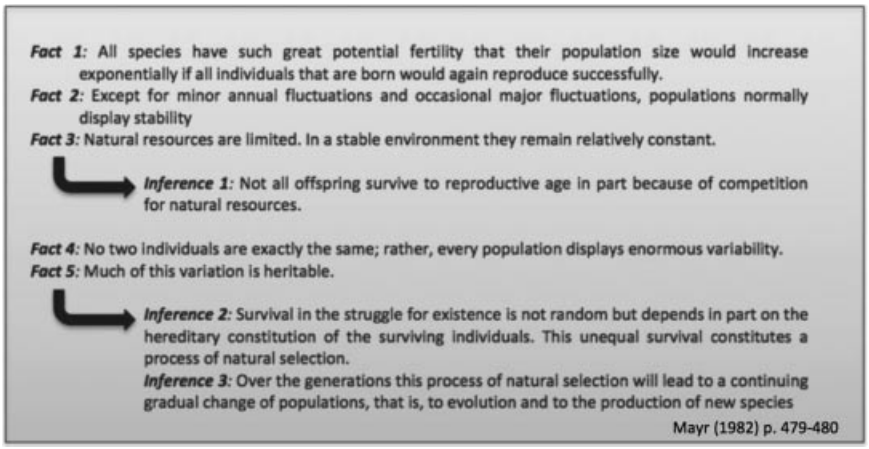


*Figure 3.* Mayr's five facts and three inferences about natural selection (Mayr, 1982, pp. 479–480).

In the November 2008 meeting, following Rachel's suggestion that the facts and inferences be used as a framework to sequence activities in the unit, Erin asked the group to think of activities they currently used that might teach the different facts and inferences. At this meeting, teachers had three resources in front of them: the current district standards, the map of ideas, and the facts and inferences. Erin mentioned that teachers had a number of activities and examples they used to teach the ideas in facts 1–3 and inference 2, but then observed, "It seems like you have a lot of, this is the simpler part of the facts and inferences, I mean it's not, getting into facts 4 and 5 it's more complicated." Erin noted that the facts and inferences did not get at where new variations come from, and stated

> Erin: I am interested to hear what kind of activities you might use to teach this idea of, or to get around this whole idea of this category of this needs based change, it's coming up again and again and it seems in hearing you all talk, it seems like you have more activities for population dynamics and looking at the variation and it seems like we don't collectively have so much for the, where the mutations come from -
> Lisa: - It needs to be something that gets the point across that all the mutations, the changes are already there when whatever conditions hits that then becomes an advantage and I don't have anything like that.
> [Springfield High School, professional development meeting, November 2008]

In this exchange, the facilitator used the phrase "needs-based change," which she pulled directly from the map of student ideas, to challenge the teachers to also consider how this idea is taught along with the facts and inferences. Teachers then discussed videos they currently showed students to teach these ideas, expressing concern that the videos might not actually address these needs-based change ideas, but might actually "feed into these ideas."

> Rachel: It just has like really fast animals, or deep sea or you know like organisms extreme organisms and how do they get here or why are they like that but now that I think of the video it definitely doesn't address, in fact it feeds into these ideas.
> Erin: Why do you say that?

> Rachel: Because it says things like, yeah we had a, you know the pronghorn antelope. Why are they so fast? Well there used to be a North American cheetah that they had to run away from. You know so it's that type of thing that doesn't help.
> Robyn: Prey has to be faster because the predator is faster then the predator has to be faster because the prey is faster.
> [Springfield High School, professional development meeting, November 2008]

Teachers then reflected upon how they had a number of activities that teach the ideas of evolution, and noted that even when they were able to get students to the point where they could "regurgitate" ideas about natural selection, they were not sure that they completely understood. Chris mentioned that in his class, he taught students the same saying over and over:

> Chris: . . ."mutations cause things to be different, some live some die. The ones that live have babies and the babies tend to look like their parents." There's like four kids that this is the exact same thing I wrote ten minutes ago yesterday and the day before that was every single day over and over. . .By the end they could all regurgitate it pretty well, but -
> [Several teachers together]: - Do they understand it?
> [Springfield High School, professional development meeting, November 2008]

After a conversation about different scenarios that demonstrate populations changing in response to the environment, Erin suggested that these examples might be developed into a formative assessment that would engage students with different scenarios and ask them to explain whether the scenario illustrated change of an individual within its lifetime, or what the teachers came to call "evolutionary" change, or a change within a population over time.

This example illustrates how the two representations of the facts and inferences and the map of ideas acted as a framework for discussing teachers' current activities, to challenge them to consider how ideas on the map were considered, and led to the idea for a new formative assessment with the facilitator's support.

In the January 2009 meeting, which was held immediately prior to enactment of the unit, the conversation came directly back to the two representations and how to use them in guiding instruction. Rachel wondered aloud how the list of student ideas might be directly adapted into a formative assessment, stating

> Wouldn't it be kind of fun to, to just print out almost as a like this would be their test, print out the example student responses and say, you know, what is wrong with this response, what is wrong with this response?. . . Well I mean, the one with the [peppered] moth, I mean, there's two different things with the moths, right? So they could just look at the moth question again, at the end, and you know, you could say something like, well, here are some sample answers and fix it or change it so that it reflects. . . because sometimes I think even if, I think it will be interesting for them to see, oh well, I would have said that. And oh, I didn't know that was wrong.
> [Springfield High School, professional development meeting, January 2009]

The other teachers responded positively to Rachel's idea, with Chris noting, "That would be good for discussion" and Lisa responding, "That would be good, and you would address directly what they should not be thinking." These comments reflect different underlying reasons for using such an assessment, such as stimulating discussion or reinforcing what students should not be learning. Despite this difference in intention, the teachers ultimately developed a formative

assessment in which students identified and corrected different student ideas from the learning progression.

*Identifying and Interpreting Student Ideas.* During enactment of the unit in late January 2009, Chris and Lisa uncovered a new student idea that was not represented in either the map of student ideas or Mayr's facts and inferences. Lisa had asked students to do a free write about "everything they knew about natural selection." After class, she and Chris, who taught next door, looked at the student work together and put it into stacks, similar to what they had done in the professional development meeting, labeling them "Eugenics/Anthropomorphic, Accurate Natural Selection (Sometimes Not Complete), Inconclusive, Lamarck." The "anthropomorphic" and "accurate" categories were drawn from the learning progression, and the 'Lamarck' category was similar to the "need-based change" category on the learning progression but named for Jean Lamarck's ideas that organisms change in response to the environment (National Academy of Sciences, 1998). The category of "eugenics" had not been previously discussed in the monthly meetings and was not represented in the learning progression. Lisa and Chris described this new idea in the February 2009 meeting as follows:

> Lisa: And then Chris and I, we were procrastinating fourth period, and we sorted them out into piles according to anthropomorphic, and one thing we found was eugenics, because in the Galapagos video, it talks about the female iguanas tolerating smaller males because the smaller males can survive an El Niño year whereas the larger males produce the larger babies and the larger the offspring the less likely they are to survive an El Niño. And so they took that to mean that the female iguanas are intentionally breeding with the, either the smaller iguana or the larger iguana according to what's going to happen the following year so that's why. . .[trails off]
>
> Robyn: Chris used the same version of it.
>
> Chris: And I think, a lot of it was because we were talking about artificial selection today, so then, I think that's why they chose that, because they were thinking like, if humans choose which animal can breed is artificial selection, then animals must do the same thing. And that's natural selection. That they get to choose.
>
> Rachel: But they do choose, it's just not -
>
> Lisa: But the reason I put it with a misconception is because animals choose based on what the conditions will be next year, whereas the accurate statement would be that animals do choose, but not based on something that's going on in the environment.
>
> [Springfield High School, professional development meeting, February 2009]

The group took to calling this the "eugenic" misconception and Lisa even added it as a distractor on a multiple-choice formative assessment activity in which students were asked to provide reasons for why populations of the *Biston betularia* or peppered moth changed color during the industrial revolution. Although Lisa alone used this version during the first year of the study, all of the teachers used it during year 2. In addition, the community agreed it should be added to the map of student ideas the researchers provided at the beginning of the study. In this sense, teachers identified and reified a new idea through their own enactment of the formative assessments that were developed to elicit student ideas.

*Merging the Two Representations Into the Daphne Learning Progression.* At the end of the first year of the study, Chris had a breakthrough when he suggested combining the two representations of natural selection—the map of ideas and the list of Mayr's facts and

inferences—into one learning progression. During an interview, when asked by the research team to describe how these two representations had influenced his instruction, he said,

> Well, I thought they were both useful, because one [Mayr's facts and inferences] is this, "this is how it works," and one is, not how it works, and what the students think [map of ideas]. So I think whether you're looking at the dark or the light, you need to see both of those things to really understand how to teach the kids, so I think both of them go together side by side, because for every student misconception, it's linked to the Mayr's five facts and inferences, and whenever there's a right idea in their student thoughts, it's because of one of those. [Springfield High School, post-interview, April 2010]

Chris went on to describe how the two maps might be combined into what he called "the ultimate graphic organizer."

Based on his suggestions the research team worked in the summer of 2009 to merge two representations together into what ultimately became the Daphne Learning Progression (Figure 4). Creating this representation began with reflections upon the map of ideas, and the discovery that the four levels confounded ideas of the origin of variation with the processes of differential survival and reproduction (see Furtak, 2009). The research team first created two separate, smaller maps of ideas for each of these dimensions of natural selection and then, following Chris' suggestion, mapped each of these smaller maps onto a larger representation of Mayr's facts and inferences. The final product included a sequential progression of "correct" ideas about natural selection on the horizontal axis and maps of how two of those ideas in develop in vertical axes below.

The teachers then used this revised version of the learning progression as a guide to interpret student ideas, both by watching each other enact the formative assessments on video, as well as to examine examples of student work. In the November 2009 meeting, teachers took up the issue of where the everyday ideas represented in the learning progression came from. Pat challenged the other teachers by asking if they had ever engaged their students in such a discussion:

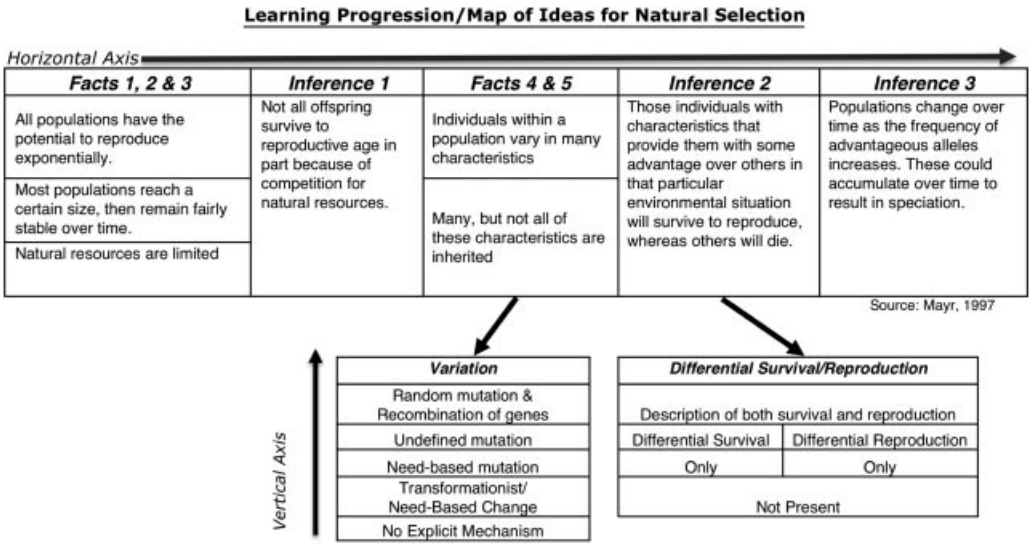


*Figure 4.* Daphne learning progression (originally presented in Furtak et al., 2012).

Pat: Did you ever discuss with kids and ask them things like, where did you get this idea of need-based change?
Rachel: No, because I think it's just so pervasive in the entire -
Pat: - but I think it might be a good idea to ask them, like where did you get this idea, like you seem to think that the environment causes these or that they need to change so they go and change to adapt. Where did you get that?
Rachel: I mean, we were talking about the chili pepper thing you were talking about, I mean [Erin] was giving us an example of how they were talking about it like that on *Science Friday* on NPR.
Pat: Oh yeah, scientists do that kind of thing all the time.
Lisa: They hear survival of the fittest and it never goes any deeper than that until they're really into a more advanced science course and so I think they probably just interpret that as you know, as their brains interpret it -
Chris: - I think whenever the word "something adapts to its environment" it's always needs-based change, that's the way that word is used -
Lisa: - and think of adaptation as an action -
Pat: - but it would still be interesting to talk to them and say, what was it that made you think this? What in your life experience gave you this impression?
[Springfield High School, professional development meeting, November 2009]

The conversation led the facilitator, Erin, to point to a specific example from Rachel's enactment of a formative assessment where she provided feedback to her students to move them from a lower level of the learning progression toward the 'correct' fact that students were expected to learn from that activity. In this way, the facilitator brought the new version of the learning progression back into the community to inform discussion and interpretation of student ideas.

*Coordinating Instructional Plans.* Teachers had several conversations through the course of the study about the two representations and their role in organizing the natural selection unit. For example, at the January 2009 meeting, Rachel asked Erin about the role of the two representations in her instruction, suggesting that the facts and inferences might be more useful for her in sequencing instruction:

Rachel: Do you think it generally, 'cause right now the way I'm leaning is you know I'm taking those five facts and I'm just going to march through and teach each one, whatever, and I don't know, do you think that's important to cover before you give them something like this?
Erin: That's a really good question because I was thinking about that earlier today, I was trying to think how does this fit with that, because they're really two different things, . . . I think that you could probably, you wouldn't have to do all of it and then it goes together, because I think that some of these student responses are pretty closely related to some of the facts and inferences, you know like, characteristics are inherited, um, you could do it there. Let's see here. I mean I guess that some of them [looking at the two representations], hmmm, that's a good question that I don't have an answer to. I guess OK because if you did it after Fact 5 then you would be so basically marching through it . . .
Rachel: I mean, not that it has to be boring or bland -
Erin: - of course not -
Rachel: - but I just feel like you can't throw this stuff at them with the results you want if they're not equipped to know. . .
Erin: Like this stuff? [holds up the map of ideas]

> Rachel: Right, or, I mean, if you just start with them. Because this is what they're all probably thinking anyway, as they sit there before they've been taught, um, do you point these out first [map of ideas], and then go back and talk about the inferences because they'll connect to it more because they said oh, well I should listen up because I would have gotten that one wrong, or, I don't know?
> [Springfield High School, professional development meeting, January 2009]

The preceding conversation indicates that teachers were not always sure how to make sense of the two representations, and how they should inform formative assessment and the way they taught the unit.

In her end-of-year interview conducted in the spring of 2009, Rachel repeated her questions about the different possible sequences for the unit, stating, "There are better sequences than others. . .is it better to, you know, address Mayr's five facts just in one chunk? Or is it better to break it up? I mean, I don't know." At the same interview, several other teachers suggested that it might be a good idea for them to try to come into closer sync with each other, rather than all doing their own unit planning as they had done before. For example, Alison said that she had followed Theresa the previous year, but hoped to come up with "The best order in which everything was taught." During professional development meetings in the fall of the 2009–2010, teachers discussed their interest in all using the same formative assessments and eventually decided to all teach their units in roughly the same sequence. In this way, teachers used their shared repertoire of formative assessments and the learning progression as an opportunity to come into sync with each other in their instruction.

At the conclusion of the study in the spring 2010, we asked teachers during interviews to explain how the learning progression had influenced their instruction. Teachers cited both Mayr's facts and inferences and the map of student ideas structures of the learning progression. Robyn called the facts and inferences structure the "backbone" of the unit, but also said she used the map of student ideas structure as well. She stated, "I think that they were both equally useful, because one allowed me to organize the unit, and the other one allowed me to organize specific lessons, and get at specific misconceptions that I hadn't really thought of before, and hadn't really put much thought into, like how do I get rid of this misconception, or how do I approach this?" Robyn also referred to the map of student ideas in the learning progression as having helped her give students feedback, stating that "in this case I took the time to jot down a couple things, or write down questions like, 'Well, what about this?' To hopefully lead them, if they looked."

Similarly, Theresa reflected in her spring 2010 interview that she had used the facts and inferences to structure her teaching of the unit: "The five facts and three inferences. I kind of used that as a way to guide my teaching or the topics that I hit . . . And then the map of student ideas, more than anything I just kind of referred back to that as I looked over the formative assessments . . . as I read the student responses to the formative assessments, it just kind of helped remind me of the places where students could run into problems and kind of helped me categorize what I was reading in the student responses."

In contrast, Lisa stated in a spring 2010 interview that she introduced the facts and inferences later, but was more focused on the map of student ideas structure. When asked how the learning progression influenced her planning of the unit, she said, "Well, definitely the misconceptions did. I didn't do the facts and inferences until the very end, mostly because I was focused on the misconceptions, instead of specifically making sure they understood why we understand natural selection the way we do." These excerpts illustrate that while teachers relied on both structures of the learning progression, they drew upon them in different ways to inform their instruction.

Although teachers alluded to the learning progression when directly asked about it, as indicated in the sections above, it was usually an implicit tool that underlay but was not always specifically referenced in professional developments or in interviews. During the course of the study, as teachers uncovered a new student idea, suggested using the facts and inferences as a backbone, and brought their units into alignment with each other and with the learning progression, the learning progression became part of a shared language within the community. Two teachers noted the unique status the learning progression held within the community and helped teachers to identify particular lessons or approaches. In the spring of 2009, Chris said he would "throw it [the learning progression] in the trash" if given it by another teacher. When asked why he would do so, Chris responded,

> Because it's not mine. For some reason we like what we do, so if I made one it would be the best one ever, and if someone gave it to me, they're probably not very good at it. Even though that's the same thing I said to them, you can give them something, people still don't want to give you something, because they want to feel like they're a part of it.
> [Springfield High School, interview, May 2009]

Similarly, Robyn noted during her interview at the end of the study that teachers at another school would not have had "the discussions that we had and I think the discussions are actually pretty important. Like it's not just the end point; it's the journey along the way." In this way, both Chris and Robyn acknowledged that the learning progression as a tool might not have the same meaning to members of another community as it did to them, given their own involvement in its development.

### *Learning Progression as Boundary Object*

At the conclusion of the Daphne Project, the research team analyzed the version of the learning progression shown in Figure 4 and used it to systematically analyze student responses to the formative assessments. Through this process, the research team found that certain student ideas were not easily captured in this representation, and that additional ideas could be mapped underneath other facts and inferences. Based on this process, the research team updated the learning progression into a new version called the Elevate Learning progression. This version was based on Chris' "Ultimate Graphic Organizer" design from the Daphne Project, but included a number of additional 'student ideas' structures for the learning progression (Figure 5).

The Elevate Learning Progression represents natural selection in multiple dimensions organized into a logical sequence of facts and inferences based on Mayr's (1982) framing. We developed a smaller map of student ideas for each dimension that illustrated how student understanding can progress from everyday ideas to the scientifically accurate explanations (see Furtak et al., 2011, for more details on this process). Thus, the Elevate Learning Progression consisted of multiple learning progressions, with the horizontal axis representing how the concept of natural selection is constructed of multiple ideas, and the vertical axis including a set of maps for each individual piece of each idea.

While some of the facts and inferences have only one map of ideas below them, we broke others into smaller component dimensions. For example, we disaggregated fact 4 into three distinct dimensions: Random Mutations, or the process by which new traits arise as a result of random genetic processes; Variation, or the idea that no two individuals within a species or population are exactly alike; and transformationist ideas, or the idea that organisms are not able to transform themselves to adapt to environmental changes. Then, for each of these dimensions, we articulated the different understandings that students may exhibit before they develop a correct understanding represented in the top level of each construct map.

Dimensions

| | *Fact 1* | *Fact 2* | *Fact 3* | *Inference 1* | *Fact 4* | | |
|---|---|---|---|---|---|---|---|
| Construct Maps | **Biotic Potential** | **Population stability** | **Limited Natural Resources** | **Struggle for Existence** | **Random Mutations** | **Transforma-tionist incorrect** | **Variation** |
| | Population reproduces but not ideal | Population Stability - unclear or vague | Change food source | | Environment causes change with genetic basis | Transforma-tionist ideas | Variation - unclear or vague |
| | Biotic Potential - unclear or vague | No population stability | Limited natural resources - unclear or vague | | Unclear or Vague | Unclear usage of 'adapt to environment' | No variation |
| | No Biotic Potential | | No mention of natural resources | | Trait not present | No transformationist ideas | |

| *Fact 5* | *Inference 2* | | | *Inference 3* | |
|---|---|---|---|---|---|
| **Heritable variation** | **Differential Survival** | **Differential Reproduction** | **Fitness** | **Speciation** | **Population changes over long periods of time/deep time** |
| Heritable – unclear, vague or incorrect | Unclear use of survival | Eugenic Reproduction | Survival of the Fittest | Speciation - vague or unclear | Population change over time – shorter or no clear duration |
| No heritability | No survival | Unclear or vague reference to reproduction | Fittest/ Strongest Survive | No speciation | Species are static |
| | | No reproduction | Unclear use of fitness | | No mention of population changing/not changing over time |
| | | | No fitness | | |

*Figure 5.* Elevate learning progression (Furtak, Morrison & Kroog, in press).

To provide an example of the level of detail we included in the new Elevate Learning Progression, we will describe the Random Mutations and provide a sample of the information we developed in Table 4.

This dimension refers to the idea that new traits arise as a result of random genetic processes. These new traits may arise through a variety of processes (e.g., crossing-over, new combinations

Table 4
*Detailed information about random mutations dimension of elevate learning progression*

| Level | Description | Example Student Response |
|---|---|---|
| Random mutations | Student describes one or more of the random genetic mechanisms by which new traits arise. | A species changes over time because of random mutations and gene shuffling. Random mutations can cause a change in a species' gene pool. And gene shuffling is the different combinations of genes that come from the parents. If species are separated long enough, the species' gene pool changes. |
| Environment causes change with genetic basis | Changes occur as a result of genetic mutations in direct response to the environment and/or not random. | Animals mutate to fit in with their natural surroundings. So becoming darker helps to keep them in camouflage. |
| Unclear or vague | Student refers to mutations or random changes leading to new traits but does not describe a mechanism for how that happens. | If a mutation happens it can effect the whole species by creating a variety of differences from color change to more or less help against gathering food and protecting against predators. |
| Trait not present | Description of differences in traits not given at genetic level or denial of change in genes. | I picked my answer because none of the other seemed all the way correct. |

of genes, mutations) and may be of many types (helpful, deleterious, or no effect). What is crucial in this category is that students acknowledge that new traits occur entirely spontaneously. The upper anchor of Random Mutations involves students stating that random mutations in an organism's DNA or genetic processes led to the generation of new traits within individuals of a population. The intermediate and lower levels of Random Mutations involve students mentioning key words like "random", "mutation," or "DNA" without really explaining those words. Student responses commonly will fall into this category when they have heard their teacher use these words in describing natural selection, but don't fully integrate these words into a description of random processes leading to new traits, or if they use those words along with anthropomorphic ideas about organisms changing themselves in response to the environment (e.g., the idea that moths can mutate to have the right color to match the bark).

We brought this version of the learning progression to partner schools in the Elevate project with the intention that it serve as an organizing framework for instruction and formative assessment design. We developed in-depth descriptions of the ideas within each of the vertical maps of ideas on the learning progression, accompanied each with examples of student responses, and provided all of this information to teachers at Monroe as part of the Elevate study. In this way, the learning progression became a boundary object that traveled between the two communities. In the following case report from Monroe High School we describe the ways in which members of that community took up the learning progression.

### *Case 2: Monroe High School*

*Learning progression enters the community.* We introduced teachers to the learning progression in the fall of 2011 following a year of baseline data collection. At the September 2011

meeting, we engaged teachers in an activity in which they explored data about the students' performance on pre- and posttests about natural selection from the baseline year and identified areas for developing formative assessments. As part of this activity, we asked teachers to examine student response data linked to the learning progression as a way to introduce the teachers to the learning progression and its potential to support them in interpreting student ideas. During this initial introduction teachers reflected upon the activities that they had enacted during the baseline year and their potential influence on student performance on the tests. In this discussion, Donna related her confusion about teaching natural selection to the results of the pre-posttest:

> I would say that we are unclear about what we should be focusing on . . . when I think about natural selection and going through that process I have my own ideas about what it is. But when it's broken down like this I'm not touching on what needs to be touched on for the understanding to occur. I'm actually seeing increase in the unclear or the second one down [referring to the levels of the learning progression] where it's more of the major misconceptions so maybe I'm unclear on what it is that I'm supposed to be teaching, that's what I see with my data. Some of the things are going up some of the things are improving but I'm seeing where I'm getting a lot of kids with that misconception.
> [Monroe High School, professional development meeting, September 2011]

In this comment Donna attempted to make sense of her student responses with respect to her own understanding of how she taught natural selection. In looking at the learning progression, Donna recognized that she had a different understanding of the process and began to wonder how her instruction had led to a greater proportion of misconceptions. Similarly, Kim also used the learning progression to explore student data from the test and related her students' performance to her instruction the previous school year. When Erin focused the teachers on the genetic origin of traits, noting that students have common ideas about mutations that come from their everyday experiences, Kim reflected, "I know for a fact that I haven't gone deep into any of that topic. We just never get to that point."

Towards the end of the meeting, Erin pointed out that at the next meeting the teachers would use the data and the learning progression to design formative assessments so that they could surface some of these ideas in class. This led Mark to think about how the learning progression's representations of student ideas could be used moving forward when planning for instruction.

> One thing is kind of neat here is that you are real specific in your facts and we got to make sure that when we are teaching this that we don't reinforce some of the misconceptions by explanations. It's nice to know where the kids' misconceptions come from.
> [Monroe High School, professional development meeting, September 2011]

The preceding examples illustrate how each of the teachers engaged with the learning progression and student responses, asking questions about the facts and inferences and reflecting on his or her own teaching in light of the data. There was little mention of other tools during this activity, although Kim did bring in standards at times when she probed the group about how the learning progression related to the standards. Thus, even at this early stage, Kim was already trying to make sense of the learning progression in light of tools provided by the state and district.

*Making instructional plans.* The three Monroe teachers differed in the ways they drew upon the learning progression as a tool for planning their instruction over the course of the study. In pre-interviews conducted during the baseline year, all three teachers referred to the CAP-A as the pacing guide for their units and noted that there was little flexibility in the amount of time they could spend on a given unit. For example, Kim said, "We have CAP documents in this district and

that's what we have to teach. So that's what I teach." Donna lamented having to move on before she was ready because of the requirements of the CAP-A, stating, "I do my best to try to make sure that they understand. However, with our CAP documents the way they're set up, we really don't have the luxury of time." While Kim kept a close allegiance to the district pacing guide in planning the unit, Mark and Donna expressed interest in using the learning progression to plan the unit, albeit in different ways.

Kim's loyalty to the district pacing guide became apparent in the first professional development session in October of 2011 in which facilitators asked the teachers to draw upon the learning progression while planning their formative assessments. By coincidence, Kim had invited a district curriculum specialist to attend this meeting. The facilitators guided teachers to use pretest scores for the current cohort of students alongside the learning progression to identify areas that the students needed to work on during the unit, and to identify common areas within the learning progression around which to develop formative assessments.

While Mark and Donna engaged in the tasks of picking focus areas from the learning progression, Kim hesitated to choose an area because, as she stated, she had not yet seen the district's revised CAP for evolution (CAP-B). At one point, Kim even turned to the district representative to ask if the district had created a guide for the CAP-B that she could see and use. "Without having seen the CAP as far as it goes with natural selection and evolution it's hard to pick where we should go. So [turning to the district representative], can you fill us in?" The group erupted in laughter, including the district representative, and before she could respond, Mark jumped in with his preference for using the learning progression to plan the unit. "This thing here [gesturing at learning progression] is the best thing to look at to help clarify what they mean. I think we need to look at this to see what's most important." Mark eventually became fixated on student ideas about fitness and suggested that their focus be on the part of the learning progression related to those ideas. "Fitness is something that's an easy fix too. We need to flat out define fitness and realize our ESLs [English language learners] have a different version."

Donna similarly wanted to use the learning progression to inform her instruction, but viewed it as a list of vocabulary to focus upon and then to look for connections between those concepts.

> Yeah, and then I almost like to approach this unit as this is the essential vocabulary that the kids need to understand, and how are we going to reinforce that, build from the basic with what the vocabulary is and how does that intertwine with each other with concepts? I just like to take this unit—start fresh from ground zero—how are we going to build this together to make this specific unit. So does that make sense?
> [Monroe High School, professional development meeting, October 2011]

However, Kim's insistence on seeing the new CAP-B before making any decisions prevented the teachers from agreeing upon an area of focus for developing formative assessments. After Donna made the preceding suggestion of using the learning progression as a list of vocabulary upon which to base the unit, Kim responded, "Well, I think we have to wait and see. I don't know what the CAP says about this part and that makes it really hard." Erin, the facilitator, then turned to the district curriculum specialist and asked her directly if the district was going to provide a plan for the Evolution unit. Erin and the district specialist then discussed how the learning progression provided more detail than the CAP-B and the district representative agreed that the learning progression and the CAP-B overlap enough so that whatever the teachers chose to focus upon would also be on the CAP-B. Eventually, Kim stopped insisting on seeing the CAP-B before making a decision and told the other teachers to choose any aspect of the learning progression to focus on as they developed their formative assessment.

> Erin: Ultimately I want you to pick three [pieces of the learning progression], but if you aren't ready to narrow that down I'm not going to push you about it. I know that we only have about five or seven minutes left before you have to get back to class.
> Donna: I really want to do random mutations, well fact four I guess.
> Erin: Kim, Mark, how do you feel about that?
> Kim: Good. Whatever. It doesn't really matter . . . [mumbles, shaking her head]
> [Monroe High School, professional development meeting, October 2011]

In this excerpt, we see that Kim only gave in to using the learning progression to set goals for the formative assessment when the district specialist had insisted that the learning progression was consistent with the detailed CAP-B. However, Kim withdrew herself from the process, letting the other teachers identify areas of the learning progression.

By the February 2012 meeting, the CAP-B had been released by the district, and Kim used it to develop her proposed plan for the evolution unit. At this meeting, which was intended to involve teachers in developing formative assessments, Kim did not mention using the learning progression as an additional tool to plan the unit.

> It's not perfect, all I did was I took the CAP and I looked at "the students will be able to do" [statements from the CAP-B], and then I used the textbook and put everything in order of the textbook and then I put a square where the CAP said we have to cover.
> [Monroe High School, professional development meeting, February 2012]

Donna attempted to connect Kim's plan back to the learning progression, but Kim continued to emphasize the CAP-B document over the learning progression.

> Donna: [taking out the learning progression] So we had talked about the biotic potential, stable populations, limited resources.
> Kim: Stable population is in [the] ecosystems unit.
> Donna: Yeah, but I think the main thing is talking about how did populations change over time. That's the big idea.
> Kim: Yeah, but I think we are supposed to do it on the genetic level, because we already did the big picture. [reading from the CAP-B] "Evolution occurs on the heritable characteristics of population change across generations that lead populations to become better adapted to their environment."
> [Monroe High School, professional development meeting, February 2012]

Donna and Mark did not continue to push Kim to relate the learning progression and the CAP-B, but rather followed Kim for the remainder of the meeting as she suggested activities within her unit plan, and suggested where the formative assessments might be placed within that plan.

Ultimately Kim's allegiance to the CAP-B won out as the primary tool that informed the way teachers planned the natural selection unit. Even though Mark went along with the CAP-B and Kim's plan for the unit, he suggested in his end of year interview that the learning progression would become a planning tool for his instruction. "I'm basically going to take our learning progression out and go through it and make sure that we're heading on the right track. It gives you a lot of really good ideas and it also gives me a lot of good ideas of what to cover too. These are all the pieces." Mark also discussed the benefit of having the representation of student ideas and their misconceptions as a tool for planning and instruction.

> I'm sure we didn't address all the misconceptions beforehand with the learning progression. It'll make sure that we address all the misconceptions and make sure they're understood the way they should. And with the learning progression they also have various different stages of their misconceptions too, which I think is helpful.
> [Monroe High School, interview, May 2012]

Here Mark focused on how he could anticipate misconceptions in advance and address them in his instruction. Mark's interest in the learning progression as a tool for planning is also apparent in his participation in the development of the formative assessment in the professional development meetings. In the next section we describe the role of the learning progression in teachers' development and revision of formative assessment tools.

*Developing Formative Assessments.* At the facilitators' request, the teachers brought draft versions of their formative assessments to the meeting in March 2012 to explore and revise within the group. One of these was on vestigial structures, a concept from the CAP-B that was not included on the learning progression. Kim had developed the second formative assessment prompt based upon one of the common writing tasks they had created as a result of the work they had done previously with the district. Erin asked the teachers what they expected the students' responses to look like for the question as written. This question initiated a long conversation in which the various boundary objects—the learning progression, the CAP-B, and the writing task—bounced up against each other as the teachers attempted to coordinate their work around drafting the formative assessment.

During this process of revision, Kim privileged the CAP-B and the common writing task rubric the teachers had previously used for evaluating what constituted a "right" answer. As the teachers were going back and forth about what they wanted student responses to look like, Kim again referred to the rubric, suggesting that the writing task was more important than which of the key ideas they identified about natural selection. Later, when teachers were revising the writing prompt to use as a formative assessment, they disagreed over whether they should use the word "species" or something less technical that might be more familiar to students. Kim went straight to the pacing guide, saying, "I've got the CAP here, let's see what it says." Sara, the second university facilitator, and Kim then looked over the CAP-B document together, noting that it included yet another representation of the concept of natural selection that was different from other resources Kim was using.

Throughout the meeting, Kim struggled with how to interpret the CAP-B and use it in drafting the formative assessment. At one point during the meeting she picked up the CAP-B and said,

> That goes back to what you were saying [pointing to Erin], what is it that we really want them to know? Because it's a big ugly mess on here [CAP-B]. I don't even know anymore. I don't know, the CAP is like what's supposed to drive everything that we do, in addition to your work [looking at Erin], but [picks up the CAP-B] this is like impossible to understand sometimes.
> [Monroe High School, professional development meeting, March 2012]

This quote illustrates Kim's struggle to understand the CAP-B and use it alongside the learning progression. While she understood the importance of setting learning goals for students, the confusion she felt over the CAP-B constrained her ability to use the learning progression to set those goals.

In contrast, Mark and Donna did not reference the CAP-B while revising the formative assessment. Mark instead referenced his interest in evaluating students' use of everyday language

with the word fitness during the revision process, an interest he identified from the learning progression. In the following excerpt Erin suggested a change in the prompt to focus more on fitness and Mark agrees with her suggestion.

> Mark: That might be a neat idea though to toss out the word fitness because, well what I think is neat about that word, is this is how they view fitness and this is what we mean by fitness, you know.
> Erin: Yeah, there's these two meanings, yeah.
> Mark: And that might be a good way of, and this as a preassessment, it's good so we can find out. [Monroe High School, professional development meeting, March 2012]

He also pushed back on Kim's insistence on using the CAP-B as the guide for designing the formative assessment. He was openly critical of the CAP-B, suggesting that the work they were doing in Elevate was making them more expert on natural selection. "You know what though, the people that wrote that to be honest I don't think will understand natural selection when we are done as well as we do." This quote suggests that Mark had more faith in the learning progression as a planning tool than in the CAP-B.

Donna also privileged the learning progression in response to Erin's question about what the teachers expected from student responses on the formative assessment. She read off the list of concepts on the learning progression as ideas she hoped students would use in their response.

> Erin: All of them or just two of them [ideas about natural selection]?
> Mark: Well just two of them, it says just two of them. The two that are the most -
> Donna [reading from the learning progression]:—so variation, organisms' inheritance, rate of population growth, differential survival and reproduction.
> [Monroe High School, professional development meeting, March 2012]

Donna actively engaged with the group in revising the prompt to be more accessible to students, often referring to what she thought would be easier for the students. "We could make it real simple and just write, 'describe the process by which animals change over time'." In this way, she attempted to make the prompt as simple as possible so that students would be able to write something.

As the preceding examples illustrate, the teachers varied in the ways in which they drew upon the learning progression as a planning tool during the process of formative assessment design. Kim's insistence on using the CAP-B ran counter to Mark and Donna's attempts at using the learning progression to develop and revise the formative assessment. The result was one formative assessment that did not reflect ideas in the learning progression and the other that merged ideas from the learning progression and the CAP-B.

*Interpreting Student Ideas.* After the teachers enacted the formative assessment in early April 2012, we asked them to use the learning progression to analyze student ideas in responses to the writing prompt. During this meeting Kim and Donna were able to identify variations in their students' responses and related them to the learning progression, as the following exchange illustrates:

> Donna: So there were some of the fact three limited natural resources. A little bit, several of kids mentioned predator prey relationships, nobody got random mutations.
> Erin: I think I saw one or two talking about genes.
> Kim: Yeah, one said something.

> Erin: But it wasn't like in a science-y way, it was kind of like how humans -
> Kim: - Humans get it.
> Donna: Transformationist, is that transforming from one animal to another? [Monroe High School, professional development meeting, April 2012]

In this example Donna and Kim attempted to use the learning progression to understand student ideas. At the same time, Donna asked a question about the transformationist ideas, indicating that she was also still trying to understand some of the levels from the learning progression.

In May 2012 during her end of year interview, Kim reflected on how the learning progression influenced how she thought about student ideas in natural selection.

> Before I don't think I ever made the connection like there were chunks of student misconceptions and chunks of student learning. I think it was kind of like all or none. You get it or you don't and I really couldn't see past that. I think it's allowed me to when I'm grading student work now to put it into little piles. Okay, this one understood this and this one understood that and this one's lacking this. It's helped me to categorize how students are understanding. [Monroe High School, interview, May 2012]

In this way Kim appeared to leave the CAP-B behind and talk more specifically about how the learning progression, despite her initial struggles, ultimately helped her reframe the way she thought about student ideas in the natural selection unit.

In contrast to Kim and Donna, Mark resisted using the learning progression to understand his students' thinking. During the April 2012 meeting, he explained that his students' lack of English skills prohibited them from answering the formative assessment and giving him any information.

> My kids didn't write a lot, it was a little bit of a language barrier. I told them not to worry about it so much if they really didn't understand it. I only had about five kids that really responded well to it. [Monroe High School, professional development meeting, March 2012]

In this way, Mark repeatedly justified his lack of interest in looking at student responses by referencing their limited English skills. While Sara attempted to engage Mark in looking through his students' responses, he repeatedly got up from the meeting table and disengaged from the conversation. In this instance, Mark's views of his students and their inability to respond to the question prohibited him from working with his colleagues to use the learning progression to interpret student ideas.

*Cross-Case Analyses.* In this section, we will reflect upon how the different versions of the learning progressions coordinated the work of the communities at Springfield and Monroe High Schools in making instructional plans, developing formative assessments, and interpreting student ideas. Given the already noted differences in the studies and school sites, we do not intend to make direct comparisons across the two cases we have presented. Rather, we intend to explore how our analyses of each site reveal information about each other and help to raise questions for the use of learning progressions as supports for classroom teaching and learning.

At Springfield High School, the key element of teachers' work in the Daphne Project was to inform the design of a new learning progression to guide their instructional planning and formative assessment design and enactment in their natural selection units. The case study above illustrates

the ways in which the Daphne learning progression was a co-constructed representation that merged information brought by the teachers, in terms of Mayr's facts and inferences and the eugenic misconceptions, as well as the researchers, in terms of their own synthesis of research into student thinking about natural selection. As the Springfield case illustrates, over time and at our initiation, the teachers coordinated their work around the two representations that were ultimately merged into the Daphne Learning Progression in three ways. First, the learning progression provided opportunities for teachers to interrogate the way they currently sequenced their natural selection unit and to ultimately reorganize their units around a common instructional sequence defined by Mayr's facts and inferences. At the same time, they decided to address the ways that particular ideas developed when teaching the associated facts and inferences to which they were linked. These two sequences were ultimately captured in the learning progression. Second, the teachers drew upon the learning progression and their shared instructional sequence to develop a set of formative assessments designed to elicit student ideas about natural selection. Finally, the ideas in the learning progression became part of a shared language within the community and helped teachers to identify particular lessons or approaches that might have reinforced naïve ideas in their students. Furthermore, teachers' engagement with the learning progression to sort and interpret ideas was evidenced by their contribution of a newly uncovered student idea to the learning progression.

Our work at Monroe centered on facilitating the use of the learning progression to create formative assessments and evaluate student work on those formative assessments to inform future instruction. Overall, a lack of a shared repertoire within the community led to differential engagement in the various goals of the professional development. As a result of the school wide initiative to focus on writing, our own introduction of the learning progression, and the district's introduction of the CAP-B, the teachers at Monroe worked with multiple tools in their repertoire and appropriated these tools in different ways. We found that teachers' work was coordinated around the formative assessments they created, but these were supported more with the CAP-B instead of the learning progression. In effect, the teachers' joint enterprise became trying to make sense of how to use the learning progression along with the other tools available to them. Kim struggled to use the learning progression as a planning tool and privileged the CAP-B in her development and revision of the formative assessment tools. However, Kim did easily engage with the learning progression in looking at student ideas generated from the formative assessment. Mark, on the other hand, seemed more interested in using the learning progression to plan and even criticized the CAP-B in light of what he was learning from the learning progression. However, he resisted using the learning progression to look at and evaluate student responses that didn't reflect correct scientific ideas. Of the three teachers Donna seemed to be the only one to engage with the learning progression in both the planning the formative assessment and evaluating student ideas.

*Role of the Learning Progression in Coordinating the Work of the Two Communities.* In contrasting the two cases, we note the stark contrast between the two schools in which we did this work. Despite the fact that they were located in the same school district, the communities existed in vastly different contexts and administrative climates. Furthermore, as we have noted several times, the role of the learning progression was different in each community. Not surprisingly, then, we observed differences in the extent to which the learning progression coordinated the work of teachers in each community.

At Springfield High School, we found that the biology teachers were able to coordinate their work as they contributed ideas to the learning progression, used the different representations of the learning progression to inform the sequencing of their units, and develop formative assessments.

Over the course of the two year study, teachers used the formative assessments and learning progression as an opportunity to bring what were previously disparate instructional units into closer sync with each other, and teachers were mutually engaged in the exchange of materials and discussion of practices within the community. All of this took place in an environment of little district or administrative oversight; that is, teachers were free to plan as they wished, and the CAP-A was only used as a rough guide for where to place instructional units throughout the school year.

Throughout this process, the learning progression was present, but in the background; the teachers were integral in its construction, contributing Mayr's facts and inferences as an organizing framework, a new student idea, and a design integrating what were initially two disparate representations. However, the teachers did not identify the learning progression as one of their main take-aways from participating in the project. In this way, the learning progression became a reified object of the Springfield community, an embodiment of the collective knowledge of teachers and researchers. As Cobb et al., (2003) wrote, "The reifying object is, therefore, a relatively transparent carrier of meaning for members of the community in which it was created" (p. 19).

In contrast, teachers at Monroe High School were working in a context in which they were reminded constantly about their school's improvement plan and all the tools that were being provided to them to help boost their students' achievement. The level of administrative oversight they experienced was so great that an assistant principal regularly participated and a district curriculum specialist also attended a meeting. Further complicating the situation, during our work at Monroe, the district significantly changed the pacing guide teachers relied upon to know what they were responsible for teaching, pushing the work of the community out of coordination.

Our framing of the learning progression as a boundary object predicts that it would be differently taken up and used by the Monroe teachers as compared to those at Springfield. Indeed, our analyses of the professional development meetings at Monroe reflect the differential use of the learning progression within that community. Instead of serving as a focal point, the learning progression was one of a jumble of tools that were not well aligned with each other. Cobb et al. (2003) similarly found that "teachers experienced and continually had to cope with a tension between the agendas of the school leadership communities and mathematics leadership community as they developed their instructional practices" (p. 20). The competing agendas represented by these tools—to have students write responses in particular ways, to completely reorganize and re-sequence an entire year's curriculum in biology according to district dictates, and to design assessments intended to draw out student ideas—created a context in which teachers were challenged to focus on any one tool to support their teaching. While there was rarely consensus in terms of how to use the learning progression, we did find that teachers coordinated their work around this tool in that they were able to successfully design formative assessments and reflect upon student ideas.

## Discussion

The NRC (2007) predicted, "Ultimately, well-tested ideas about learning progressions could provide much needed guidance for both the design of instructional sequences and large-scale and classroom-based assessments" (p. 220). In this paper, we took up this suggestion by exploring two cases of teacher communities engaging with learning progressions through the lens of communities of practice (Wenger, 1998). We found that the mutual engagement and joint enterprise of each community seemed to depend not only upon the role teachers played in development of the learning progression, but also the coordination of the learning progression with other tools provided teachers to structure their planning. At Springfield, teachers took ownership of the learning progression as they co-developed it, and did not concern themselves

with coordinating this tool with others provided by the district. In contrast, teachers at Monroe were introduced to the learning progression as users, and as a result—at least Kim—did not use it in the same way. In this section, we will reflect upon the two cases in terms of their implications for learning progressions as tools for teachers, the learning progression structures, and suggestions for future work.

*Learning Progressions as Boundary Objects*

In this paper, we followed Kazemi and Hubbard's (2008) suggestion that boundary objects provide a focus for the study of professional development. Following Star and Griesemer (1989), we viewed the learning progression as a boundary object in that it could "serve to coordinate the perspectives of various constituencies for some purpose" (Wenger, 1998, p. 106). Our intention was that teachers use the learning progression to coordinate the work of their learning communities in developing formative assessments, identifying student ideas, and organizing instruction. We found that the learning progression took on meaning through its use at each of the different schools and served the purposes of planning instruction, developing formative assessments, and interpreting student ideas in different ways. Star delineated three components for boundary objects: interpretive flexibility, the structure of work process needs and arrangements, and the dynamic between ill-structured and more tailored uses of the objects. The learning progression reflected each of these components at each of the different sites, as well as within our own research group.

With respect to Star's (2010) conception of interpretive flexibility, or the varying of the use and interpretation of the object varying across contexts at each site, we found that the teachers at each site interpreted the learning progression in different ways. At Springfield the teachers focused on how the unit could be sequenced with Mayr's facts and inferences and the best order of instruction. At Monroe, the teachers interpreted the representation differently, with one teacher interpreting the learning progression as a list of vocabulary words to focus instruction on, whereas another teacher emphasized the intuitive ideas as represented in the learning progression as markers to look for during instruction. At Springfield the interpretive flexibility of the learning progression supported the convergence of the teachers around the unit of instruction because they could talk through which component led into another. The interpretive flexibility of the learning progression hindered the collective work of the teachers at Monroe, in that their differential interpretations prohibited their mutual engagement in professional development activities.

With respect to the structure of work process needs and arrangements, Star (2010) noted that boundary objects allow community members to work together in the absence of consensus. The interpretive flexibility of the learning progression meant that teachers could still use it to coordinate the work of creating common formative assessments without full consensus on the role the learning progression would play in their formative assessment practice. Indeed, we observed teachers in both studies working around the learning progression without necessarily using it in the same ways. At Springfield, we saw teachers coming to unique conclusions about how to structure their unit during the first year in response to the learning progression, and at Monroe, we observed teachers taking up the learning progression and using it to inform their instruction and interpretation of student ideas in different ways.

We did observe a dynamic between both tailored and ill-structured uses of the learning progression. At both schools we noted instances in which teachers referred to ideas within the progressions without actually calling it out by name at all, indicating the influence of the representation on their community. In other instances, teachers pored over the learning progression together, considering how it might inform the structure of their units or design of

formative assessments. According to this decomposition of the role of the learning progression, it served as a boundary object even if it did not coordinate the design of formative assessment in the two communities in the same way.

*Role of Context, Participants, and Communities*

Viewing summaries of the cases in proximity to each other raises a number of questions about the role of school context in terms of the teachers themselves, the district pressures, and other school initiatives, as well as the ways in which different teachers took up and used the learning progression. With respect to school context, the lack of oversight at Springfield enabled teachers to freely reconstruct their units around the learning progression they helped to develop, and the formative assessments they designed grew out of a combination of their own conversations about the learning progression and their existing instructional activities. The reification of their ideas about the organization of the unit into the learning progression contributed to the coordination of their work around this tool. In contrast, the accountability climate at Monroe meant that the learning progression served a different function within that community. The learning progression was just one of multiple tools provided teachers to organize their instruction, and teachers struggled to balance it with the other information they had been provided. In this way, the learning progression may have maintained its coherence and meaning across the different communities, but it was taken up differently as a result of the participants and climate of each school. This result suggests that the accountability context in which teachers use learning progressions may be integral to the ways in which they are taken up as tools to support teaching and learning. These results are perhaps not surprising given the role that context and participants play in the communities of practice framing (Lave & Wenger, 1991).

We also raise the issue that the participants at each site also influenced the outcomes of the study. While it was not a specific focus of this analysis, one might also attend to specific differences between individuals in each community (e.g., van Es, 2009). Certainly, we do not claim that all individuals in every community held the same view of students and the formative assessments. Our results indicate that some teachers within the study held deficit perspectives of their students, reflecting in interviews and professional development sessions that their students would not be capable of understanding particular ideas, or engaging with certain formative assessment activities. Other teachers noted that the intention of formative assessment was to show students what the incorrect answers were, while others saw the assessments as opportunities to draw out student ideas.

The combinations of individuals at each school site contributed to different conversations and different experiences at each school. At Springfield, teachers described different purposes for the formative assessments, and found different ways of using the different structures of the learning progression—for example, Rachel and Theresa relied on the facts and inferences to sequence their instruction, whereas Robyn and Lisa focused more on the map of student ideas. At Monroe, teachers' engagement with the learning progression varied in relationship to Mark's deficit framing of students, Donna's focus on vocabulary, and Kim's belief that district and state materials limited what she was able to teach. Such beliefs may play a crucial role in teachers' practice (e.g., Luft & Roehrig, 2007; Richardson, 1996; Wallace & Kang, 2004) and may act as filters through which teachers come to understand new practices (Yerrick, Parke, & Nugent, 1997). Ultimately, as Cobb et al. (2003) noted, we do not wish to identify the extent to which individuals within the communities might have different personal resources for the purpose of finding deficiencies, but to take these differences as an indicator of the overall pedagogical resources that may—or may not—be present within the community. Professional development experiences should provide teachers opportunities to draw upon these resources, and to share their instructional goals with each other

as a way to address their core belief sets about students, curriculum, and assessment (Wallace & Kang, 2004).

Lastly, we would be remiss to not note that the nature of teachers' engagement with the learning progression in the two communities was fundamentally different; at Springfield, teachers were positioned as tool developers; at Monroe, teachers were asked to use the tool. Our analysis showed that in the co-development of the learning progression the Springfield teachers reworked how they organized their unit, not because they took on a structure from someone else, rather than reorganized their unit using their own developing understanding.

These results indicate not only potential advantages of teachers engaging in co-construction of the learning progression as a tool to plan for their instruction, but also that drawing input from teachers on the design of learning progressions could be a useful way to get buy-in, as well as to honor and document the insights teachers have to learners and ideas at their own school. It is possible that these tools may be more helpful if teachers are engaged in the process of developing them (Keys & Bryan, 2001). These findings have importance for the NGSS, as they suggest that providing teachers opportunities to engage with the learning progressions on which the standards are based as designers, adapting the progressions to their own school sites and their own knowledge may increase the extent to which the standards are adopted.

A number of questions follow from these issues of participants, context, and community. For example, how might the cases look differently if the learning progression was developed at Monroe, and brought to Springfield? Would the learning progression have been a more central part of teachers' repertoire of tools if they helped to develop it? What if the CAP document had been changed during our time at Springfield, and by the time we got to Monroe the teachers were already accustomed to it? Would the Springfield teachers have felt similarly disoriented by the tools if they were working at a school with greater district oversight? While we cannot respond to these questions, we believe that they help us to identify critical elements of each case that were at play in each case.

For example, the number of tools relied upon within the community and their coordination was a crucial difference between the studies. In addition, the changing district expectations during the study at Monroe created an extra layer of district involvement that was not present at Springfield High School. Finally, the actual practices around the learning progression—developing and reifying it versus appropriating it—were quite different in each study. These results suggest that using learning progressions with teachers is relevant to the contexts in which they are used, and that the consistency of the learning progression with the other tools that are a part of the repertoire of the community is a potential source of tension.

### *Reflecting Upon the Learning Progression Structures*

As we reflect upon our analysis, we acknowledge that the accessibility of the learning progression in its different incarnations may have influenced the way in which it was taken up by each community. Over the course of the 2 years at Springfield, the learning progression was assembled piece by piece, beginning with two different representations that were ultimately synthesized into one. This developmental process may have allowed teachers to interact with each structure of the Daphne learning progression separately, considering on the one hand the decomposition of a well-articulated explanation as represented in Mayr's facts and inferences, and on the other hand the representation of student ideas related to that well-articulated representation. Our analysis indicates that teachers did indeed work with the two structures separately as they considered how to structure their instruction and interpret student thinking. Then, when the two representations were merged, teachers may have been able to better coordinate their work around the final tool as they had been afforded the time and opportunity to work with each piece of it

separately. In contrast, the Elevate version of the learning progression was presented to teachers as at Monroe as a completed tool, and as such teachers were not afforded the same opportunities to take up and work with individual pieces of the learning progression in the same way.

In retrospect, we admit that the learning progression constructed at Springfield might have been conceived in a format that would have better supported its adoption by the Monroe community. For example, it could have focused on fewer dimensions, as it did in its version we used at Springfield, allowing the Monroe teachers to coordinate their work around fewer dimensions. Similarly, we could have presented the learning progression to this community piecewise, starting with the facts and inferences and then focusing on a limited number of smaller dimensions rather than giving it to them wholesale and asking them to identify sections of focus for themselves. Furthermore, one might imagine a version of our learning progression that would move away from Mayr's representation as an organizing structure and decompose the development of a well-articulated explanation based upon the way it develops across grade level, and better represent the productivity of particular student ideas within dimensions rather than as a stand-alone dimension. This approach would draw upon a principle articulated by Wiser, Smith, and Doubler (2009), who intended their learning progression to establish "learning goals in terms of anchors and stepping stones rather than in terms of pieces of expert understanding" (p. 3). This type of learning progression would better mirror those created by Catley et al. (2005), Lehrer and Schauble (2012) and Metz, Sisk-Hilton, Berson, and Ly (2010), and may ultimately assist teachers in drawing upon the ways in which student ideas develop across multiple grade levels, not only within one instructional unit.

Future studies might focus upon how the representation of student ideas in the learning progression might influence the way teachers use it to guide their instruction. Indeed, the multidimensionality of the Elevate learning progression might have included an overwhelming amount of information that spread teachers' attention too thin, versus the simpler representations used in the Daphne study. It is possible that had the learning progression at Monroe focused on fewer aspects of natural selection, it would have been taken up differently. It is possible that teachers would have felt more supported and felt differently had these representations been presented to them differently. Furthermore, future studies could contrast different methods for introducing learning progressions to communities to explore the ways in which teachers responded. For example, one such study could work with the same learning progression but then explore whether presenting it wholesale versus piecemeal would better support teachers' coordination of work.

*Professional Development to Support Teachers in Using Learning Progressions*

In closing, we acknowledge that the findings of this study have implications for supporting instruction with learning progressions. Given the reliance of the *Next Generation Science Standards* (Achieve, Inc., 2013) on learning progressions, thousands of teachers will soon have opportunities to explore the ways in which learning progressions might support classroom instruction. The results of the present study suggest that based on differences in contexts of schools, teachers will take up and work with them in different ways and therefore support the need for implementation research that addresses not only what works, but for whom and under what circumstances (Penuel & Fishman, 2012).

A key finding of this study has been to identify the essential role of long-term professional development to support teachers as they learn to use learning progressions to inform their instruction. At each school site we observed ample evidence of the professional development facilitators guiding teachers in understanding the information the learning progression contained, and drawing upon it to guide their instructional design and interpretation of student ideas.

Furthermore, as the Monroe case illustrates, teachers will need support as they coordinate the learning progressions with other tools they have been provided in the past. However, our findings also suggest that the learning progression was often an implicit tool for teachers which influenced the way they described student ideas, but was not necessarily explicitly referenced during interviews and professional development settings. Future studies might explore the ways in which the tacit influence of learning progressions was related to teachers' instruction in this and other studies.

Teachers often make sense of reforms collectively, relying on their shared understanding of what they are being asked to do, as well as how teaching and learning are organized in their schools (Coburn, 2001). As teachers make sense of reform, they not only interpret the reform, but they also actively create their response to that reform. This active creation of responses to changes in the environment of schools has been referred to as sensemaking (Coburn, 2001, 2004; Spillane, Reiser, & Reimer, 2002). Future studies may focus explicitly on learning progressions from the perspective of sensemaking, as teachers measure the utility of learning progressions as compared to their current practices in the design of their learning opportunities for students.

Nevertheless, as Grossman, Smagorinsky, and Valencia (1999) noted, teaching is a profession focused upon appropriation of tools. The NGSS are the latest in a series of tools that teachers will be asked to integrate into their practice as appropriators, not as co-developers. Ultimately, the coming challenge for science teachers, professional developers, and educational researchers will be to better understand the supports that teachers will need to use these objects to coordinate their work at their school sites. Only then will the full potential of learning progressions to guide classroom instruction be realized.

## References

Achieve, Inc. (2013). Next Generation Science Standards. Retrieved April 10, 2012, from http://www.nextgenscience.org/next-generation-science-standards

Akkerman, S. F., & Bakker, A. (2011). Boundary crossing and boundary objects. Review of Educational Research, 81, 132–169.

Atkin, J. M., Coffey, J. E., Moorthy, S., Sato, M., & Thibeault, M. (2005). Designing everyday assessment in the science classroom. New York, NY: Teachers College Press.

Beason, L. (1993). Feedback and revision in writing across the curriculum classes. Research in the Teaching of English, 27(4), 395–422.

Bennett, R. E. (2011). Formative assessment: A critical review. Assessment in Education: Principles, Policy & Practice, 18(1), 5–25.

Black, P., Harrison, C., Lee, C., Marshall, B., Wiliam, D., Delta, P., & Bloomington, K. (2004). Working inside the black box: Assessment for learning in the classroom. Delta, 1–15.

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., & Wiliam, D. (1998). Assessment and classroom learning. Assessment in Education, 5(1), 7–74.

Black, P., & Wiliam, D. (2009). Developing the theory of formative assessment. Educational Assessment, Evaluation and Accountability, 21(1), 5–31.

Borko, H., Jacobs, J., Eiteljorg, E., & Pittman, M. (2008). Video as a tool for fostering productive discussions in mathematics professional development. Teaching and Teacher Education, 24(2), 417–436.

Brookhart, S. M., Moss, C. M., & Long, B. A. (2010). Teacher inquiry into formative assessment practices in remedial reading classrooms. Assessment in Education: Principles, Policy & Practice, 17(1), 41–58. doi: 10.1080/09695940903565545

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 Achievement.

Clare, L., Patthey-chavez, G. G., Valdés, R., Matsumura, L. C., Valdes, R., & Garnier, H. (2002). Teacher feedback, writing assignment quality, and third- grade students ' revision in lower- and higher-achieving urban schools. The Elementary School Journal, 103(1), 3–25.

Cobb, P., McClain, K., De Silva Lamberg, T., & Dean, C. (2003). Situating teachers' instructional practices in the institutional setting of the school and district. Educational Researcher, 32(6), 13–24.

Coburn, C. E. (2001). Collective sensemaking about reading: How teachers mediate reading policy in their professional communities. Educational Evaluation and Policy Analysis, 23(2), 145–170.

Coburn, C. E. (2004). Beyond decoupling: Rethinking the relationship between the institutional environment and the classroom. Sociology of Education, 77(3), 211–244.

Coffey, J. (2003). Involving students in assessment. In J. M. Atkin & J. E. Coffey (Eds.), Everyday assessment in the science classroom. (pp. 75–87). Arlington, VA: NSTA Press.

Coffey, J. E., Hammer, D., Levin, D. M., & Grant, T. (2011). The missing disciplinary substance of formative assessment. Journal of Research in Science Teaching, 48(10), 1109–1136.

Coffey, J. E., Sato, M., & Thiebault, M. (2005). Up close and personal. Teacher Development, 9(2), 169–184.

Corcoran, T., Mosher, F. A., & Rogat, A. (2009). Learning progressions in science: An evidence-based approach to reform. Philadelphia, PA: Consortium for Policy Research in Education.

Dagher, Z. R., & Boujaoude, S. (2005). Students' perceptions of the nature of evolutionary theory. Science Education, 89, 378–391.

David, J. L. (2008). Pacing guides. Educational Leadership, 66(2), 87–88.

Duschl, R., Maeng, S., & Sezen, A. (2011). Learning progressions and teaching sequences: A review and analysis. Studies in Science Education, 47(2), 123–182.

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. *Learning Progressions in Science Conference*. Iowa City, IA.

Furtak, E. M. (2012). Linking a learning progression for natural selection to teachers' enactment of formative assessment. Journal of Research in Science Teaching, 49(9), 1181–1210.

Furtak, E.M., & Heredia, S. (in press). Exploring the Influence of Learning Progressions in Two Teacher Communities. Journal of Research in Science Teaching.

Furtak, E. M., Ruiz-Primo, M. A., Shemwell, J. T., Ayala, C. C., Brandon, P., Shavelson, R. J., & Yin, Y. (2008). On the fidelity of implementing embedded formative assessments and its relation to student learning. Applied Measurement in Education, 21(4), 360–389.

Furtak, E. M., Morrison, D. M., Iverson, H., Ross, M., & Heredia, S. C. (2011) *A Conceptual Analysis of the Conceptual Inventory of Natural Selection: Improving diagnostic utility through within-item analysis*. Paper presented at the annual meeting of the National Association of Research in Science Teaching Annual Meeting, Orlando, FL.

Furtak, E.M., Thompson, J., Braaten, M., & Windschitl, M. (2012). Learning Progressions to Support Ambitious Teaching Practices. In A.C. Alonzo & A.W. Gotwals (Eds.), Learning Progressions in Science (pp. 405–434). The Netherlands: Sense Publishing.

Gardner, J. (2010). Developing teacher assessment: An introduction. In J. Gardner W. Harlen L. Hayward G. Stobart & M. Montgomery (Eds.), Developing Teacher Assessment. (pp. 1–11). Berkshire, England: Open University Press.

Geraedts, C. L., & Boersma, K. T. (2006). Reinventing natural selection. International Journal of Science Education, 28(8), 843–870.

Greeno, J. G. (2006). Learning in activity. The Cambridge handbook of the learning sciences (pp. 79–96.). Cambridge, United Kingdom: Cambridge University Press.

Grossman, P. L., Smagorinsky, P., & Valencia, S. (1999). Tools for teaching English: A theoretical framework for research on learning to teach. American Journal of Education, 108(1), 1–29.

Harrison, C. (2005). Teachers developing assessment for learning: Mapping teacher change. Teacher Development, 9(2), 255–263. doi: 10.1080/13664530500200251

Heritage, M. (2008). Learning progressions: Supporting instruction and formative assessment. (p. 31). Washington, DC: Retrieved from http://www.ccsso.org/Resources/Publications/Learning_Progressions_Supporting_Instruction_and_Formative_Assessment.html

Heritage, M., Kim, J., Vendlinski, T., & Herman, J. (2009). From evidence to action: A seamless process in formative assessment? Educational Measurement: Issues and Practice, 28(3), 24–31. doi: 10.1111/j.1745-3992.2009.00151.x

Huberman, M. (1993). The lives of teachers. New York, NY: Teachers College Press.

Kazemi, E., & Hubbard, A. (2008). New directions for the design and study of professional development: Attending to the coevolution of teachers' participation across contexts. Journal of Teacher Education, 59(5), 428–441. doi: 10.1177/0022487108324330

Keys, C. W., & Bryan, L. A. (2001). Co-constructing inquiry-based science with teachers: Essential research for lasting reform. Journal of Research in Science Teaching, 38(6), 631–645.

Lave, J., & Wenger, E. (1991). Situated learning: Legitimate peripheral participation. Cambridge, United Kingdom: Cambridge University Press.

Lehrer, R., & Schauble, L. (2012). Seeding evolutionary thinking by engaging children in modeling its foundations. Science Education, 96(4), 701–724.

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. (1982). The Growth of Biological Thought: Diversity, evolution, and inheritance. Cambridge, MA: The Belknap Press of Harvard University Press.

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

Merriam, S. (1998). Qualitative research and case study applications in education. San Fransisco, CA: Jossey-Bass Publishers.

Metz, K. E., Sisk-Hilton, S., Berson, E., & Ly, U. (2010). Scaffolding children's understanding of the fit between organisms and their environment in the context of the practices of science. In Proceedings of the International Conference of the Learning Sciences. (Vol 1, pp. 396–403).

Miles, M. B., & Huberman, A. M. (1994). Qualitative data analysis. Thousand Oaks, CA: Sage Publications.

National Academy of Sciences. (1998). Teaching about evolution and the nature of science. Washington, DC: National Academy Press.

National Research Council. (1996). National Science Education Standards. Washington, DC: National Academy Press.

National Research Council. (2001). Inquiry and the National Science Education Standards. Washington, DC: National Academy Press.

National Research Council. (2007). Taking Science to School: Learning and Teaching Science in Grades K-8. Committee on Science Learning, Kindergarten Through Eighth Grade. R. A. Duschl, H. A. Schweingruber, & A. W. Shouse, (Eds.). Board on Science Education, Center for Education. Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

Pellegrino, J. W. (2012). Assessment of science learning: Living in interesting times. Journal of Research in Science Teaching, 49(6), 831–841.

Penuel, W.R., & Fishman, B.J. (2012). Large-scale science education intervention research we can use. Journal of Research in Science Teaching, 49(3), 281–304.

Richardson, V. (1996). The role of attitudes and beliefs in learning to teach. In J. Sikula (Ed.), Handbook of research on teacher education (2nd ed., pp. 102–118). New York, NY: MacMillan.

Rogoff, B. (1995). Observing sociocultural activity on three planes: Participatory appropriation, guided participation, and apprenticeship. In J. V. Wertsch, P. del Rio, & A. Avarez, (Eds.), Sociocultural studies of the mind. New York, NY: Cambridge University Press.

Sadler, D. R. (1989). Formative assessment and the design of instructional systems. Instructional Science, 18(2), 119–144.

Shavelson, R. J. (2009) Reflections on learning progressions. *Learning Progressions in Science Conference*. Iowa City, IA.

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

Smith, C. L., Wiser, M., Charles, W., & Krajcik, J. (2006). Implications of research on children' s learning for standards and assessment: A proposed learning progression for matter and the atomic-molecular theory. Measurement: Interdisciplinary Research and Perspectives, 4(1–2), 1–98.

Songer, N. B., Kelcey, B., & Gotwals, A. W. (2009). How and when does complex reasoning occur? Empirically driven development of a learning progression focused on complex reasoning about biodiversity. Journal of Research in Science Teaching, 46(6), 610–631.

Spillane, J. P., Reiser, B. J., & Reimer, T. (2002). Policy implementation and cognition: Reframing and refocusing implementation research. Review of Educational Research, 72(3), 387–431.

Star, S. L. (2010). This is not a boundary object: Reflections on the origin of a concept. Science, Technology & Human Values, 35(5), 601–617.

Star, S. L., & Griesemer, J. R. (1989). Institutional ecology, 'translations' and boundary objects: Amateurs and professionals in Berkeley's museum of vertebrate zoology, 1907–39. Social Studies of Science, 19(3), 387–420.

van Es, E. A. (2009). Journal of the learning participants ' roles in the context of a video club. *Education*, October 2011, 37–41.

Wallace, C. S., & Kang, N.-H. (2004). An investigation of experienced secondary science teachers' beliefs about inquiry: An examination of competing belief sets. Journal of Research in Science Teaching, 41, 936–960.

Wenger, E. (1998). Communities of practice. New York, NY: Cambridge University Press.

Wiliam, D., & Thompson, M. (2007). Integrating assessment with learning: Will it work? In C. A. Dwyer (Ed.), The future of assessment: Shaping teaching and learning. (pp. 53–82). New York, NY: Routledge.

Wiser, M., Smith, C. L., Doubler, S, & Asbell-Clarke, J., (2009). Learning progressions as tools for curriculum development: Lessons from the Inquiry Project. Paper presented at the Learning Progressions in Science (LeaPS) Conference, June 2009, Iowa City, IA.

Yin, R. K. (2003). Case study research: Design and methods. Thousand Oaks, CA: Sage Publications.

Yerrick, R. K., Parke, H., & Nugent, J. (1997). Struggling to promote deeply rooted change: The "filtering effect" of teachers' beliefs on understanding transformational views of teaching science. Science Education, 81, 137–159.

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