Title: Developing Beginning Teachers’ Practices of Science Teaching by Learning from Students

Abstract

Developing teachers’ capabilities through learning from practice is one core problem for improving teaching and teacher learning (Ball & Cohen, 1999). This qualitative multiple case study explores how novice teachers learn from their students and modify teaching practices when they engage in formative assessment activity, and what conditions best support their learning from students. Fourteen secondary science teacher candidates of a university based teacher preparation program participate in this study. Their assessment tasks (questions), student responses and teachers’ analysis, teaching videos, and interviews are used as sources of data. The findings illustrate three models of formative feedback loops—cognitive, social, and behavioral—that characterize the nature of teachers’ learning from their students. The in-depth analysis using three representative cases shows that the type and nature of the formative feedback loop is not only shaped by teacher candidates’ depth of understanding about disciplinary teaching and learning, but also reflects the nature of social contexts where the work of learning from students is situated, the ways in which the activity is structured, and candidates’ professional momentum toward being a certain kind of teacher. The implications for creating opportunities for teachers to learn from students are discussed.

Key words: learning from practice, learning from students, student work analysis, practices, teacher learning, teacher preparation, formative assessment
Introduction

Providing the best opportunities for beginning teachers to develop their own routines and practices that help them to continue to learn about teaching throughout career is one important goal of teacher education. There is general consensus that initial training can only lay the foundations for career-long development towards expert teaching (Darling-Hammond & McLaughlin, 1995; Feiman-Nemser, 1983; Grossman & McDonald, 2008; Hiebert, Morris, Berk, & Jansen, 2007; Windschitl, Thompson, & Braaten, 2011) Creating beginning teachers’ capacity for much better learning about teaching as a part of teaching is a powerful way to improve both teaching and teacher learning (Ball & Cohen, 1999).

Teachers can develop powerful evidence-based practices that support students’ participation and understanding by successfully learning from their students (Bianchini & Cavazos, 2007; Darling-Hammond & Richardson, 2009; Little, 2004). When closely looking at student responses to their instruction, teachers have opportunities to learn about the knowledge and experiences of students, as shaped by their identities as knowers and learners of science (Calabrese Barton & Tan, 2009; Tan & Calabrese Barton, 2008), and how they play out in students’ engagement and participation in classroom communities. Recognizing students’ ideas, partial understandings, misconceptions, ways of thinking, and identities as learners enables teachers to modify their practices in a way of better supporting students’ engagement both rigorously and equitably. This potential ‘two-way feedback loop’ for both teacher and student learning make the idea of learning from students powerful and promising as highlighted in many previous studies on teacher learning (Ball & Cohen, 1999; Bianchini & Cavazos, 2007), collaborative inquiry into student work (Kazemi & Franke, 2004; Little, Gearhart, Curry, & Judith, 2003; Thompson, et al., 2009; Windschitl, et al., 2011), and assessment for learning (Black, Harrison, Lee, Marshall, & Wiliam, 2004; Gerard, Spitulnik, & Linn, 2010).

Despite its potential in developing powerful instructional practices, little has been known about how teachers learn from their students and which conditions provide the best opportunities for their learning. This study investigates how beginning science teachers learn from students through formative assessment activity. Formative assessment is a type of activity that supports teachers’ learning from students, in particular, students as sense-makers (Black & Wiliam, 1998; Coffey, Hammer, Levin, & Grant, 2012) and helps teachers to modify their practices using information from the assessment. Specifically, this study examines what beginning teachers learn about their students when they engage in formal formative assessment activity, how they learn from their students, and how their engagement in the activity influences (or not) their development of teaching practices.

Background

Learning from students and developing practices of teaching

The process of learning from students involves teachers paying attention to particular aspects of information about a student as a science learner, and then making sense of it in a way that informs their teaching. Both what to attend to and how to make sense of it reflects teachers’ depth of understanding on teaching and learning (Little, et al., 2003), their goals as a teacher, and their professional identities (Kazemi & Franke, 2004). Teachers can learn about students’ ideas, participation, and/or identities as a science learner by attending to particular aspects of information about their students. I draw upon the notions of professional vision (Goodwin, 1994)
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Goodwin (1994) discusses professional vision that “consists of socially organized ways of seeing and understanding events that are answerable to the distinctive interests of a particular social group” (p. 606). Participants of professional activities, such as teachers, use highlighting and coding as the practices to build their professional vision. Highlighting is the process of attending to and identifying particular aspects of a complex social activity. Coding involves interpreting what they attend to after picking out a specific aspect of activity. Professional vision recognized through the practices of highlighting and coding reflects someone’s depth of understanding of an event being seen as well as their attached cultural values. People who have a different professional vision construct different stories about the same event by highlighting different aspects of activities and making different interpretations. For instance, a maestro can tell a story about the quality of a symphony by highlighting and coding particular aspects of it that most people do not even notice. An exemplary teacher tells insightful stories about teaching and learning while picking out important features of instruction that novice teachers do not notice even when they attend to the same instructional event together. Built upon Goodwin’s work, van Es and Sherin (Sherin & van Es, 2005; van Es & Sherin, 2008) propose the ability to notice classroom interaction as a key feature of teaching expertise. They highlight the roles of teacher knowledge on teaching, learning, and learning environment in teachers’ capability of noticing important features of classroom practices in the context of a teachers’ video club.

Telling a story of any event to a particular social group (i.e. professional community) through highlighting and coding is also influenced by the goals of a teacher, prioritized values, and social contexts where the work of highlighting and coding is situated. Consider two teachers who tell stories of what they learned about students after watching the same teaching episode. The two teachers who have different prioritized goals in their mind (e.g., teaching for social justice versus engaging students in scientific inquiry) may pick out different aspects of teaching and learning, and then make an interpretation in light of their goals and prioritized values in the moment. What and how teachers learn from their students are contingent on social contexts in which the work of highlighting and coding is situated as well. Teachers always tell stories of teaching and learning in response to and addressing expectations and relationship with people (i.e., members of communities of practices) who become the audience of their stories. While telling stories of teaching through highlighting and coding, a teacher continuously (re)positions his or herself as a member of a professional community that shares particular practices, norms, and values in the moment. Therefore, it becomes, in part, being a certain kind of person as a teacher—developing identities as a teacher (Kang & Anderson, 2009; Kazemi & Franke, 2004; Sfard & Prusak, 2005; Wenger, 1999).

Learning from students is productive and meaningful only when the lessons drawn from the experiences inform the teacher’s instruction in a way of better supporting students’ meaningful interaction with both disciplinary ideas and people. Change or modification of practices of teaching is an essential part of learning from students, and teachers should be able to plan and enact a specific strategy of action that addresses any issues about student learning that they notice based on their interpretation of them. The enactment of strategy of action is the key part of the work of practitioners, such as teachers (Kennedy, 1999), which leads them to develop powerful evidence-based practices. Those strategies of actions, however, are fundamentally constrained by teachers’ capability of noticing and interpretation of students’ learning. Strategies
of action are also constrained by both a teacher’s resources (e.g., depth of understanding about disciplinary subject, current teaching practices, a teacher’s interpersonal skills etc.) and other resources that a teacher can access to and leverage in the moment (e.g., tools, advice or comments, practices and resources from other professionals).

In short, what teachers learn from their students depends on what they attend to in regards to students as science learners (i.e. highlighting), and how they make sense of it (i.e., coding or interpreting). The work of highlighting and coding that is projected in their verbal or written stories about students is shaped by their understanding about the disciplinary subject, and teaching and learning. This work is also influenced by their identity work in the moment—trying to be a certain kind of teacher with goals and prioritized values—while telling stories of teaching and learning as a member of professional communities. Teachers develop practices of teaching by enacting strategies of action as their responses.

**Learning from students by designing assessments and analyzing student work**

This study focuses on beginning teachers’ learning from students when they engage in designing and analyzing student work, framed as formative assessment activity, during their initial training. Formative assessment is defined as the process by which teachers use evidence of students’ understanding to modify teaching to make it more effective (Black, et al., 2004). Classroom formative assessment is described as a continuum between preplanned, curriculum-embedded assessment, and spontaneous, “on-the-fly” assessment (Bell & Cowie, 2001a; Ruiz-Primo & Furtak, 2007). Typically, when teachers engage in formal formative assessment, they gather information about students’ developing understanding from preplanned activities, interpret and act upon this information (Bell & Cowie, 2001b; Furtak & Ruiz-Primo, 2008). While engaging in formal formative assessment activity, teachers take time for analyzing student responses in order to plan an action based on the information that they gain. Therefore, effective engagement in a formal formative assessment provides intense opportunities for teachers to learn from their students by systematically analyzing student work and their instruction. Teachers can learn about their students as “sense-makers” paying attention to students’ ideas and reasoning (Coffey, et al., 2012), and to make the needed modification of their practices based on the evidence of students’ understanding (Treagust, Jacobowitz, Gallagher, & Parker, 2001).

Previous studies of formative assessment provide some insights on the complexity and depth of challenges for beginning teachers’ learning from students with respect to both designing assessments and analyzing student work. Designing student work by selecting particular assessment tasks or questions is a critically important first step (Clarke & Clarke, 1998; Furtak & Ruiz-Primo, 2008). Furtak and Ruiz-Primo’s study (2008) demonstrates how the types and nature of prompts that teachers use influence the quality of student responses produced in a both written and verbal form, which is the starting point of learning from students. The interpretative nature of assessment work also poses another challenge for successful learning from students (Morgan & Watson, 2002) because it requires depth of knowledge about the discipline, teaching and learning, as well as analytical reasoning skills. Coffey, Hammer, Levin, and Grant (2011) note that the formative assessment is fundamentally “attending to and responding to student ideas, reasoning, as a seamless part of teaching” (p. 4, italics added), with roots in disciplinary activity and goals. What teachers learn from students when they engage in formative assessment activity, therefore, depends on their capabilities of attending and responding to student ideas. In the context of formal formative assessment, the opportunities for teachers to learn is constrained
by the quality of student written responses produced from assessment designed by teachers themselves.

**Conceptual framework of learning from students**

Drawing on the notion of professional vision and the literature on formative assessment, this study conceptualizes the process of learning from students as having four dimensions: (a) providing *opportunities* for students to give information about themselves as science learners through the design of assessment tasks or questions, (b) *highlighting* (i.e., attending to or framing) particular information about students from the produced student work, (c) *interpreting* (i.e., coding) what they highlight in relation to student learning, and (d) *responding* to students via planning and/or enacting specific strategies of action (see Figure 1). When teachers design assessment tasks (questions), teachers provide *opportunities* for students to show their understanding or participation. As their responses to the provided opportunities, students produce certain outcomes (e.g., written responses, drawing). While teachers analyze student work collectively and/or individually, teachers *highlight* certain information and make *interpretations* about student learning. Finally, teachers plan or enact specific strategies of action as their *responses* based on their interpretation. The successful engagement of this process leads teachers to create a *formative feedback loop* that informs both teachers’ instructional practices and students’ learning.

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**Research Questions**

This study examines 14 secondary science teacher candidates’ learning from students when they design and analyze student work with the support of a university based teacher preparation program. The following questions guide this study:

1. How do secondary science teacher candidates learn from their students by designing and analyzing student work with supports of a reform-oriented teacher preparation program?
   a. What kinds of opportunities do teacher candidates provide for their students to give information about students themselves as science learners through their assessment tasks?
   b. What do they highlight from student responses and how do they interpret what they highlight?
   c. How do they use the information about students to modify their instruction? What strategies of actions do they plan and (or) enact as their responses?

2. Why do teacher candidates develop different kinds of practices of teaching by designing and analyzing student work?

3. How does the activity of designing assessment and analyzing student work, framed as formative assessment activity, mediate teachers’ learning from students and development of evidence-based practices?

**Method**

This investigation is a multiple case study (Stake, 2004; Yin, 1989) with 14 secondary science teacher candidates in a university-based teacher preparation program for a research period totaling three years. I first describe the contexts where the activity of designing and
analyzing student work is situated and the way in which the activity is structured before turning into research activity.

Research context and the structure of activity

The context of this study is a reform-oriented five-year undergraduate teacher preparation program at a large Midwestern University. Teacher candidates take four sequenced field-based disciplinary-specific methods courses over two years, beginning with the senior (4th year) to internship year (5th year). One cohort of about 30 secondary science teacher candidates works with two instructors for two years. The program is designed to gradually increase candidates’ experiences in the field while providing principled coaching with the goal of supporting candidates’ development of research-based practices. In their senior year (4th year) candidates are placed in local schools as pairs, and have opportunities of observing a mentor teacher’s lessons and enacting their lesson plans with the guidance of the course instructors. During their internship in the 5th year, they work at the field site as a full-time intern four days a week and take methods courses at the university. Candidates are provided coaching from course instructors and field supervisors around the teaching cycle—planning, teaching, assessment, and reflection—by engaging in deliberately designed activities of the program.

Designing and analyzing student work is one of the core activities of the methods courses across the senior and internship year. Candidates are required to design two to three formative assessment tasks/questions tied to their proposed learning objectives, and to enact them at their field placements. It is so called ‘a deliberately designed occasion for learning’ provided by the program to support candidates’ learning from their students. A candidate designs or selects assessment tasks/questions drawing upon resources available to them, including mentors, programs, or their field supervisor’s recommended resources. Candidates also get formal feedback on their tasks or questions from their course instructors before enactment. Candidates collect student work, and analyze and discuss the collected student work with their instructors and peers in their methods courses. Finally, they select three focus students who are at different achievement levels, and develop written reports.

Participants

A total of 14 teacher candidates from three cohorts participated in this study. In addition, fourteen mentor teachers and two course instructors who worked with the participating candidates were each interviewed. The purpose of the interviews was to understand the nature of professional communities and of candidates’ interaction with people in important social contexts where the work of learning from students was situated. Participating candidates were selected from a pool of volunteers as a way of representing the student population of the program. Four candidates from three consecutive cohorts were selected during the period of data collection, 2008-2010 balancing out their school contexts, major, gender, and school level (see Table 1). The first four candidates from cohort I—Monica, David, Teresa, and Susie—were interns (5th year), and the second four candidates, from the cohort II—Leslie, Shannon, Mary, and Kevin—were seniors (4th year) in the Year 1 of this study (2008-09). Two of them, Leslie and Shannon, continued to participate in this study in Year 2 (2009-10) during their internship period, and another two candidates, Adam and Alisa, replaced Mary and Kevin due to the distance of their internship placements from the research site. The third group of four candidates, from cohort
III—Lori, Lynn, Stella, and Scott—participated during the Year 2 (2009-10) as seniors along with the four interns from cohort II (see Table 1 for the details of participants’ profiles).

**Data Collection**

Data were collected for two years to examine how and why teacher candidates develop practices of science teaching by learning from their students through formative assessment activity. The sources of data include: (a) two to four sets of written documents that include student responses to the assessment tasks/questions, candidates’ analysis, and plan for or report of action, (b) candidates’ teaching videos, (c) individual interviews using each candidate’s teaching video with candidates, mentor teachers, and course instructors, and (d) individual interviews with candidates using a clinical interview video.

**Written documents.** The major source of data was two sets of written documents produced from candidates’ participation in formative assessment activities. These documents included the assessment tasks or items, student responses, candidates’ analysis on student responses, and their plan for or report of action. The documents showed at least three students’ responses to two or three assessment tasks, and the candidates’ analysis. One set of documents was produced from an ‘inquiry activity sequence’ at the last stage of their program. Compared to other general teaching episodes, this inquiry activity sequence was deliberately designed and strongly structured by the program to prompt teacher candidates to engage their students in authentic disciplinary practices.

**Candidates’ teaching videos.** Candidates videotaped their lesson as part of their course work along with producing a written report of their teaching. Each candidate’s teaching video provides information about the nature of designed student work and the nature of candidates’ interaction with students.

**Interviews using teaching videos with candidates, mentor teachers, and course instructors.** I conducted individual interviews with all 14 candidates, the 14 mentor teachers, and the two course instructors. During the interviews, I showed each candidate’s self-made teaching video to the candidate him or herself, their mentor teacher, and course instructor. The interviews provided opportunities for candidates to tell stories about themselves and practices of science teaching while highlighting and coding students’ responses to their instruction. The interview was semi-structured; typically one interview took between 60 and 70 minutes. Short segments of videos (3 to 7 minutes long) that captured candidates’ interaction with students were used for interviews.

**Interviews about a struggling science student in a video.** I also conducted individual interviews with the eight teacher candidates from cohort I and II, showing a clinical interview video with a sixth grade student, Jeremiah. This interview, by using the same video, created a ‘controlled’ environment where candidates were provided with exactly the same information about a struggling science student through video, and had opportunities of highlighting, interpreting, and responding to the student. In this video, Jeremiah talked about his rich personal experiences of gardening with his brother, demonstrating his knowledge about plants. At the end of the video, he dismissed the school knowledge associated with the term “photosynthesis” by saying, “I don’t know a lot about photosynthesis. I did not pay attention to that part.” During the individual interviews, the candidates watched and responded to Jeremiah by answering questions. This interview was used as complementary data to triangulate candidates’ patterns of learning from students that emerged from other data sources.
Data Analysis

Data analysis was conducted with the help of a computer software program for assisting qualitative analysis. At the initial stage, I developed analytical memos while reading through the data to develop the coding schemes. The coding scheme was refined iteratively along with the development of conceptual framework. The 14 candidates’ cases were coded with respect to four dimensions of learning from students (i.e., provided opportunities, highlighting, interpreting, and responding) using the developed coding schemes. The unit of analysis was one student response coming along with opportunity, highlighting, interpreting, and responding. The coding results were quantified as a relative percentage chart to find the patterns in each and across candidates. This relative percentage chart showed which aspect of information about students (i.e., content understanding, social/personal aspect, and behavioral aspect) was relatively emphasized in their highlighting, interpreting, and responding.

Based on the initial coding results, I subsequently set up comparisons of three cases in similar contexts (i.e., under-resourced urban high schools) but showed different ways of learning from students. The comparison of cases in similar context helps me understand the uniqueness and complexities of the process in-depth (Stake, 2004, p. 457). I then used a constant comparative approach to analyze the data on comparable dimensions of learning from students, the nature of locally created opportunities of learning for each candidate, the nature of participation in professional communities, and the relationship with people and resources across three cases (Denzin & Lincoln, 2005). This approach helped me move beyond description to a theoretical understanding of teachers’ learning from students through their participation in formative assessment activity.

Findings

I found three groups of candidates who learned from their students in substantially different ways as they designed and analyzed student work, and showed different progress in developing their practices. This section first presents the characteristics of learning from students of each group with respect to the nature of opportunities provided with assessments, highlighting and interpretation of student work, and responding. It follows three candidates’ cases, Leslie, Susie, and Teresa, as a representative of each group, to provide in-depth picture on how and why candidates learned from students and modified (or not) their teaching practices. The description of contexts and the nature of each candidate’s participation in activity helps show how formative assessment activity, as framed in this study, mediated candidates’ learning from students.

Learning from students while attending to student thinking, social engagement, and behaviors

The 14 teacher candidates engaged in the practices of providing opportunities (i.e. designing assessments), highlighting, interpreting, and responding while attending to particular aspects about students (see Table 2). Student thinking group consisted of five candidates who focused mostly on students’ ideas and their sense-making process. Social group was the two candidates who particularly attended to students’ social and emotional engagement. The seven candidates who mostly focused on behavioral or management aspect were grouped as Behavioral group.

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1 See the coding scheme in Appendix 1
**Student thinking and social group.** Overall the candidates in both the thinking and social groups successfully used information from students to modify their teaching practices enacting specific strategies of action. They tended to design or select tasks or questions that revealed rich information about students as science learners. Their tasks or questions provided students opportunities of either using scientific ideas in or applying these ideas to novel situations, or developing their explanation about certain phenomena through reasoning. For example, one candidate in the social group designed an activity where students, in teams, drew a picture of how ice melts in their hand, and then explained what is happening at a molecular level and where the energy goes. This candidate asked, “Why does the table surface feel “colder” than a wood surface.”

Students of these candidates usually produced complex and extended responses as they engaged in the designed opportunities. The candidates in the student thinking group mostly highlighted important information about students as sense-makers, such as students’ initial or developing ideas, partial understanding on the topic, and misconception. The candidates in the social group highlighted students’ patterns of participation and interaction with people in different social contexts attending to their emotional or social involvement.

Two candidates in the student thinking group, Leslie and Alisa, made their interpretation and suggested or enacted specific strategies of action that were tightly connected to the highlighted evidence of student understanding or their interpretation of student difficulties—where the difficulties came from. The interpretation of students’ difficulties was related to the nature of instructional activities provided by themselves, students’ personal experiences, missing experiences, or social/cultural resources. For example, in the unit on the rock cycle, one candidate stated in response to a student’s comment, “Diamond could have confused her because if she was thinking of it as jewelry in her mind, it would not be completely naturally occurring.” Both Leslie and Alisa suggested or enacted specific strategies of action that directly addressed students’ cognitive difficulties, such as asking specific questions or providing complementary experiences. The other three candidates in the student thinking group, however, frequently missed providing interpretation or planning/enacting any specific strategies of action, indicating that they failed to completely form the formative feedback loop even when they were provided the opportunities of learning from students.

Two candidates in the social group often drew upon rich information about students’ backgrounds, such as family, home, social and emotional characteristics, and took them into account while making interpretations about students’ written responses. For example, Monica, one of the candidates in the social group recognized that her student was recently placed in foster care, and considered it in her interpretation: “He was recently placed in foster care and I think the number of class days he missed drastically affected his results. In general, he seemed to struggle most on the application questions that not only used information from this unit but also required students to draw upon knowledge from prior units.” The strategies of action of the two candidates in the social group were uneven. Sometimes the strategies of action were specific and addressed students’ difficulties in understanding the materials or participation. Sometimes their strategies of action were broad and general, such as “showing the value of learning,” which did not necessarily address the manifested student difficulties (see Table 3).

**Behavioral group.** The seven candidates in the behavioral group tended to attend students’ behaviors, personality, and management issues while highlighting and interpreting
student response. The analysis suggests that they were less successful in making modifications to their teaching practices in a way that addressed manifested student difficulties.

There were stark differences in types and nature of opportunities provided by the candidates in the behavior group from the ones by the student thinking group and the social group. The candidates in the behavioral group mostly designed or selected tasks or questions that engaged students in simply reproducing textbook explanations or factual information. Some of the tasks or questions had students display some skills or procedural knowledge by engaging in simple problem solving type work. Some examples are: “What are the four major categories of biomolecules?” “Today (Feb.3rd) is the birthday of Dr. Henry HiemLich. The Hiemlich maneuver works because of which gas law?” “Name the major types of atomic bonds and explain the differences between them.”

Students of the behavioral group candidates’ classrooms mostly produced simple and short answers as they engaged in those opportunities, about such things as chemical formula, terminologies, definitions, or description of simple cause and effect. The characteristics of both questions and produced student responses were sensitive to the subjects (e.g., physics, chemistry) to some degree. Tasks designed by physics candidates tended to ask students to explain what and why things happen in a certain real world scenario, whereas tasks designed by chemistry candidates were often focused on problem solving using a chemical formula. The candidates in both groups mainly highlighted correctness or completeness of student responses making binary opposites such as right or wrong, complete or incomplete in a broad and general way. When they highlighted students’ ideas, they easily described them as a misconception or wrong idea that needed to be removed.

Then, the candidates in the behavioral group tended to simply highlight the correctness of students who gave the right answer. Their interpretation about students who failed to give them the right answer or failed to complete the work was mostly attributed to students’ attitudes, attentiveness, behaviors, personalities, and motivation issues. For example, one candidate, David, interpreted one of the “wrong responses” of his student, Pat who thought of the bladder as part of the digestive system as the following:

Pat got all but three of them correct and for some reason she still labeled the bladder as part of the system. I am a little confused here because we haven’t even talked about the urinary system yet and I made it a point to say that urine was not involved with the digestive system and that it only creates solid waste. This student is definitely more talkative in class, so there is a chance that she may have missed this. The only other organ she missed was the gall bladder which we didn’t spend much time on other than just saying it was up under the liver and it stores the bile created by the liver.

For the most part, the candidates in the behavioral group did not make any further interpretation about their observation. At most units of analysis, candidates’ responses were broad and non-specific, and were not directly related to students’ difficulties. Examples of this type of response to students are “spending a little bit more time with it...because it is a difficult part and students need more practice” or “giving them the framework of notes like the teacher had.” Sometimes candidates in this group provided few to no responses (see Table 3).

The case of Leslie in the student thinking group: Attending to student thinking and addressing students’ difficulties with specific instructional strategies of action.
Leslie was a white female majoring in Biology. She participated in this study for two consecutive years from her senior to internship year. She worked at the diverse urban high schools in both years where classroom management was a big challenge for most candidates. Her mentor teachers in both years were fairly traditional but supportive. They were open to new ideas and tried to “provide [Leslie] with whatever type of experience [she] would like” even though their instruction was fundamentally didactic. Leslie consistently paid attention to her students’ ideas and their understanding of science. Leslie liked asking questions of students or getting questions from students because questions allowed her to “pull information out of the students.” Leslie asked many questions to her mentor teacher, Mrs. F, focusing on students’ thinking and their responses on the topic, such as “How do you think the students are going to respond to this?” “Do you think they are going to struggle with this?” Leslie’s classroom was dynamic and interactive because students worked with their partners or as a group, and asked her many questions. Her course instructor, Dr. G, described Leslie as “one of our top candidates” who is “very attentive” to any comments or advice, and “even revising her unit or lessons, even if technically she didn’t need to revise it.” In her teaching philosophy statement, Leslie stated, “It is my job as a teacher to help students make the connections between science content and real life. It is also my responsibility to provide opportunities for students to find the science in their everyday activities, bringing a new awareness that allows them to find value in, as well as take ownership of their learning.”

**Learning from students by engaging in the inquiry activity teaching sequence.**

**Opportunities.** It was within the unit of evolution by natural selection that Leslie designed her inquiry activity lesson sequence. Students formulated questions about evolution for themselves, engaged in two data collection activities (i.e., a toothpicks activity and the bird beak lab). They analyzed data and discussed the results along with the idea of Darwin’s theory of natural selection introduced by Leslie.

Leslie designed several embedded assessments throughout her inquiry activity, but the key questions appeared on the lab worksheet toward the end of the activity. The questions were, “How did the environments affect the shape of the beak that could survive on each of the islands?,” “Explain evolution using the three key ideas of (a) natural selection, (b) over reproduction, and (c) random mutation, including examples that explain your ideas, on a blank paper.” Students had to explain the mechanism of certain phenomena (i.e., change in population) using scientific theories or models (i.e., evolution by natural selection) that was co-constructed through collective classroom inquiry activities (i.e., toothpicks lab, bird beak lab). Leslie provided opportunities for students to use scientific theories or models to explain natural phenomena with thoughtful scaffolding.

**Highlighting & interpreting.** Leslie’s questions produced rich information about students’ ideas and their thinking. Leslie carefully compared student responses with the ideal responses that she expected, and identified what students knew, partially knew, and what was missing. For example, Leslie stated:

The students all stated that evolution was a change in species over time. Many of them were also able to explain what natural selection was; however, very few of them stated that natural selection was the force behind evolution. Some students could not explain natural selection the way it was described in the book or in the notes but they could give great examples about how it works. [Leslie, Intern, Inquiry activity report]
In this account, Leslie interpreted students’ responses that included appropriate examples about the mechanism of evolution positively although students did not describe “the way it was described in the book.”

**Responding.** Leslie interpreted the lack of clarity in students’ responses regarding the relation of a genetic change in the process of evolution as caused by her unclear assessment task. Leslie thought that it is important to “establish a strong problem at the beginning of the inquiry activity sequence,” so that students can “try to come up with their own explanations to the problem at this stage” to “dig deeper into students’ thinking.” Leslie’s strategies of action were very specific and directly tied to highlighted student difficulties. Leslie stated, “I would give them a rubric that would help students identify the important concepts as well as give them a problem to solve.” The analysis of Leslie’s highlighting, interpreting, and responding indicates that she received productive feedback on her instructional practices from students by designing and analyzing student work.

**Patterns of Leslie’s learning from students across multiple data.** The results showed that Leslie consistently provided opportunities for students to reveal their scientific ideas or thinking by engaging them in scientific practices even from the beginning of her senior year. For instance, in her lesson about DNA fingerprinting from her senior year, Leslie had her students respond to the question of “why might the non-coding regions of a person’s DNA be more variable than their coding regions of DNA (think back to what you have learned about mutation)?” In another lesson about microscopes and cells from her senior year teaching episode, Leslie had students observe onion and cheek cells to find similarities and differences between plant and animal cells, and then use that information to solve a problem of identifying an unknown material on the table. Her assessment questions included types of questions that ask factual information, but those questions were asked in the contexts of investigation or application activities.

As the responses to Leslie’s assessment questions or tasks, students produced many interesting answers that showed their ideas, misconceptions, and thinking processes. Leslie identified students’ scientific ideas, including partial understandings or misconceptions from the responses, interpreted students’ ideas in relation to the experiences provided through her instruction or students’ prior experiences, and then suggested specific instructional modifications that were directly connected to the students’ identified difficulties (see Figure 2). For instance, in her lesson about microscopes and cells where students compared and contrasted plant and animal cells from the observation of onion and cheek cells, Leslie identified a low achieving student’s difficulties in understanding cell structure, highlighting misconceptions about the nucleus. Leslie stated, “My low achieving student, Cathleen, was unable to correctly identify a cell and a nucleus. She even had the misconception that a nucleus was its own cell which she called a ‘neluic cell.’” She thought that the misconceptions about the nucleus might be associated with insufficient observations about cells and nucleus provided with her instruction. Leslie stated, “I think it would have been useful for me to point to a cell and a nucleus on more than one kind of cell instead of just doing it once during the demonstration.” She suggested providing more experiences for observing differently shaped cells to help students find patterns among them. She said, “I would spend more time looking at pictures of cells under the microscope...I think that for some students, it would have been useful to practice identifying all kinds of different shaped cells and point out that the nucleus is always inside a cell, never on its own and never its own cell.” Leslie’s responses were specific and tied to the difficulties that she identified
in students. The analysis suggests that Leslie was successful in learning from her students by designing and analyzing student work guided by the program as demonstrated in this one teaching episode.

The patterns of practices that emerged from Leslie’s own teaching episodes were even consistent with her approaches toward assessing and responding to Jeremiah, the student in the clinical interview video. In this controlled context, Leslie identified accurately what Jeremiah did know and did not know in great detail, including Jeremiah’s misconceptions about leaves and soil. For instance, Leslie succinctly summarized, “He knows that you need air, water, and light; you need those things, which is what you need for photosynthesis. He does know that it is not from the soil; he just goes back to it. He knows the key ingredients and he knows that plants have something special that animals do not.” Leslie focused on Jeremiah’s misconception about leaves and soil, and interpreted Jeremiah’s ideas as a sensible way of making sense about plants. Leslie said,

I think it is just, because that is just the only thing that he could think about logically that, in his mind, before he got to class, it is probably what he thought. And even though he sat through X many days of listening about photosynthesis, he still is going back to what he already knew, or already thought he knew (Leslie, senior, Interview using a clinical interview video).

As her response to the question of “What would you do as a teacher if you have a student like Jeremiah?” Leslie suggested doing an experiment with students to address their misconceptions: “I might do the soil experiment with them, just to kind of prove that [plants] do not use soil. And then talk about we know that they need air, water, and light to survive; what are they doing with the air, water, and light, too?” In short, the analysis demonstrates that Leslie learned from her students as she designed and analyzed student work, so to modify and develop practices of teaching that were strongly grounded in evidence.

**The case of Susie in the social group: Attending and responding to students’ social needs with general instructional approaches.**

Susie was an Asian female intern who majored in Chemistry and minored in English as a Second Language. Similar to Leslie, Susie came into the program in her junior year without any teaching experience. Susie worked at the same school as Leslie, West high, but with a different mentor, Mrs. B. When Susie participated in this study, she was in her internship year, thus it was her second year in Mrs. B’s classroom.

Susie’s mentor, Mrs. B, had approximately 20 years of teaching experience at the high school level. Mrs. B had a strong view about good science teaching that was characterized as structured and skill-oriented. She stated that “most of [her] students are never going to use chemistry again,” but they will use those life skills. If they develop those skills from her class, “they can learn the science at any time.” Mrs. B’s approaches to mentoring were also highly structured and skill-oriented. Mrs. B always monitored Susie’s practices in her classroom, and explicitly modeled all small ‘techniques of teaching’ for Susie. Dr. R said, “It’s like having somebody from the military be your teacher, not in a bad way, but in the sense of structure. [Mrs. B] was very clear about expectations, she scaffolded things, she helped students, and she was always there for them.” Susie also added, “I don’t know if this is even the right wording but this is the wording that [Mrs. B] uses. She is good at training her students. So it’s very orderly and organized.”
Susie’s learning from students by engaging in the inquiry activity teaching sequence.

Opportunities. The topic of Susie’s inquiry sequence was how various factors affect the rate of solution and solubility in the unit of solution. Susie opened her inquiry sequence with students’ discussion after splitting the whole group in half. One half of the class was asked to list factors that impact solubility (“What factors might affect how fast something dissolves?”) and the other half to list as many factors that impacted rate of solution (“What factors might affect how much of something can dissolve?”). Students had to come up with at least one factor through their discussion, write them down, and submit them to Susie. Susie compiled all the factors that students came up with, and then assigned each student one factor (i.e., temperature, surface area of the solvent, stirring, crushing). Each student designed a lab that answered the question, “How does [the assigned factor] affect solubility or rate of solution” using a sugar cube and water. After each student designed a lab individually, Susie had a whole class discussion about students' lab designs. Then, students were assigned to different lab groups to test different variables using the discussed lab designs. Students collected data (e.g., counting sugar cubes or timing) and wrote a lab report. In the lab report, students had to “explain how their factor impacted or did not impact rate of solution/solubility based on the data they collected” at a molecular level. Finally, she engaged students in a roundtable discussion where each group of students provided a mini presentation. Students presented: (a) what question their lab was attempting to answer, (b) whether they were testing for rate of solution or solubility, (c) what factor they were testing, (d) their data/lab results, and (e) conclusions that could be drawn from their data. This inquiry activity lesson sequence was wrapped up with a whole-class discussion on the rate of solution and solubility at the molecular level.

In this inquiry activity sequence, Susie provided an open-ended opportunity for students to give Susie rich information about themselves, including their understanding about designing experiments, engagement in scientific practices, and knowledge of rate and solubility, by having students design a lab by themselves. Similar to Leslie, Susie provided opportunities for students to use scientific models developed from their inquiry activities (i.e., solubility lab) to explain data that students collected through their lab. The key question that students had to answer was, “Explain how your factor impacted or did not impact rate of solution/solubility based on the data you collected.”

Highlighting & Interpreting. As the responses to the designed opportunity, students produced long and complicated answers that showed their ideas and thinking. Susie carefully compared student responses with the ideal responses that she expected, and identified what students knew, partially knew, and what was missing. Susie highlighted students’ confusion among observation, patterns, and conclusions. She stated, “Some students did not draw a conclusion, only stating the patterns they found. Some simply stated that as their factor increased/decreased, the rate of solution/solubility went up/down.” Susie also highlighted and problematized students’ tendency of “simply validating a known fact” using process. She interpreted this problem as her failure to provide scaffolding for students effectively as shown in the following statement:

I feel that I did not effectively scaffold the process of scientific research. It seemed that even while performing the lab, the students were convinced they knew the outcome and results. As a result, they may have forced conclusions that were not properly supported by their data. Also, I did not scaffold the process so that students were looking at the big picture. Rather, they saw it as completing separate, unrelated tasks. The resulting
outcome was that the students were not able to critically analyze and piece together the parts of the lab (the question they were trying to answer, the data collected and the meaning and significance of their data).

Both Leslie and Susie interpreted students’ responses, in particular the one that did not meet the learning objectives, in relation to their instruction based on a strong understanding about the discipline, in this case, the integrated nature of scientific knowledge and practices.

**Responding.** Susie planned a specific strategy of action to address the students’ difficulties based on her interpretation of student difficulties. Susie learned that “many students did not recognize the essence of science—experiments are about answering questions”, “Data and results are not analyzed based on correctness; they only help us answer our question by proving or disproving a correlation.” She also noticed that “students were uncomfortable with the idea that their data proved that variables were unrelated” despite the fact that “both conclusive and inconclusive results were equally valuable” in science. As her strategy of action, Susie decided, “In order to scaffold students’ learning in an inquiry lesson, that this idea [the essence of science] must be discussed.” To better support students’ difficulties in drawing a conclusion from data, Susie added guiding questions, such as “As temperature increased, what happened to the time it took for the sugar cube to dissolve” followed by, “What does this tell you about the rate?”

**Patterns of Susie’s learning from students across multiple data.** Two teaching episodes from the internship year were analyzed to examine the types of opportunities, highlighting, interpreting, and responding as Susie designed and analyzed student work. The first teaching episode was produced in the first semester of her internship with a general frame of unit planning; whereas the second one, the inquiry activity sequence described above, was the one that was designed by the program with the special intention of engaging candidates in reform-minded teaching during the last semester of their internship year. In addition, the interview using the same clinical interview video was analyzed to triangulate the patterns of Susie’s highlighting, interpreting, and responding that emerged from Susie own teaching episodes.

There was a stark difference in the ways that Susie engaged in the activity for learning from students in two episodes. Different from her inquiry teaching episode that provided students opportunities to reveal complicated scientific ideas with relatively long responses, Susie provided opportunities for her students to mostly produce factual information or display skills or procedural knowledge. Not surprisingly, the two different types of assessment questions from two different teaching episodes generated different types of student responses, which affected the following dimensions of learning from students. In the general teaching episode, Susie mostly highlighted whether students got right or wrong answers or completion of the tasks in her unit report. She then interpreted students’ wrong answers or incompletion in relation to behavior issues. For example, Susie reported about one low-achieving student, Alex, as following:

> Alex did not have his pre-lab completed and was asked several times in class to get started on it and finish it so he could get started on the lab. It appeared his lab partner was doing most of the work. He simply wrote down whatever she was writing. As I tried to ask him to explain the calculations he was doing, he was not able to explain it. In addition, he did not have time to finish the questions in class and chose to leave them blank. It appeared that he had absolutely no understanding of what was going on, beside the fact that we were counting and weighing beans.
Susie’s strategies of action in this episode were “assign independent activities or dividing the roles” for students to complete their work independently, and “find an alternative way of presenting and lecturing” to make “drill and kill type of activities” less boring. Her responses addressed some social dynamics in the classroom but were not directly related to students’ difficulties. Things that Susie could learn from students were constrained by the kinds of opportunities that she provided with her assessment questions or activities. It was a stark contrast to her inquiry activity where she highlighted students’ ideas and their difficulties in understanding the topic, and interpreted it by linking to her instructional approaches or students’ prior experiences, and responded to them with some instructional strategies relevant to students’ difficulties.

During the interview using a clinical interview video, Susie identified what Jeremiah did know and did not know accurately including his misconception about soil during the interview. Interestingly, she also highlighted the social and emotional context that might play certain roles in Jeremiah’s responses. Susie said, “I think that was very important for the student, when [the interviewer] stated ‘don’t worry about being nervous’ and that kind of thing. It made the student feel that this was a safe place where he could express his thoughts and feelings and say I don’t know if he really didn’t know.” Susie interpreted Jeremiah’s dismissal of learning photosynthesis as the failure to make connections between abstract ideas (i.e., vocabulary) and students’ prior knowledge. Accordingly, as her responses to Jeremiah, Susie emphasized the importance of helping students to see the value of learning in order to persist in learning the abstract ideas. She suggested that, “It’s important to go from bigger to smaller and not jump to an equation, or to vocabulary, or to specific parts of a process before explaining the application first.” Susie’s responses to Jeremiah were general and related to his difficulties to some degree, but may or may not address his specific difficulties in understanding the role of soil and leaves in plants making their food.

In short, Susie’s approaches toward assessing and responding to students were contingent upon the context, specifically the structure that the work of designing and analyzing student work was situated in. By asking different types of questions, she provided various opportunities for her students to give information about what they knew. It also provided different opportunities for Susie herself to learn about students because students created different kinds of responses. When she received quality student responses, she was able to use some of that information about students to provide productive feedback. Susie’s responses were often grounded in general observations about students’ social aspects and patterns of participation in the classroom rather than interpretations of specific student ideas and their difficulties with the topic.

**The Case of Teresa in the behavioral group: Attending to behaviors and management, and addressing students’ wrong or incomplete responses with motivational strategies.**

Teresa was an Asian female intern who majored in biology and minored in chemistry. She had experiences of teaching under-privileged students in an outdoor setting in the Redwood forest in California. Teresa had a strong desire to be an urban science teacher to begin with, and got placed at an under-resourced urban high school in her internship year. Teresa wished to teach science by having students touch and feel object as opposed to work with papers or worksheets. She thought that her students would get excited and learn science if she could “take students off site and outside to do a cool activity.” Similar to Leslie and Susie, Teresa worked with a fairly traditional but supportive mentor. Mrs. R’s approaches to teaching science can be easily
characterized as worksheet-driven activities focusing on illustrating the science content in the textbook. Mrs. R opened up to her intern’s ideas because she thought “this is the time for them to try an activity, because there’s always a fallback.”

Throughout her internship year, Teresa struggled a lot to manage her classroom. Teresa said, “This year I think it’s been the biggest thing that I’ve struggled with is classroom management…I feel like I have less resources, you’re inside a classroom with twice as many students.” The course instructor, Dr. R said, “I feel like [Teresa] had no control in the classroom. Until the spring, she was really struggling…she let the kids walk all over her. They did not respect her.” Dr. R also stated that Teresa “blamed students a lot” in her journals while giving her “lip service” to the fact that the urban students needed to have more support, to be guided, and to develop these skills. Despite the obvious challenges, Teresa did not seek out any help or advice from either the course instructor or her mentor teacher. Teresa’s mentor, Mrs. R. said, “I don’t feel like Teresa ever really actively sought out anything [from me]”, “I don’t ever remember Teresa saying, “Can you help me with this?” or, “Do you have anything for this?” She did a lot of work on her own.” Dr. R expressed her concern because Teresa “never shared her concerns with her mentor, even when she was asked. So Teresa wasn’t communicating with her mentor in ways that might have been helpful to her because she might have gotten some helpful feedback and support from Mrs. R.”

**Teresa’s learning from students by engaging in the inquiry activity teaching sequence.**

**Opportunities.** Teresa’s inquiry sequence was enacted as the start of the unit on bacteria. Teresa opened her inquiry sequence showing an episode of a popular TV show, ‘House’ to spark students’ interest and to illustrate the difference between virus and bacteria with diagnostic medicine. Then, Teresa asked students when they have used antibiotics and disinfectants in their lives. Teresa went over the pre-lab, and began her inquiry lab. The lab was to compare the effectiveness between antibiotics and disinfectants using two types of bacteria (i.e., E. Coli and B. Subtilis). Students develop a hypothesis as to what would happen if they placed six different antibiotic discs and six disinfectant discs onto agar plates inoculated with the bacteria. Students performed the lab (i.e., plating disinfectants and antibiotics discs on two agar plates inoculated with two different bacteria). The following day, they measured the zones of inhibition, recorded the data in their own tables, and analyzed individual and class data. Students read the textbook, and wrote a lab report. Teresa went over the lab report with students, and then had them turn in their report.

Teresa provided several opportunities for students to reveal their ideas by asking embedded assessment questions, and her key assessment questions appeared at the end of the episode, in her lab report. Students had to explain the reason why the antibiotic and disinfectants function differently along with its mechanism by answering to the questions of “Why the antibiotic plates were effective in inhibiting specific types of bacterial growth only, and why almost all the disinfectants inhibited both types of bacteria pretty significantly”, “How antibiotics inhibit growth and how disinfectants inhibit growth or kill bacteria.” In the cases of Leslie and Susie, students were guided to come up with their own explanation by making connection with both the data produced from their activities and the co-constructed scientific ideas or theories. In the case of Teresa, all students were guided to copy the correct explanation in the textbook.

**Highlighting & Interpreting.** Students had all kinds of trouble during the experiments, and produced “fairly inconsistent data” as Teresa noted. Not surprisingly, they struggled to
respond to Teresa’s questions, and copied the explanation from the textbook in the end. Teresa’s highlighting was primarily focused on correctness of the answer. She thought that “overall students did well on this”, “they seemed to have many of the correct responses in the end” and “they were able to arrive at the same end conclusions.” Teresa also highlighted students’ struggles of analysis of the experiment. It was puzzling to Teresa that students “couldn’t put it all together” even after they “saw the pattern of data” and “understood what antibiotics and disinfectant was” from her point of view. Teresa interpreted that it was because of their lack of “critical thinking skills” or “training.” Teresa noticed that most of students just copied the mechanism from the reading, so “It didn’t really take a whole lot of thought.” But she interpreted it as one success because students “learned the skill of looking up answers in reading,” which they have been “working on all year.” Teresa thought that “Overall, they did pretty well.”

**Responding.** Few strategies of action were suggested or enacted by Teresa during this inquiry teaching episode, which makes sense given her overall positive interpretation of student response. Teresa’s responses, if they appeared, were general and not directly address students’ difficulties. For example, Teresa recognized students’ difficulties in analyzing data. Her response was “I need to just continue to try to push them to learn to think critically about things because they aren’t trained to do that yet.”

**Patterns of Teresa’s learning from students across multiple data.** The results of data analyses suggest that overall, Teresa consistently failed to develop specific strategies of action that addressed students’ difficulties manifested on their work. Teresa mostly provided opportunities for students to explain the facts, laws, and theories that students know or remember. For instance, in her other teaching episode about cell structure and function, Teresa asked only simple recall type questions (i.e., 12 multiple-choice questions about factual information on cells), which generated very limited information about students and their ideas. Teresa Highlighted student answers focusing on right vs. wrong or complete vs. incomplete, or in many cases identified little or no information about students. She interpreted students’ wrong responses mostly in relation to student attitudes, behaviors, and motivational issues or did not make any interpretation. Teresa’s suggested or enacted strategies of action were general and often not directly related to students’ difficulties.

During the interview using Jeremiah’s video, Teresa did not highlight Jeremiah’s ideas or difficulties in understanding photosynthesis, although she appreciated a little bit Jeremiah’s knowledge about plants. Interestingly, Teresa highlighted ‘what Jeremiah did not know’ more than ‘what he did know,’ which was opposite to both Leslie’s and Susie’s cases. Teresa interpreted that Jeremiah failed to understand photosynthesis because “he didn’t pay attention during photosynthesis [lesson].” Teresa suggested getting him interested using his garden as a hook, and using hands-on activities.

In short, the data suggests that Teresa was less successful in learning from her students by designing and analyzing student work that was deliberately structured by the program. Teresa mostly asked recall-type questions that generated the kinds of student responses that had limited information about them. The other dimensions of learning from students (highlighting, interpreting, and responding) were necessarily constrained by the types of student responses generated by engaging in the provided opportunities. Teresa’s patterns of learning from students were consistent across her own teaching episodes as well as her interview with a clinical video.

**Discussion**
The analysis of opportunities provided by each candidate, their highlighting, interpreting, and responding suggests that each candidate created different kinds of formative feedback loops for themselves as they designed and analyzed student work. Both its completeness and the nature of the formative feedback loop help explain how candidates developed different kinds of practices in response to what they learned from students.

We can turn to the three representative cases of Leslie, Susie, and Teresa, which capture different kinds of formative feedback loops—cognitive, social, and behavioral feedback—which emerged from the large data set (see Figure 2). The case of Leslie illustrates a ‘cognitive feedback loop’ created by four out of 14 candidates either partially or in a complete form. The candidates in the student thinking group, including Leslie, learned about students as sense-makers by providing opportunities for students to reveal their developing ideas and thinking, and modified their instruction in a way of better assisting students’ sense-making process. The cognitive feedback loop created by Leslie allowed her to continuously learn about students’ ideas and to develop instructional practices that address students’ difficulties. The case of Susie illustrates a ‘social feedback loop’ created by two candidates. These were the ones who particularly attended to and took account of students’ social and emotional involvement in their participation. These two types of feedback loops—cognitive and social—are not mutually exclusive, though. Leslie noticed more students’ personal and social characteristics in her internship year than in her senior year, and took account of it in her interpretation, indicating her add-in social feedback loop to a strong base of the cognitive feedback loop; whereas Susie primarily created a social feedback loop with a few exceptions. The four teacher candidates in the student thinking and social oriented groups, who were able to make a complete formative feedback loop, used important information about students, either as a sense-maker or as a participant of classroom learning community, responded to their students productively in that they modified their instructional practices in a way of assisting students’ intellectual and social engagement.

The candidates in the behavioral group mostly created a ‘behavior feedback loop’ (see Figure 3). As illustrated with the case of Teresa, these candidates mostly provided limited opportunities for students by asking factual type or skill oriented questions, highlighting and interpreting student responses focusing mostly on students’ attentiveness, behaviors, and motivation; responding to them with general motivational strategies. Teresa’s case captures the complexity as well as the depth of difficulties for these candidates. Even when Teresa was provided rich information about students’ thinking with the substantial guidance of her program, she was puzzled about students’ difficulties, and interpreted it as a matter of “skill” or “lack of practices” of the students in urban high schools.

In addition, the completeness of a formative feedback loop explains different progress made by each of the candidates in developing teaching practices. The amount of field experiences of each candidate does not fully account for different progress made by the participating candidates, which indicates that learning on-the-job does not necessary ensure development of evidence-based practices. The six teacher candidates from the student thinking and behavioral groups failed to create a ‘complete formative feedback loop,’ showing different points of ‘break’ in their loop. Those who were from the student thinking group had difficulties
in formulating specific strategies of action even when they successfully identified students’ difficulties, which reminds us of “problems of enactment” (Kennedy, 1999). Heritage and his colleagues reported that teachers are better at making reasonable interpretations about students’ understanding from assessment information than they are at deciding the next instructional steps (Heritage, Kim, Vendlinski, & Herman, 2009). These candidates may benefit if the move from interpretation to responding is carefully scaffolded with targeting tools and resources. The feedback loop of the candidates in the behavioral group, however, was broken far ahead of time by failing to design assessment tasks that produced rich student responses. As illustrated in the case of Teresa, sometimes they failed to attend important information about students even when they were provided rich student responses. It was less likely for the candidates in this group to provide opportunities for their students to give information about students’ understanding and participation through their assessment tasks without substantial support at the initial stage of providing opportunities. It was also less likely that the candidates made significant modification of their practices without substantial scaffolding in the practices of highlighting, interpreting, and responding.

**Why do candidates create different kinds of formative feedback loop while engaging in formative assessment activity?**

The findings suggest that learning from students is both highly intellectual and social work, which poses different kinds of challenges in each candidate’s engagement in this formative assessment activity. The intellectually demanding nature and its impact on their learning from students were particularly evident in the opportunities provided by candidates and their interpretation. One important difference between two groups of candidates (i.e., those who made significant modification of their practices and who did not) was the nature of opportunities that they provided with their assessment questions. As reported in previous studies, the nature and quality of the questions yield different types of student responses (Black & Wiliam, 1998; Furtak & Ruiz-Primo, 2008; National Research Council, 2001). Asking (or selecting) good questions, however, is not an easy task, especially for novice teachers. Candidates asked students about the important ‘content’ of science from their point of views, and the types of questions that candidates asked (or selected) reflected how they think of the ‘content’ of science as well as their understanding about disciplinary understanding (i.e., what it means to understand science, what counts as evidence of learning). The candidates who created the cognitive feedback loop, for example, asked the kinds of questions or engaged students in activities that demonstrate whether students make connection between observable phenomena or data with scientific theory or model. This group of candidates described science as the integrated process that produces scientific knowledge, “habit of mind,” and a tool for “making sense of our every day experiences.” The way that this group of candidates thinks of science as content for their teaching is far beyond a simple combination of content and process (or skills). On the contrary, the candidates in the behavior group repeatedly talked about science as authoritative and correct ‘why’ stories about phenomena and sets of skills. The ways in which these candidates think of understanding science were projected to the designed or selected tasks for their formative assessment. In their assessment, students were asked to reproduce the correct story (i.e., textbook explanation) by making connections among the pieces of information provided by authoritative sources (e.g., teacher or textbooks) or to solve problems. Candidates’ highlighting and interpretation about student responses were also filtered through their views on disciplinary teaching and learning. Candidates in the student thinking and social group problematized their own practices when they found students’ partial or developing ideas for the most part, whereas
candidates in the behavioral group problematized students (i.e., their attitude, attentiveness, or behavioral issues) regarding their failure of providing correct answers. Many previous studies focusing on student work analysis pointed out the significant role of teachers’ understanding about disciplinary teaching in interpreting student responses (e.g., Little, et al., 2003; van Es & Sherin, 2002; van Es & Sherin, 2008; Windschitl, et al., 2011). Windschitl and his colleagues (2011) note that the early career science teachers’ habits of mind, grounded in their views on teaching and learning, influenced the ways in which teachers selected classroom tasks, analyzed student work, and communicated their analysis with others during collaborative inquiry, which constrained what the teachers could learn from the analysis of student work. Building on Windschitl et al.’s work, this study shows how teachers’ understanding about disciplinary teaching and learning impact their learning from students by constraining the quality of student responses produced from their assessments in the first place, and its cascading impact on the practices across highlighting, interpreting, and responding.

The different kinds of formative feedback loops created by candidates reflected not only their depth of understanding on science teaching and learning, but also was influenced by the ways in which the activity was structured, the ways in which candidates interacted with members of professional communities (i.e., course instructors and their mentor teachers), and leveraged resources during the work (e.g., strategies of actions, tools, helps from others). The socially situated nature of the work of learning from students was particularly evident in the case of Susie and Teresa. The activity of designing assessment and analyzing student work was situated in different historical and social contexts (i.e., different stages of student teaching and evolving relationship with her mentor teacher, students, and course instructors). Susie’s two different formative feedback loops created in two different teaching episodes partly reflects Susie’s relationship with her mentor teacher and course instructors, and the expectations that she had to address, negotiate, and respond in the moments as a member of multiple professional communities. Susie’s case illustrates how candidates’ learning from students reflects their professional momentum of being certain kind of teacher, their “developing professional identities as teachers” (Kazemi & Franke, 2004, p. 206). Teresa, and all the other fourteen candidates, as a learner of science teaching, brought with relatively strong ideas about good science teaching and the kinds of teacher they wanted to be. The assessment tasks designed (selected) by Teresa reflected the image of teaching and learning that she wanted to see in her classroom (i.e., providing first-hand experiences, being part of the story). Teresa mostly relied on her previous experiences at an outdoor setting in California, while rejecting ideas, suggestions, and assessment activities from both her mentor teacher and her program. Her choice of resources significantly impacted her opportunities to learn from her students that are mostly full of short, missing, inaccurate answers, or seemingly disengaged students.

How does the activity of designing and analyzing student work mediate teachers’ learning from students?

There is growing evidence that collective inquiry into practice using student work is a useful activity to promote teacher learning in the context of professional development (Darling-Hammond & Richardson, 2009; Little, et al., 2003; Thompson, et al., 2009; Windschitl, et al., 2011). In this study, collective examination of student work was brought to the context of initial training as a part of formal formative assessment to support teacher candidates’ learning from their students and the development of evidence-based practices. The close examination of the ways in which the candidate who created different types of formative feedback loop participated
in the activity helps explain how the formative assessment activities as framed in this study mediated each group of candidates’ learning from their students.

The candidates in the student thinking group, who had a deeper understanding about disciplinary knowledge and practices, took most advantage of this activity by leveraging resources from the program when they designed assessments, interpreting student answers, and searched for strategies of action. These candidates created quality opportunities to learn for themselves that included rich student responses due to the quality of assessment tasks. Then, the candidates were able to see what they could not normally see by drawing their attention to individual students’ various ideas, reasoning, experiences that each student draw upon, and students’ different ways of interacting with materials and people. In particular, unexpected but interesting student responses from typically underserved students appeared to be especially useful to this group of candidates and accelerated their learning because these responses showed different ways of thinking and vast resources that students brought up with in their sense-making process. When they encountered those student responses, candidates in this group looked for different strategies of action and complementary experiences to support students’ scientific reasoning. Their success in attending and responding to students as sense-makers and participants in classroom learning community was partly grounded in candidates’ strong orientation to students’ ideas and thinking. However, it was further boosted by the work of examining student work in formative assessment activity helping them broaden their professional vision.

The candidates in the social group got most benefits from the work of designing assessment and analyzing student work when the activity was explicitly structured in a form of inscribed documents focusing on student ideas and disciplinary engagement by scaffolding the practices of highlighting and interpreting. As illustrated in Susie’s case, the structured activity provided by the program helped candidates negotiate among competing ideas and resources. The provided guideline that structures the inquiry teaching activity sequence also helped these candidates generate their own learning opportunities that included rich information about students. Furthermore, the explicitly structured guideline helped them attend and respond to important information about students, such as students’ developing ideas.

The activity of designing assessments and analyzing student work, in its current form, seemed to be less successful to help the candidates in behavioral group to modify their current teaching practices. The candidates in this group were the ones who initially had “unproblematized views on the relationships between teaching and learning” (Windschitl, et al., 2011), strong professional momentum toward a certain image of teaching that does not fit with the reform-oriented vision for the most part, and limited interpersonal skills that were critical in negotiating for themselves among competing ideas. While participating in the activity, they attended to students’ engagement or disengagement within the subjectively created opportunities that usually did not include rich information about students. The fact that the feedback loop of this group of candidates was broken in the first place, which obviously made it difficult for them to attend and respond to students’ ideas and participation, suggests that designing assessment tasks need to be much better supported to initiate a productive formative feedback loop.

Conclusion and Implications

This study explored how 14 secondary science teacher candidates learned from their students and developed practices of teaching when they engaged in formative assessment
activity. Based on the nature of opportunities that each group of candidates provided for their students, their highlighting and interpretation of student responses, and responding, this study proposed three models of formative feedback loops—cognitive, social, and behavioral feedback loops—that characterize the nature of teachers’ learning from their students. The in-depth analysis using three representative cases demonstrated that the type and nature of the formative feedback loops was not only shaped by teacher candidates’ depth of understanding about disciplinary teaching and learning, but also reflected the nature of social contexts where the work of learning from students was situated, the ways in which the activity was framed and structured, and candidates’ professional momentum toward being a certain kind of teacher.

Both cognitive and social feedback loops capture teachers’ responsiveness to their students even though the things that teachers learn about students are quite different (e.g., students’ developing ideas, social/emotional involvement). I argue that both formative feedback loops are promising because both can help teachers develop rigorous and equitable teaching practices by responding to their students productively. The cases of Leslie and Susie suggest that formative feedback loop can be expanded or shifted as candidates participate and respond to social contexts. This study only provides a glimpse of it, though. Given its potential roles in developing rigorous and equitable practices, the mechanisms of shift or expansion and its impact on teaching practices need to be further investigated.

It should be noted that the formative assessment activity was one deliberately designed opportunity provided by a reform-oriented teacher preparation program to support candidates learning about students’ ideas and to develop capabilities of learning from practices. Despite the fact that the 14 teacher candidates were commonly provided the opportunities to learn from their students, only half of the candidates were successful in modify their practices using important information about their students in a way of better supporting student learning. The process of learning from students is incredibly complex and challenging to most beginning teachers because of both its high level of intellectual demands and socially situated nature of the work. It raises the questions of how to help candidates deepen their understanding about disciplinary teaching and learning, and how to support candidates’ practice of attending and responding to their students in contexts, as shaped by their developing professional vision.

There are some implications for designing quality opportunities to support teachers’ learning from students. First of all, the fact that teachers’ learning from students is fundamentally constrained by the nature of student responses to assessment tasks (questions), the process of designing assessment tasks need to be scaffolded to the greatest extent. It is especially important for candidates in the behavioral group who are less likely to design or select the kinds of assessment tasks that produce rich student responses. Second, carefully structured activities and scaffoldings that assist disciplinary engagement and draw attention to student ideas can support teachers’ practices of highlighting and coding targeting for a particular purpose. This will be particularly useful to candidates like Susie who sometimes overlooked important information among competing ideas. Finally, student responses that include unexpected but interesting ideas from typically underserved students can be a powerful leverage point for learning from students. Those student responses were especially effective to the teachers who initially have a strong interest in student ideas. It is challenging to generate those responses, however, because students who created those kinds of responses are the ones who frequently miss the work or school, and who often turn in empty responses. Because of that, I would argue it is even more important to provide teachers opportunities of analyzing those student responses and learn that they can to be
much better served with the teacher’s thoughtful instruction. Some strategies, such as having students produce the work in class time, not as homework, can be considered.

Supporting beginning teachers in developing their capacity of learning about teaching from their students is a powerful way to improve both teaching and teacher learning (Ball & Cohen, 1999). Understanding the complex process of learning from students and developing empirically grounded theory of teacher learning allow us to create our ‘formative feedback loop’ as teacher educators, and help us to develop a powerful pedagogy of teacher education. This study sheds light on our understanding of how new teachers learn from their students by unpacking its nature and process in contexts with the hope of creating powerful formative feedback loops in teacher education.

References


### Table 1. Profiles of the 14 teacher candidates

<table>
<thead>
<tr>
<th>Cohorts</th>
<th>Pseudonym</th>
<th>Gender</th>
<th>Major</th>
<th>School context</th>
<th>Stages of program</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cohort I</td>
<td>Monica</td>
<td>F</td>
<td>Biology</td>
<td>Suburban HS</td>
<td>Intern</td>
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<tr>
<td></td>
<td>David</td>
<td>M</td>
<td>Biology</td>
<td>Suburban HS</td>
<td>Intern</td>
</tr>
<tr>
<td></td>
<td>Teresa</td>
<td>F</td>
<td>Biology</td>
<td>Urban HS</td>
<td>Intern</td>
</tr>
<tr>
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<td>Intern</td>
</tr>
<tr>
<td></td>
<td>Leslie</td>
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<td>Urban HS</td>
<td>Intern/senior</td>
</tr>
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<td>Cohort II</td>
<td>Shannon</td>
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<td></td>
<td>Mary</td>
<td>F</td>
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<td>Suburban HS</td>
<td>Senior</td>
</tr>
<tr>
<td></td>
<td>Kevin</td>
<td>M</td>
<td>Physics</td>
<td>Suburban HS</td>
<td>Senior</td>
</tr>
<tr>
<td></td>
<td>Adam</td>
<td>M</td>
<td>Bio/Phy</td>
<td>Suburban HS</td>
<td>Intern</td>
</tr>
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<td></td>
<td>Alisa</td>
<td>F</td>
<td>Earth science</td>
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<td>Intern</td>
</tr>
<tr>
<td>Cohort III</td>
<td>Lori</td>
<td>F</td>
<td>Biology</td>
<td>Urban HS</td>
<td>Senior</td>
</tr>
<tr>
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<td>Lynn</td>
<td>F</td>
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<tr>
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<td>Stella</td>
<td>F</td>
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<td>Senior</td>
</tr>
<tr>
<td></td>
<td>Scott</td>
<td>M</td>
<td>Physics</td>
<td>Urban MS</td>
<td>Senior</td>
</tr>
</tbody>
</table>

### Table 2. Three different trajectories of learning from students

<table>
<thead>
<tr>
<th></th>
<th>Student thinking focused</th>
<th>Social engagement focused</th>
<th>Behavioral/management focused</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete feedback loop</td>
<td>Leslie, Alisa</td>
<td>Susie, Monica</td>
<td>Teresa, David, Shannon, Stella</td>
</tr>
<tr>
<td>Incomplete feedback loop</td>
<td>Lori, Scott, Mary</td>
<td></td>
<td>Adam, Kevin, Lynn</td>
</tr>
</tbody>
</table>
### Table 3. Characteristics of the four dimensions of learning from students in each group

<table>
<thead>
<tr>
<th></th>
<th>Student thinking &amp; Social group</th>
<th>Behavioral group</th>
</tr>
</thead>
</table>
| **Opportunities provided through tasks/questions** | Tasks (questions) reveal rich information about students as science learners  
- Applying knowledge to novel situations  
- Developing explanations about phenomena through reasoning | Tasks (questions) reveal limited information about students as science learners  
- Reproducing factual information/canonical scientific explanation  
- Displaying some skills or procedural knowledge |
| **Highlighting** | Mostly highlighting information about students as science learners either focusing on ideas or participation  
- Students’ ideas, partial understanding, misconception, their way of thinking  
- Patterns of participation in different contexts | Mainly highlighting correctness of student responses or completeness making binary opposites  
- Right or wrong answer  
- Complete or incomplete the work  
- Little or no information about student ideas around the topic |
| **Interpreting** | Interpreting student responses mostly in relation to nature of instructional activities provided by teacher, students’ personal/missing experiences, or social/cultural resources | Interpreting student responses mainly in relation to students’ attitudes, attentiveness, behaviors, personalities, and motivation |
| **Responding** | Suggesting or enacting specific strategies of action (i.e., ideas of instructional modification) that directly addresses students’ difficulties | Suggesting or enacting general/broad ideas, such as hands-on activities, that are not directly related to students’ difficulties manifested in their responses |
Figure 1. Formative feedback loop

Learning from students

Figure 2. Cognitive and social feedback loop
Figure 3. Behavioral feedback loop

- Responding
- Interpreting
- Opportunities to reproduce canonical scientific ideas
- Identifying students’ ideas broadly
- Identifying right/wrong or completion
- Puzzling: Interpreting in relation to behaviors, attentiveness, motivations
- Responding with general motivational strategies