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Exploring the Development of Core Teaching Practices in the Context of Inquiry-based Science Instruction: An Interpretive Case Study

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Abstract

This paper describes our reflection on a clinical-based teacher preparation program. We examined a context in which novice pre-service teachers and a mentor teacher implemented inquiry-based science instruction to help students make sense of genetic engineering. We utilized developmental models of professional practice that outline the complexity inherent in professional knowledge as a conceptual framework to analyze teacher practice. Drawing on our analysis, we developed a typography of understandings of inquiry-based science instruction that teachers in our cohort held and generated a two dimensional model characterizing pathways through which teachers develop core teaching practices supporting inquiry-based science instruction.

Keywords

Core teaching practices, Inquiry-based science instruction, Teacher development, Teacher questioning

Introduction

Emphasis on inquiry-based teaching practices in science classrooms around the world (Achieve Inc, 2013; Krainer, Jungwirth, & Stadler, 1999; Wake & Burkhardt, 2013) has shifted the focus of teaching away from delivering content and toward supporting students in making sense of concepts by "figuring out phenomena" (Krajcik, 2015). To help teachers make this shift, teacher education researchers have identified core teaching practices that emphasize student sense making via inquiry-based instruction (Grossman, Hammerness, & McDonald, 2009; Kazemi, Franke, & Lampert, 2009; Lampert, Beasley, Ghousseini, Kazemi, & Franke, 2010, pp. 129–141; Lampert et al., 2013). In the U.S., researchers have begun to re-conceptualize teacher preparation by: (1) identifying core teaching practices that effective and experienced teachers utilize when implementing inquiry-based instruction, and (2) providing novice pre-service teachers' opportunities to rehearse core teaching practices through clinical-based coursework. Ball, Sleep, Boerst, and Bass (2009) specified that such practices: (1) occur frequently during instruction, (2) maintain the complexity involved in teaching and learning, and (3) have the potential to improve student learning and achievement. Across disciplines, researchers identifying core teaching practices have produced complex models that specify advanced behaviors through which teachers support student sense making during inquiry-based instruction. Our experiences in teacher preparation, however, suggest that novice pre-service teachers struggle to both understand the complexity and nuance of core teaching practices, and use core teaching practices effectively to implement inquiry-based instruction and support student sense making.

This interpretive case study describes our reflection on a clinical-based teacher preparation program in which novice pre-service teachers implemented inquiry-based science instruction to help students make sense of genetic engineering. The setting of our reflection was a U.S. teacher preparation program designed after a co-op model from engineering, which engaged a small cohort of novice pre-service teachers in science methods coursework embedded in the classroom of a more experienced high school science teacher (van den Kieboom, Birren, Eckman, & Silver-Thorn, 2013). The classroom was selected as a site for the co-op based on the high school teacher's reputation as skilled in inquiry-based science instruction.

Our teacher education model reflected recent U.S. reform recommendations which place clinical practice at the center of teacher preparation (Grossman et al., 2009; National Council for Accreditation of Teacher Education, 2010). The individual attention and clinical emphasis of this context appeared favorable for supporting novice pre-service teachers to develop mastery of core teaching practices that support successful implementation of inquiry-based science instruction. However, extensive reflection on video-recorded teaching during the co-op provided an opportunity to examine the challenges novice pre-services teachers encountered while enacting core teaching practices supporting inquiry-based science instruction. Analysis of our clinical data in light of the literature on developmental trajectories of professional practice (Dall'Alba & Sandberg, 2006; Dreyfus, 2004) led us to consider assumptions about the developmental readiness of novice pre-service teachers to enact core teaching practices, specifically teacher questioning, which supports inquiry-based instruction with fidelity. Teacher questioning, in particular, emerged as an important indicator of varied levels of development of core teaching practices. Although teacher questioning itself has not been named as a core teaching practice, the centrality of teacher questioning is evident in classroom discourse across various models. Thus, a theoretical contribution of this paper is to bring current disciplinary emphasis on core teaching practices into conversation with extant literature emphasizing the importance of teacher questioning in inquiry-based science instruction, linking both to a framework for understanding professional development trajectories.

Conceptual framework

Inquiry-based science instruction

According to Minner, Levy, and Century (2010), "the term *inquiry* has figured prominently in science education, yet it refers to at least three distinct categories of activities – what scientists do, how students learn, and a pedagogical approach that teachers employ" (p. 3). Thus, inquiry-based pedagogy is a student centered approach to teaching that encourages the use of scientific processes to actively engage students in learning by building their own knowledge through hands-on, investigative activities (Achieve Inc, 2013; Steffe & Gale, 1995; Yager, 1991). Inquiry-based pedagogy encourages students and teachers to utilize practices similar to those of scientists who: (1) pose and investigate questions, (2) plan and design experiments, (3) prioritize evidence, (4) develop explanations connected to scientific knowledge, and (5) use data as evidence to share results (National Research Council [NRC], 1996). In facilitating student engagement in each of these processes, teachers often utilize questioning to guide students through scientific inquiry.

Despite the emphasis on inquiry-based science instruction in K-12 Science, Technology, Engineering, and Mathematics (STEM) reform initiatives around the world, teacher use of and success with this approach has largely been limited and inconsistent (Capps & Crawford, 2013; Marshall, Horton, & Smart, 2009). Researchers argue that many science teachers hold simplistic conceptions of: (1) scientific knowledge and (2) how inquiry-based instruction can be used to support students in investigating and constructing scientific knowledge (Capps & Crawford, 2013; Windschitl, Thompson, & Braaten, 2008). One way to support teachers in implementing inquiry-based science instruction is to specify the core teaching practices supporting inquiry-based instruction and to adequately prepare teachers to enact these practices during teacher preparation (Grossman et al., 2009).

Core teaching practices

Among the various models that have identified core teaching practices supporting inquiry-based instruction, the practice of teacher questioning is essential. For example, in mathematics education, Ball et al. (2009) identified leading whole class discussions and eliciting student thinking as core teaching practices that require effective questioning on the part of teachers to support students in making sense of concepts. Likewise, the model for core teaching practices supporting inquiry-based science instruction described by Windschitl, Thompson, Braaten, and Stroupe (2012) includes: (1) identifying a conceptual goal, (2) eliciting student ideas to adapt instruction, (3) eliciting student ideas to help students make sense of material activity, and (4) pressing students for evidence-based explanations. According to Hiebert, Morris, Berk, and Jansen (2007) novice pre-service teachers have particular difficulty identifying a robust and conceptual goal for their lessons. Windschtl et al. also emphasized the foundational position of the practice of identifying a robust conceptual goal, which must be in place in order for the three remaining discussion-oriented practices to be implemented effectively. Accordingly, in Fig. 1, we have illustrated the four core teaching practices for supporting inquiry-based science instruction with the practice of identifying a conceptual goal situated prominently as central to the model. Aside from the vital initial step of identifying a robust conceptual goal, each of the other core teaching practices in Windschitl et al.'s. framework requires skilled teacher questioning to support students in making sense of concepts.

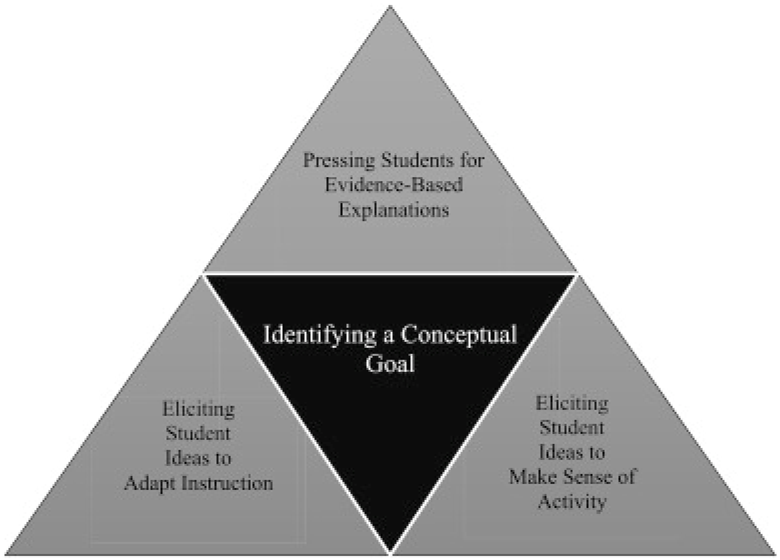

Fig. 1. Model of core practices supporting inquiry-based science instruction adapted from Windschitl et al. (2012).

Teacher questioning

Questioning supports science teachers in eliciting and building on student ideas as well as pressing students to use scientific evidence to explain their thinking during inquiry-based science instruction (Windschitl et al., 2012). Mathematics and science teacher educators have categorized different types of questions to help teachers be thoughtful about more and less effective questioning strategies to support inquiry-based instruction (Chin, 2007; Erdogan & Campbell, 2008; Franke et al., 2009; Lustick, 2010; Moyer & Milewicz, 2002; Sahin & Kulm, 2008). Table 1 provides an overview of questioning categories. In science education, for example, Chin (2007) provided four categories of teacher questions distinguished in terms of productivity in scaffolding student thinking and constructing scientific understanding with a vision to improve teachers' questioning practices. Likewise, Lustick (2010) described five types of questions teachers commonly pose in science classrooms. In addition, Erdogan and Campbell (2008) identified a taxonomy of 15 questioning categories divided into three types of questions: closed-ended, open-ended, and task oriented. They associated open-ended questions with higher level constructivist teaching practice.

Table 1. Comparing the Categorization of high-leverage questioning. Chin (2007); Lustick (2010); Erdogan & Campbell (2008); Erdogan & Campbell (2008); Windschitl et al. (2012).

	Increasing order of sophistication =>				
Chin (2007)	Verbal Jigsaw – Focus on scientific terminology, key words & phrases	Framing – Use questions to frame a problem, issue or topic		Semantic Tapestry – Weave disparate ideas together into a conceptual framework	Socratic – a series of questions to prompt and guide thinking
Lustick (2010)	Dictionary Questions – Seeks a definition	Encyclopedia Questions – Seeks facts	Textbook – Seeks a factual explanation	Google – Seeks more specialized factual information	Cutting Edge – seek understanding of ill-defined phenomena
Erdogan & Campbell (2008)	Closed-Ended – Invite brief factual answers			Task-Oriented – Manage student understanding during investigation	Open-Ended – Requires extended explanations and reveal patterns of reasoning
Kazemi & Stipek (2001) – adapted for scientific inquiry	Low-press – Seek simple descriptions or solutions				High-press – Seek engagement in conversation beyond simple answer, responses link evidence to conceptual understanding
Windschitl et al. (2012)	No press for a scientific explanation	"What happened" explanation		"How/partial why" explanation	Causal explanation

In mathematics education, Kazemi and Stipek's (2001) categorization of low and high-press questions closely parallels Erdogan and Campbell's (2008) taxonomy. However, Kazemi and Stipek's more streamlined categorization of low and high-press questions highlights essential aspects of Erdogan and Campbell's complex taxonomy of open-ended questions that support inquiry based instruction and closed-ended and task oriented questions that focus more on content mastery and classroom management. Kazemi and Stipek analyzed questioning in the context of the entire teacher-student or teacher-class interaction, thus a question is considered high-press based not only on the teacher's wording of the question, but also on the students' responses and the teacher's subsequent reaction. In Kazemi and Stipek's terms, when posing low-press questions, teachers expected and/or permitted their students to provide a simple answer or solution to a problem. In contrast, teachers who asked high-press questions insisted that students engage in conversations that go "beyond descriptions or summaries of steps to solve a problem; they linked their problem-solving strategies to mathematical reasons" (p. 64).

Low-press and high-press questions are differentiated according to the demand for student reasoning. Thus, in responding to low-press questions students attempt to "land" on an answer the teacher has in mind. In contrast in high-press questions the teacher pushes students to reason through solutions and reveal their own conceptual thinking. To clarify further, high-press questioning only makes sense in the context of problem- or inquiry-based instruction since rote or didactic teaching fails to present contexts or tasks that support students in explaining their thinking. Windschitl et al. (2012) illustrated an order of increasing sophistication across teachers' discursive strategies that aligned well with Kazemi and Stipek's (2001) low and high-press questioning categories. It is important to note that in Windschitl et al.'s. view, if the teacher fails to understand the role of questioning in inquiry-based instruction and proceeds to use only low-press questions, the conceptual learning embedded in the instruction can be reduced. Further, a preponderance of low-press teacher questions may reveal that the teacher's goal for the lesson is to emphasize more factual memorization rather than conceptual development. Thus, the teacher's use of different types of questions as implemented in their practice can provide insight into the four core teaching practices supporting inquiry based instruction (Windschitl et al., 2012). The priority Kazemi and Stipek (2001) placed on questioning interactions is vital in considering core teaching practices supporting inquiry-based instruction because these exchanges provide insight into the teacher's identification of a conceptually robust instructional goal that is fundamental to an inquiry-based lesson.

Models of professional practice development

Development of core teacher practices (e.g. questioning and identifying conceptually robust instructional goals) have been treated as a collection of knowledge and skills accumulated through a combination of educational and field experiences. However, developmental models of professional practice have outlined the complexity inherent in professional knowledge, thus developmental models of professional growth describe the development of complex and context-dependent *professional practices* that reflect increasing expertise (Dall'Alba & Sandberg, 2006; Dreyfus, 2004). Education researchers have also described numerous instances where effective professional teaching practice requires a complex combination of content knowledge, pedagogical knowledge, and classroom experience (see for example Borko, Mayfield, Marion, Flexer, & Cumbo, 1997). Reform efforts that emphasize a shift in teaching - from traditional models focused on delivering content to inquiry-based teaching focused on supporting student sense making - have helped to raise questions about what sorts of skills contribute to effective teaching practices (Capps & Crawford, 2013). In our view, models of core teaching practices represent descriptions of the professional practice of advanced and expert teachers. Accordingly, we adapted professional growth models from Dreyfus (2004) and Dall'Alba and Sandberg (2006) to assist our understanding of novice pre-service teachers' early development toward core teaching practices identified with effective inquiry-based science instruction (Windschitl et al., 2012).

Dreyfus (2004) described a widely referenced five-stage model of professional growth that progresses from novice to expert (see Fig. 2). Beginners are introduced to decontextualized "rules for determining actions on the basis of [context-free] features" of a task. Thus, at the most rudimentary stage of skill development, novices (Stage 1) attempt to apply these rules into contextualized tasks. Dreyfus contended that, "merely following rules will produce poor performance in the real world…. The student needs not only the facts but also an understanding of the context in which that information makes sense" (p. 177). Over time, and with experience of real situations, novices begin to understand aspects of context that inform the performance of a task. With such examples in mind the novice, now turned "advanced beginner" (Stage 2) can apply context-dependent maxims that are more nuanced in their application than the rule systems they largely replaced.

Fig. 2. Stage model of professional practice development adapted from Dreyfus (2004).

As experience accumulates, various options become numerous, but the professional lacks “a sense of what is important in any situation” making performance extremely difficult and complex. To address this difficulty (Stage 3, Competent Performer), professionals learn to select from a collection of systematic approaches “that then determines those elements of the situation or domain that must be treated as important” (Dreyfus, 2004, p. 178). The selection of a relevant systematic approach offers the professional the ability to focus on the most salient features of the problem in context, making performance related decisions easier. However, the uncertainty associated with making tenuous choices about which approach is most appropriate, alongside having attained a level of mastery that imbues the professional with responsibility for decisions alongside limited confidence in the outcome makes the competency stage quite stressful.

Dreyfus’s (2004) model further specifies that as the competent performer tries out different perspectives in different contexts, he or she develops a preference for certain approaches in particular contexts, strengthening his or her understanding of the skill in relation to the context, termed “situational discrimination” (p. 178–179). “Proficiency [Stage 4] seems to develop if, and only if, experience is assimilated in this embodied atheoretical way” (p. 179). Proficiency is characterized by an ability to identify problems and desirable solutions, but the professional continues to struggle to develop effective plans of action and reverts to rule systems to identify solutions. In contrast, the expert (Stage 5) intuitively identifies both the problem and the path to a solution by drawing on her “vast repertoire of situational discriminations” (p. 179–180). Dreyfus explained that, “normally an expert does not calculate. He or she does not solve problems. He or she does not even think. He or she just does what normally works and, of course, it normally works” (p. 180). Of central importance throughout Dreyfus's model of professional practice development is the emphasis on contextualized experience in applying skill and knowledge as central in progression from novice practice to expert practice. However, Dreyfus's model fails to consider variations in development of types of professional skill. Accordingly, we incorporated Dall’Alba and Sandberg’s (2006) consideration of specific trajectories of professional practice development.

Dall’Alba and Sandberg (2006) added dimension to Dreyfus's (2004) stage model, contending that advanced skill development is dependent on both contextual practice and a foundational understanding of professional practice itself. They suggested that while it is necessary to consider how increasingly sophisticated professional practice develops, it is also vital to explore the nature of the practices that are being developed. Thus, skill development is heavily influenced by the professional's understanding of the nature of practices inherent in the profession in which they are engaged:

The professionals' way of understanding their practice forms and organizes their knowledge and skills into a particular form of professional skill. When practice is understood in a certain way, knowledge and skills will be developed accordingly. For example, when teaching is understood as knowledge transfer, efforts to improve tend to focus on the teachers' presentation of content. When teaching is understood as facilitating learning, developing skill and monitoring and enhancing the learning that occurs is emphasized. In other words, the way in which professional practice is understood, in an embodied sense, is fundamental to how the practice in question is performed and developed, by both individuals and collectively (p. 390).

Thus, the development of professional practice supporting inquiry-based science teaching requires an early shift in novice pre-service teachers' understanding of classroom teaching practice from traditional models to reform-based models.

For our purposes, if novice pre-service teachers understand the goal of science instruction as effectively delivering content, then their professional teaching practice will involve increasingly sophisticated and intuitive application of methods for content delivery (e.g. low-press questions that stimulate factual recall). In contrast, if novice pre-service science teachers view their role as supporting and facilitating inquiry-based instruction, development of classroom teaching practices will involve advancing their ability to support student sense making in keeping with core practice models (e.g. high-press questions that support students in making sense of evidence to form conceptually robust explanations). Thus, we envision development of core teaching practices that support inquiry-based science instruction proceeding in two dimensions: the teacher's understanding of professional practice constitutes the first dimension (Dall'Alba & Sandberg, 2006) and the second dimension reflects the teacher's development of sophisticated practices according to Dreyfus's (2004) stage model of professional development. In applying this conceptual framework in the context of our interpretive case study, we propose a model that highlights differences between the practices of teachers with different levels of experience and suggests phases of development through which teachers may progress.

Research questions

As discussed earlier, characterizing the types of questions teachers pose as low or high-press (Kazemi & Stipek, 2001) can provide insights into the development of professional teaching practice (Dreyfus, 2004) and understanding of teaching practice itself (Dall'Alba & Sandberg, 2006). Given the centrality of questioning to core teaching practices supporting inquiry-based science instruction, we examined the practices of two novice pre-service teachers and one mentor teacher to explore the following questions: (1) How do teachers attempting to implement inquiry-based science instruction make use of low- and high-press questions, and (2) How do the different ways teachers utilize low and high-press questions lend insight into their development of core teaching practices supporting inquiry-based science instruction (Fig. 1)?

Research design

The study presented in this paper is an interpretive case study centered on close analysis of video-recorded teaching practices of three science teachers implementing an inquiry-based lesson. The study considered the ways in which the teachers came to understand and enact inquiry-based science instruction as a developmental process, thus, the definition, or meaning of inquiry each teacher enacted was a central focus of the analysis. According to Schwartz-Shea (2006):

A central goal of interpretive approaches is understanding human meaning making; issues of causality are not necessarily excluded but are understood much differently than in the variables gestalt…. Being attuned to meaning making involves a recognition of, and sensitivity to, the ambiguities of human experience; researchers presuppose that meanings are negotiated and constructed, and they often deliberately investigate efforts to promulgate or resist particular meanings, at the same time that they explore the variation of meanings across contexts (p. 123).

Through our analysis and comparison of the practices of three teachers implementing the same inquiry-based lesson, we: (1) tested existing models of core teaching practices supporting inquiry-based science instruction within the context of the case study, and (2) developed our own model describing a developmental trajectory that included the teachers' understanding of inquiry and their enactment of core practices supporting it. While we do not argue that this model is generalizable, in keeping with an interpretive epistemology we offer it as a product of descriptive analysis of which aspects are likely transferable to other contexts.

Context and participants

To examine the differences in teacher practice more closely, we collected video data of two novice pre-service teachers and one experienced mentor teacher implementing the same science unit plan which the novice pre-service teachers designed together. For purposes of comparison, we also analyzed the practice of their experienced mentor teacher as he adapted and implemented the plan.

Our research was conducted at a private university in the Midwestern U.S. in the context of a National Science Foundation (NSF) Noyce Teacher Scholar Program. The Noyce Teacher Scholar Program supports undergraduate STEM majors in becoming K-12 mathematics and science teachers. Our Noyce program followed a co-op model adapted from the university's College of Engineering in which small cohorts of prospective STEM teachers are immersed in a high-need urban school (based on the percentage of students qualifying for free and reduced lunch) as a part of their disciplinary and general methods courses. The co-op examined in this paper was situated in an urban, charter academy with a core emphasis on science.

The cohort of two novice pre-service teachers (Ms. Davidson, biology and education major and Ms. Matthews, biomedical engineering and education major),[1] and the first author, serving as the science methods instructor, worked extensively in the classroom of a mentor science teacher with eight years of experience (Mr. Simpson). The science methods course was embedded in a science classroom with the novice pre-service teachers participating in discussions and observing classroom practice with their university instructor (author 1) and completing 80 h of field experience in the same setting over the course of a semester. The science methods course served as the second field experience in the novice pre-service teachers' program and their first opportunity to plan and implement whole group instruction. The science methods instructor emphasized practices supporting inquiry-based instruction and a student-centered classroom structure in the methods course materials and discussions. As part of the methods course, the two novice pre-service teachers collaborated to develop and implement a unit on genetic engineering. The teachers then enacted each of the unit's six 55-min lessons in a parallel fashion with Ms. Davidson teaching each lesson first (2nd hour), followed by Ms. Mathews (3rd hour) and Mr. Simpson (6th hour). Because the teaching practice occurred during the field experience rather than during the science methods course, Mr. Simpson was present for all lessons. Ms. Davidson and Ms. Matthews were typically present only when they taught. The first author was also present for most of Ms. Davidson and Ms. Matthews's instruction with exceptions for scheduling conflicts.

Data sources and data analysis

Data for this study included the novice pre-service teacher designed genetic engineering unit plan, accompanying daily lesson plans, and video-recordings of class periods in which each teacher implemented the unit plan. The unit plan included four lessons: (1) the background for genetics and genetic engineering, (2) the ethics of genetic engineering, (3) the products of genetic engineering, and (4) the processes of genetic engineering. The novice pre-service teachers described the unit plan as reflective of reform-based science instruction. Our finer grained analysis further reflected on a single lesson the novice pre-service teachers specifically identified as an inquiry-based science lesson. However, we will make the explicit argument in the findings that this description is further evidence of the early stage of their development with regard to core teaching practices supporting inquiry-based science instruction. During research and development of the unit, the novice pre-service teachers consulted with the university instructor and mentor teacher for advice on plans and logistical details.

In order to analyze teaching practices enacted by teachers at different stages of professional practice development (Dall'Alba & Sandberg, 2006; Dreyfus, 2004), we initially segmented the video-recording into epochs and transcribed the classroom discussion. Next, we used an open qualitative coding method (Strauss & Corbin, 1998) to analyze teaching practices in the transcribed epochs. Categories at this coding level included managing lessons, providing explanations, facilitating group work, posing questions, responding to explanations, and making real-world connections. After comparing the ways the teachers enacted each of these practices, we recognized the centrality of questioning to the participants' enactment of core teaching practices supporting inquiry-based instruction and focused further exploration on teacher questioning as an indicator of development that distinguished the practice of the more experienced teacher from the novice pre-service teachers. In order to analyze questioning practices we drew on Kazemi and Stipek (2001) to categorize each questioning exchange initiated by each teacher as low or high-press. We considered patterns of questioning across the three instances of the inquiry-based science lesson by: (1) calculating the frequency with which each teacher posed each type of question, and (2) examining each teachers' use of each type of question within the context of the lesson. Specifically, we analyzed how the practice of teacher questioning provided insight into the teachers' development in relation to core teaching practices supporting inquiry-based science instruction.

Findings

Planning for inquiry-based science instruction

As Table 2 illustrates, Ms. Davidson and Ms. Matthews developed their unit around a conceptual goal that emphasized students' ability to analyze the processes and ethical implications of genetic engineering. We consider this to be a fairly robust conceptual goal for the unit as it encouraged students to engage in higher order cognitive work. However, the objectives for the unit plan undermined the conceptual depth of the larger goal by emphasizing skills associated with a lower cognitive demand (e.g., describe, explain, identify). Although, the lesson examined for this paper was described by the novice pre-service teachers as an inquiry-based science activity, the goal Ms. Davidson and Ms. Matthews identified maintained a lower cognitive demand as well, calling for a definitional understanding of the term “genetic engineering”.

Table 2. Evidence of goal setting and questioning in unit and lesson plans.

Unit Plan Major Goal	The goal of this unit is for students to be able to analyze how genetic engineering is being used in the scientific community and determine whether it is ethical or not based on the associated risks and benefits.
Unit Plan Objectives	• Describe, through written answers, how genes and DNA affect the traits of an individual (emphasizing the idea that genes encode proteins, which produce traits). • Examine examples of genetically engineered organisms and describe, in writing, at least one difference between these organisms and organisms experiencing genetic mutations or variation. • Describe, without using their notes, what genetic engineering is. • Summarize, in writing, the process of genetic engineering, emphasizing the 5 main steps. • Explain, in writing, the purpose of plasmids, restriction enzymes, and sticky ends. • Explain, in writing, three benefits associated with genetic engineering. • Identify, in writing, three risks associated with genetic engineering. •

	Describe three causes of concern for animal welfare during genetic modification. • Defend a personal claim about the ethics of genetic engineering using at least 2 of the risks or benefits discussed in class.
Lesson Goal	Genetic engineering is the artificial manipulation, modification, or recombination of DNA or other nucleic acid molecules in order to modify an organism or population of organisms. Genetic engineering is often used to produce a desired trait in an organism that does not naturally produce this trait. This big idea will be supported through the comparisons of the concepts of genetic variation and genetic mutation.
Lesson Plan Discussion Questions	What similarities do you see between the case studies in the neither column? Do you see any differences? What differences do you see between the neither case studies and the genetic mutation case studies? Between the neither and the genetic variation case studies? Do genetically mutated organisms tend to have positive or negative results? What kind of traits do the "neither" organisms portray, positive or negative? Are these traits ones that could be produced on their own? Can the traits be found in other cases throughout the species or is this trait something completely new?

Ms. Davidson and Ms. Matthews structured the inquiry-based lesson described in this paper around eight examples projected from individual PowerPoint slides (sample slide provided in Fig. 3) and asked students determine if each example constituted genetic variation, mutation, or neither. Included in the plan (Table 2) were a series of questions the novice-pre-service teachers developed to facilitate their discussion of genetic engineering with students. While examining the questions they developed in isolation, it is difficult to envision exactly how they anticipated the discussion of genetic engineering proceeding. Some of the questions potentially required a higher cognitive demand, asking students to identify and explain similarities and differences among a series of examples, which could be used to develop explanations from evidence. On the other hand, some questions appeared rather closed ended (e.g. are the traits in the neither category generally positive or negative?), but if these questions were used to initiate a discussion of the value of genetically engineered traits over mutations, one could envision a fruitful and higher order discussion progressing. Thus, having examined the plan from which all three teachers worked, we turned to video-recordings of their lessons to explore the practices through which they enacted inquiry-based science.

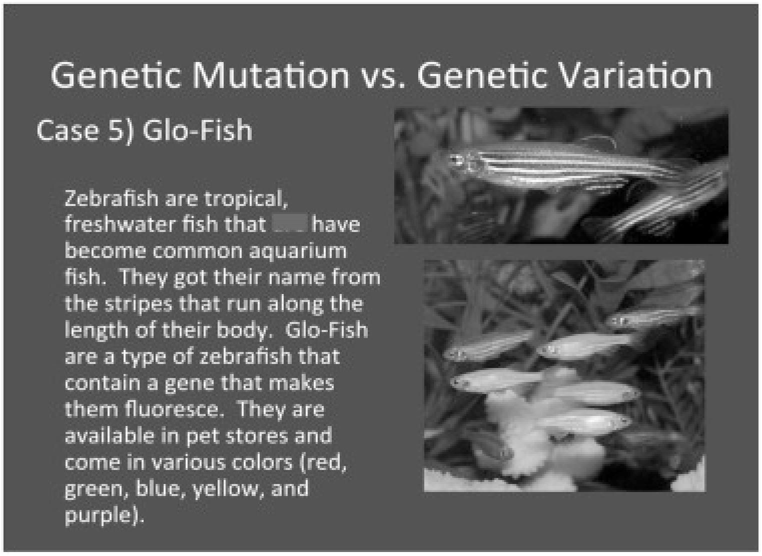

Fig. 3. Activity slide presenting the Glo-fish example.

Implementing an inquiry-based lesson

A numerical summary of the types of questions each teacher posed provided background for a more detailed discussion about the three teachers' questioning practice. As illustrated in Table 3, Ms. Davidson posed 35 low-press and no high-press questions. Ms. Matthews asked 20 low-press, and seven high-press questions. In contrast Mr. Simpson asked eight low-press and 20 high-press questions.

Table 3. Summary of teachers' questioning practices.

	Low-press Questions	**High-press Questions**	**Total Questions**
Davidson	35	0	35
Matthews	20	7	27
Simpson	8	20	28

Table 3 further highlights the importance of identifying the type and use of questioning as a teacher practice since the total number of questions posed by each teacher was fairly similar (35, 27 and 28 respectively). However, if the number of questions were considered as a proxy for effective inquiry-based science instruction, the result would be misleading. This finding contrasts somewhat with Erdogan and Campbell's (2008) finding that teachers employing constructivist teaching practices asked significantly more questions than those employing less constructivist practices. In our analysis, we found that the number of questions alone was not indicative of the quality of inquiry-based science instruction, but rather the quality of questioning interactions the teacher initiated. This point is illustrated by the fact that while Ms. Davidson posed the most questions overall (35), all of her questions were low-press and her instruction did not attempt to support students in making sense of natural selection as the big idea underlying genetic engineering. Her constant use of low-press questions that sought confirmation of factual and predetermined answers suggested that her conceptualization of her instructional goal was more about vocabulary and definitions than conceptual growth. However, due to the preponderance of low-press questions, her practice initially appeared somewhat student-centered because she was constantly interacting with students. Finally, we identified a pervasive Initiate, Response, Evaluate (IRE) pattern in Ms. Davidson's practice that also was evident in Ms. Matthews teaching. The IRE pattern has been identified as common in traditional, teacher-centered classrooms (Lemke, 1990). The high number of low-press questions with little consideration of student responses in shaping the lesson characterized the IRE approach and further reinforced a factual rather than conceptual goal for the lesson.

Mr. Simpson asked fewer questions overall (28), but his pattern of questioning (8 low-press and 20 high-press) revealed the more robust conceptual goal for which he adapted the lesson, student sense making around the relationship between genetic engineering and foundational evolutionary concepts in which his students were able to engage (See Fig. 1, eliciting student ideas to make sense of material activity). While differences in the total numbers of questions were evident in our overall classification of practices, the way questioning patterns influenced inquiry-based instruction emerged by tracing those patterns in a detailed analysis of transcript excerpts. For the sake of comparison, in the next section we focus on each teachers' discussion of the fifth example, Glo-fish (fish that are genetically engineered to glow in the dark. See Fig. 3). We dissect excerpts of each teachers' practice (Figs. 4–6) with particular attention to: (1) their use of questioning, (2) the implications of questioning interactions for each teachers' instructional goal, and (3) the developmental sophistication of each teacher's enactment of inquiry-based science instruction.

1. **Ms. Davidson:** So let's move on to the next one. We're looking at Glo-fish. If you guys could take a stab at what you think glow fish are due to.
2. **Ms. Davidson:** All right so is everybody ready to give me what their thought is? *Can I see everybody's cards please as to what you think it is? Mutation, Variation, or Neither.* **(Low-Press Question)** Can I see your cards? [students hold up cards]
3. **Ms. Davidson:** Neither. All right so I'm seeing a majority of neither. And several mutations. *So can somebody that thought that this was a mutation, can they tell me why that they think it's a mutation?* **(Low-Press Question)**…
4. **Student:** Because it contains a gene that makes them fluorescent, that makes them glow.
5. **Ms. Davidson:** He said because it contains a gene that makes them glow.
6. **Ms. Davidson:** *So some of you that said it was neither, why do you think it's neither?* Lauren, I saw that you had a neither card up can you tell me why you think it was neither variation or mutation. **(Low Press Question)**…
7. **Student:** I don't know I just thought it was neither.
8. **Ms. Davidson:** You just thought it was neither. *Does anybody have another reason why as to they think it would be neither?* **(Low-Press Question)**
9. **Ms. Davidson:** All right so the correct answer is indeed the fact that it is neither variation or mutation. Once again, this is kind of like the rice. It doesn't contain a gene that naturally occurs in it. Because if you look at the zebra fish up top [referring to the slide], you can do certain things and make it fluoresce like these fish down here. So it is indeed neither.
10. **Student:** Do they light up in the dark?
11. **Ms. Davidson:** They just produce a different color and if you like shine a black light on them they fluoresce. You know like you go cosmic bowling? Bowling like your bowling balls glow? Like the same light …
12. **Ms. Davidson:** So let's move on to our next case study so we're going to be looking at corn this time around. I'm going to give you guys a minute to decide if you think this is a mutation, variation, or neither.

Fig. 4. Transcript excerpt Ms. Davidson.

1. **Ms. Matthews:** So variation is used to explain diversity within a population. We don't all look the same right? Hair color is one trait that varies between individual because of the alleles that are passed down from parents, so good. Glo-fish. These are kind of cool. So this is what a normal zebra fish looks like…this, these brightly colored ones, these are the Glo-fish….
2. **Ms. Matthews:** All right, let's take a vote, ready for your cards. *What do you think about Glo-fish? Pick one card.* **(Low-Press Question)** Okay. We've got a couple of different answers here.
3. **Ms. Matthews:** So somebody in the group that said neither, why don't you give me your reason. *What do you think?* **(Low-Press Question)**
4. **Student:** It's because we couldn't figure out [inaudible].
5. **Ms. Matthews:** All right, somebody who said, wait you said variation right? Somebody said mutation, *What do you guys think?* **(Low-Press Question)**
6. **Student:** Because they inherit the same genes.
7. **Ms. Matthews:** They inherit the same genes. *Do zebra [fish] normally have genes that make them fluoresce? That makes them glow?* **(High-Press Question)**
8. **Student:** No. It don't say they have the gene it says they glow [referring to slide].
9. **Ms. Matthews:** No. Right. And for that reason….the Glo-fish contain that gene, the normal zebra fish, it says……Mr. Simpson?
10. **Mr. Simpson:** *Where are they available? So are they available in the wild?* **(High-Press Question)**
11. **Students:** NO
12. **Ms. Matthews:** So it's neither, right? But it is neither because it is something that is not found out in nature it's not something that if you were to go to a tropical fresh water part of the world, you would not see Glo-fish swimming around in the water. Okay? All right, so let's look at number 2 on your sheet.

Fig. 5. Transcript excerpt Ms. Matthews.

1. **Mr. Simpson:** All right, let's do this one, Glo-fish!... Hold em up, hold it up, Hold it up…. I have mutation, mutation, mutation. I've got variation… Now why are you guys holding up all three?... [Similar overview of other examples]
2. **Mr. Simpson:** Now. Hold on. We had two that we were confused about. One was the fish and one was the (snap, snap, snap). Not the corn. (students chatter) The rice! The fish and the rice. Okay. So even in your journal, *I kept asking Tyler what would be the purpose of having, the advantage of having vitamin A for the rice? Is there an advantage for the rice?* **(High-Press Question)**
3. **Students:** [Talking over one another] Yes? No?
4. **Mr. Simpson:** *Who gets the advantage?* **(High-Press Question)**
5. **Students:** [Several students in unison] We do….
6. **Mr. Simpson:** The advantage is not for the rice. The advantage is for me. I eat this rice, I get vitamin A.
7. **Mr. Simpson:** The fish. *Is there an advantage to having that fluorescent color?* **(High-Press Question)**
8. **Students:** [In unison] No!
9. **Mr. Simpson:** *What advantage does it grant?* **(High-Press Question)**
10. **Student:** That animals can see you in the dark.
11. **Mr. Simpson:** *Do you want to be seen in the dark?* **(High-Press Question)**
12. **Student:** No
13. **Mr. Simpson:** No. *So who gets the advantage? Did you read where those things are found? Let's think about it. Let's go back. It's found where?* **(High-Press Question)**
14. **Students:** [In unison] In Pet stores.
15. **Mr. Simpson:** *So who gets the advantage of the pretty colors?* **(High-Press Question)**
16. **Students:** [In unison] We do!
17. **Mr. Simpson:** Last one. Silk proteins. *Does this goat get any advantage of having silk proteins in it's milk?* **(Low-Press Question reframed as a High-Press Question)**
18. **Students:** No.
19. **Mr. Simpson:** No. So what they all have in common.… Remember when we did the silk video. Remember, silk is one of those things, it's one of the strongest things in nature? So people actually harvest this silk and they use it to make bullet proof vests and things like that. *So where does this all come together? Notice. Where does this gene come from?* **(High-Press Question)**
20. **Student:** Spiders?
21. **Mr. Simpson:** *Where did the gene for the golden rice come from?* **(High-Press Question)**
22. **Students:** Oranges?
23. **Mr. Simpson:** It comes from sweet potatoes and carrots. *Where does the gene come from for the fish?* **(High-Press Question)**
24. **Students:** Jellyfish.
25. **Mr. Simpson:** *So is this a mutation? No. There's something else going on here. You have one gene going from one organism from another. Just randomly, it pops up.* **(High- Press Question)**
26. **Student:** Sexual Reproduction?
27. **Mr. Simpson:** *No, What is it Kevin?* **(High-Press Question)**
28. **Student:** Genetic Engineering!
29. **Mr. Simpson:** Genetic Engineering! So this is kind of the theme of the unit. I am going to move forward, and I want you take out your notebooks; I want you to go back to your seats right now.

Fig. 6. Transcript excerpt Mr. Simpson.

Ms. Davidson

Ms. Davidson introduced each example by reading the information on the slide and raising the question of whether the trait was a result of genetic variation, genetic mutation, or something else (Fig. 4, Turn 2). After providing several minutes for small group discussion, students were directed to use cards to indicate their responses. Reacting to a split response from students, Ms. Davidson asked for a volunteer to explain their answer that Glo-fish was a 'mutation' (*incorrect answer*, Turn 3). The student speculated that the glowing was a genetic trait, but neglected to relate that understanding to why the trait occurred (Turn 4). Ms. Davidson repeated the answer (Turn 5) and moved on to ask another student to explain why they chose 'neither', (*correct answer*, Turn 6). The student stated that she did not know why she guessed 'neither' (Turn 7). Ms. Davidson repeated the student's statement and accepted the answer (Turn 8). Ms. Davidson then sought another volunteer to suggest another reason that the answer would be neither (*low-press question*, Turn 8). When no student volunteered, Ms. Davidson provided the correct answer as well as a rationale for the correct answer (Turn 9). It is important to note that the question Ms. Davidson initially posed in Turn 6 (asking students to explain their choice) had the potential to initiate a high-press exchange. However, when students failed to provide an answer, Ms. Davidson filled in the implied "blank" rather than continue to press students to reveal their thinking. This instance demonstrates that the purpose of the question is often most evident in the interaction that follows, since the question itself could be used to achieve varied purposes.

While Ms. Davidson asked students to provide support for their answers, her use of questioning indicated that her instructional goal was primarily an attempt to rule out wrong answers and emphasize a complete and expected canonical response. Following Ms. Davidson's recitation of the factual answer and the justification she expected, one student asked for more information about the glowing trait in fish (Turn 10), which suggested that all of the students might not have understood the context. Ms. Davidson attempted to relate the Glo-fish example to another real life context of cosmic (glow in the dark) bowling (Turn 11), but this example fell flat since students did not appear to share that experience. Ms. Davidson then let the Glo-fish conversation drop, moved on to the next example (Turn 12), and continued the lesson without addressing that some students may not have entirely grasped the Glo-fish example and what it contributed to their understanding of genetic-mutation, variation, and engineering.

Our analysis of Ms. Davidson's questioning practice further revealed the lack of conceptual depth associated with the goal for her lesson. A nuanced reading of the excerpt in Fig. 4, with particular emphasis on her summary (Turn 9) suggests that her intrinsic goal for the lesson was for students to generate a canonical definition for the three categories of genetic variation, mutation, and "other." Ultimately, Ms. Davidson expected students to associate the "other" category with human intervention through genetic engineering. Thus, while the lesson Ms. Davidson enacted was an inductive form of science instruction, it represented a rudamentary understanding of inquiry through which a teacher delivers content to students while avoiding directly telling them the information. For example, in order to ensure that students were exposed to the proper canon, Ms. Davidson delivered the fact-based definitional content when she stated; "so the *correct* answer is indeed the *fact* that it is neither variation or mutation" (Turn 9). In sum. Ms. Davidson's lesson, retained the factual emphasis of didactic instruction rather than the conceptual emphasis of core teaching practices required for robust inquiry-based science instruction (Windschitl et al., 2012). Considered through the lens of Dall'Alba and Sandberg's (2006) understanding of professional development, Ms. Davidson's practice indicated that despite reflecting priorities of inquiry-based instruction in discussions, her fundamental understanding of teaching practice retained a prioritization of content delivery more consistent with didactic instructional models. Therefore, as we will argue in subsequent sections, Ms. Davidson enacted a nascent understanding of inquiry-based science instruction.

Ms. Matthews

Ms. Matthews introduced the Glo-fish example with a more fluid transition. She completed a discussion about variation in hair color, emphasizing the importance of variation for explaining genetic diversity in a population (Turn 1). Then she explained that some zebra fish have the Glo-fish trait. This seemed like a more promising introduction for promoting student sense-making than Ms. Davidson's more abrupt introduction of the Glo-fish example. After Ms. Matthews posed the low-press question, "What do you think about Glo-fish?" (Turn 3), she provided students an opportunity to discuss their impressions in small groups. She then returned to a more traditional IRE pattern of interaction with the whole class that failed to support students in making sense of the example (Fig. 5). Responding to a split response (Turn 5), Ms. Matthews solicited a series of reasons from different student groups, quickly accepted explanations, and moved on (Turns 4–7).

Toward the end of the lesson, one student suggested that the slide did not specify that the Glo-fish trait was genetic (Turn 9). Ms. Matthews missed the source of this confusion and stumbled over her response. She asked Mr. Simpson to assist her in resolving the student's confusion (Turn 10). Mr. Simpson responded by providing a high-press question; "*Where are they available? So are they available in the wild?*" (Turn 11). Mr. Simpson's question refocused the discussion and directed students to consider the relationship between where Glo-fish are found and possible source of the trait, the more robust conceptual idea embedded in the lesson. In this interaction, Mr. Simpson scaffolded Ms. Matthews's teaching practice, (Turn 12) pressing students to make sense of the fact that the glowing trait only occurs in captivity, has a market value, and the effect that developing the trait in the wild would have on the population.

The success of the interaction around questioning practices between Ms. Matthews and Mr. Simpson is further evident in the subsequent summary (Turn 13), in which Ms. Matthews vocalized the sense making in which Mr. Simpson was trying to help students engage. Despite a lesson structure that failed to press students to conceptually engage in making sense of patterns of inheritance, Ms. Matthews was able to verbalize some of these connections for students following intervention from Mr. Simpson. In our view Ms. Matthews executed a version of inquiry-based instruction very similar to Ms. Davidson. However, Mr. Simpson's intervention pushed her to adjust the lesson goal to include the conceptual foundation underlying the discussion of genetic mutation, variation and engineering. Applying Dall'Alba and Sandberg (2006)'s developmental framework to this situation, we contend that Ms. Matthews's content delivery understanding of teaching practice was challenged by Mr. Simpson's provision of a conceptually challenging question, thus offering her support in transitioning her goal for the lesson in real time.

Mr. Simpson

Mr. Simpson adapted the inquiry-based science lesson prepared by the two novice pre-service teachers to reflect a more demanding conceptual goal, using the idea of natural selection to help students make sense of mutation, variation, and genetic engineering (Fig. 6). In contrast to the novice pre-service teachers, Mr. Simpson quickly overviewed the examples (Turn 1), giving students a much shorter time to work in small groups to form a response about whether the example represented variation, mutation, or other. After introducing all of the examples, he then returned to the specific examples students had not resolved previously (beginning in Turn 2), emphasizing the question of advantage for the organism ("*who* gets the advantage," Turn 4) rather than asking students to formulate a complete and correct answer. The discussion included seven high-press questions (Turns 2 to 16). In contrast to the two novice pre-service teachers' discussions, which we have noted followed an IRE pattern and involved serial interactions between the instructor and one student, Mr. Simpson posed a series of related high-press questions to which the entire classes responded. Since his questions (ex. Turns 4, 9, 11, 13, 19) pushed the class to make sense of the concept of evolutionary advantage, throughout this discussion, all students were involved in making sense of evolutionary relationships through the relationship between the examples and the scientific concept.

Mr. Simpson introduced the final example (Turn 17) as an opportunity for students to apply the concept they had been wrestling with by posing a high-press question that asked them to extend their understanding to consider the advantage silk proteins in milk afford a goat. Following a summary of the advantage of all of the traits discussed, Mr. Simpson pressed students to think about the processes of genetic engineering by tracing the source of each gene that benefits humans rather than the trait's host (turns 19–24). Then, Mr. Simpson transitioned from making these two points to pressing for students to quickly address Ms. Davidson's and Ms. Matthews's goal for the lesson: “If a trait does not result from genetic mutation or variation, where does it come from?” (Turn 25). After identifying the term “genetic engineering” as the name of the source of such changes, Mr. Simpson abruptly closed the lesson and transitioned the students to a journal task.

Based on our analysis, Mr. Simpson's questioning practice emphasized high-press questions and revealed his robust conceptual goal of supporting conceptual growth surrounding foundational concepts of genetic evolution and natural selection. By restructuring the two novice pre-service teachers' lesson, Mr. Simpson was able to support students' sense making as opposed to matching more factual definitions to terms. Examining his transcript, we noted a fluidity in his exchanges with students where his questions pressed them to “figure out [a] phenomenon”, sources of generational change (Krajcik, 2015). In contrast, in the novice pre-service teachers' interactions, each example represented a singular exchange in which students were to generate a correct categorization of the example. It was not apparent that they had developed a strategy for helping students make sense of how the examples fit together with the larger conceptual underpinnings of natural selection. Thus, they failed to facilitate student sense-making, an enactment of the core teaching practices that seemed to come second nature to Mr. Simpson.

While Mr. Simpson's questioning practice demonstrated that his development of professional teaching practices were more advanced than those of the two novice pre-service teachers (Dreyfus, 2004), it also indicated that his understanding of inquiry teaching demanded a robust conceptual goal for his instruction and emphasized engagement over content delivery. However, this lesson retained a teacher-centered quality that did not fully reflect reform-based instructions' emphasis that *students* should be making sense of scientific ideas (Krajcik, 2015). Rather, Mr. Simpson engaged students in teacher-centered sense-making only to the point that their ideas seemed to replicate his own thinking. This point is evident in his abrupt transition to the journal activity once the class discussion indicated that students had linked the advantage of each trait in the examples of golden rice (Turns 2–6), Glo-fish (Turns 7–16, 23–25), and silk proteins (Turns 17–23) to humans through genetic engineering. Mr. Simpson's teaching style here revealed his retention of some of the characteristics of teacher-centered instruction, despite his engagement of students in making sense of the concept of genetic engineering. A more student-centered inquiry-oriented teacher would have asked students to extend their mastery of this concept. For example, one or more examples through students could either design an idealized trait or identify an artificial one would have allowed students to demonstrate and expand their newly mastered conceptual understanding. This finding is in keeping with our suggestion that all three teachers are experiencing a developmental trajectory of core teaching practices supporting inquiry-based science instruction. While Mr. Simpson's practice is far more advanced than the two novice pre-service teachers' practice, and he offers much in terms of mentorship and support for novice teachers, his enactment of inquiry-based instruction retains some aspects of a didactic style and further development is possible.

Discussion

In this interpretive case study we compared the teaching practices of two novice pre-service and one experienced science teacher as they implemented an inquiry-based science lesson. Close analysis of video-recordings of their practices revealed important differences in 1) the questioning practices of each teacher, 2) the instructional goal each teacher prioritized in enacting the lesson, and 3) the understanding of inquiry and development of core teaching practices supporting inquiry-based science instruction.

In keeping with various literature categorizing teacher questioning (Chin, 2007; Erdogan & Campbell, 2008; Kazemi & Stipek, 2001; Lustick, 2010) and relating them to effective inquiry-based science instruction (Achieve Inc, 2013; Krainer et al., 1999; Wake & Burkhardt, 2013), our analysis suggested not only that low-press questions are less effective in supporting students in making sense of concepts, but that they can reveal an emphasis on content mastery over conceptual growth. However, our theoretical lenses incorporating teacher questioning as an indicator of core teaching practices (Ball et al., 2009; Windschitl et al., 2012) and teacher development (Dall'Alba & Sandberg, 2006; Dreyfus, 2004) provided additional insight into the potential of categorizing teacher questions as low or high-press to consider teachers' 1) development of a clear and robust conceptual goal for a lesson activity, and 2) understandings of inquiry-based science instruction.

Teacher questioning and instructional goals

The goal Ms. Davidson and Ms. Matthews identified for their lesson was to introduce concepts of variation, mutation, and genetic engineering. However, their approach amounted to requesting that students develop proper definitions for unfamiliar concepts based on a series of disconnected examples of each category. Despite repeated suggestion on the part of the first author that they consider alternative approaches to support and deepen student thinking, the two novice pre-service teachers persisted in their view that requiring students to *generate* definitions qualified as inquiry-based instruction. Thus, their apparently limited understanding of inquiry-based science instruction translated into a largely didactic, but inductive teaching style characterized by low-press questioning strategies. Ms. Davidson and Ms. Matthews's failure to facilitate students in attaching examples of genetic traits to a causal explanation produced an activity focused on mastering content (definition of genetic variation, mutation, and engineering) rather than making sense of a concept (genetic evolution through natural selection). Since the teachers had a formal definition of genetic engineering, mutation, and variation in mind, they failed to recognize any need to elicit student thinking beyond the specific answer for which they were searching. Thus, only low-press questions were required to guide students in seeking to define the types of genetic differences and the implicit goal of the lesson was revealed to be highly factual and definitional rather than conceptual despite their apparently more conceptual description of their instructional goal (Table 2).

While Ms. Davidson and Ms. Matthews characterized this activity as inquiry-based instruction, limitations in their instructional goal reduced the cognitive demand of the activity for students. Thus, Ms. Davidson and Ms. Matthews maintained a conceptual goal synonymous with more didactic teaching practices while adapting their pedagogy to appear more student-centered than a traditional lecture format. Accordingly, our study reinforces models of core teaching practices arguing that identifying a robust conceptual goal is vital for inquiry-based instruction (Hiebert et al., 2007; Windschitl et al., 2012). We suggest that a preponderance of low-press questions may be indicative of a more traditional understanding of teaching practice, despite a visibly interactive teaching style.

In contrast to the two novice pre-service teachers, Mr. Simpson used a series of high-press exchanges to build on student contributions and facilitate connections between the examples and the concept of natural selection. Thus, Mr. Simpson's use of high-press questions was more effective in assisting students to make sense of genetic engineering and was indicative of more advanced practice. His discursive practices (Windschitl et al., 2012) revealed his ability to conceptually connect the various examples to the *causal phenomenon* of natural selection. Mr. Simpson's example reinforces our suggestion that high-press questioning practices are required to support students in making sense of complex concepts and are indicative of robust conceptual lesson goals. Thus, we argue that high-press questioning strategies are both a vital and systematically identifiable characteristic of the core teaching practices that can support inquiry-based science teaching.

Further, the successful interaction in which Mr. Simpson provided Ms. Matthews a high-press question suggests that targeted mentoring of novice pre-service teachers in real time as they attempt to implement inquiry-based science instruction is promising for scaffolding their development of core teaching practices. Accordingly, teacher educators may find it useful to support novice teachers by introducing high-press questions to scaffold core teaching practices supporting inquiry-based science instruction. In sum, our results indicate that identifying the specific questioning strategies that are linked to core teaching practices at this finer-grain of analysis potentially provides a foundation for: (1) helping novice pre-service teachers to understand fundamental differences between inquiry and traditional pedagogies and (2) mentoring and measuring such practices during field and student teaching experiences.

Core teaching practices reflecting different understandings of inquiry-based instruction

‘Faux Inquiry’

The limited conception of inquiry reflected in our novice pre-service teachers' questioning practices resonated with our broader experiences as teacher educators. Despite exposure in multiple courses to theoretical foundations and examples of experience-based and concept-building discourses designated by inquiry-based instruction, Ms. Davidson and Ms. Matthews consistently planned activities that retained traditional instructional goals within more inductive lessons. As discussed, Ms. Davidson and Ms. Matthews developed their ‘inquiry’-based lesson around the premise of *not* telling students the definitions of genetic mutation, variation, and engineering. Having students construct their own definitions, rather than providing a traditional lecture accompanied by an assigned introductory reading from a text, constituted their understanding of inquiry-based science instruction. Anecdotally, ongoing observation of Ms. Davidson and Ms. Matthews as they later progressed through student teaching and entered the teaching profession indicated that with classroom experience and ongoing scaffolding, they made substantial progress in developing lessons around more robust conceptual goals and utilizing high-press questions to effectively support student exploration and sense-making.

Based on this analysis and its resonance with early attempts at inquiry-based instruction by many novice pre-service teachers we have mentored, we suggest that this stage, in which solicitation of facts or definitions is viewed as inquiry-based instruction may be an early step in a trajectory of developing a more robust conception and enactment of inquiry pedagogy. We expect that this stage may be particularly intractable for teachers who themselves have learned science primarily through traditional methods. We contend that prior to internalizing the importance of student sense-making and conceptual depth fundamental to inquiry-based instruction, many novice teachers develop a hybrid approach that retains the goals of delivering content, while expecting students to generate facts and definitions themselves inductively. We adopted the term “faux-inquiry” to describe this novice conception of inquiry-based instruction because it retains the substance of traditional teaching goals while attempting a more inductive pedagogy (Fig. 7).

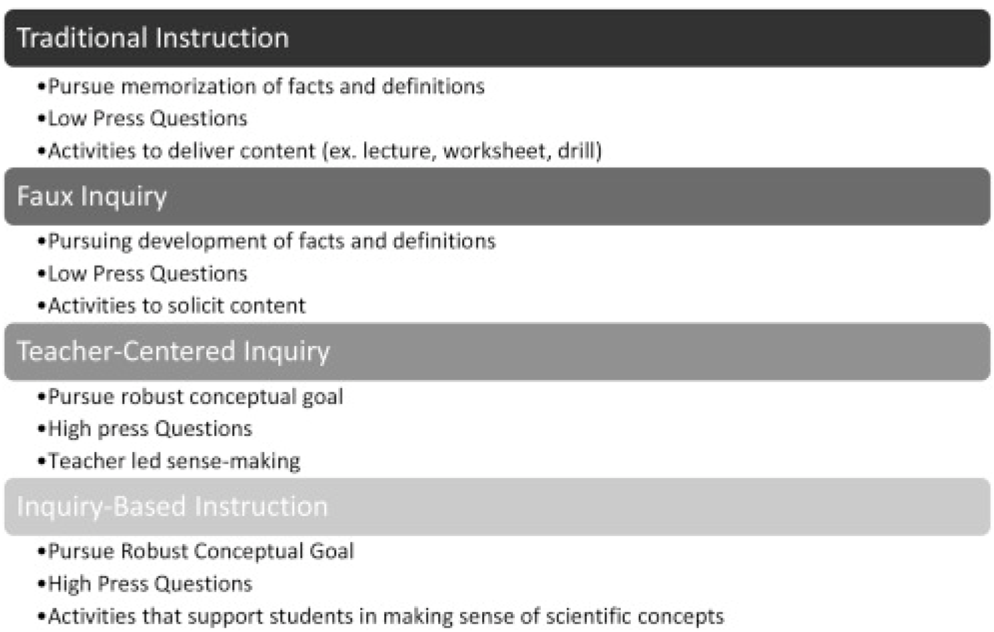

Fig. 7. Summary of understandings of teaching.

The extensive use of low-press questions within an apparently student-centered lesson appears consistent with faux-inquiry instruction. In light of Dreyfus's (2004) stage model of professional practice development, we suggest that through professional experiences many novice teachers progress through a stage of development that reflects: (1) a lack of practice in enacting teaching (Dreyfus, 2004) and (2) a rudimentary understanding of inquiry (Dall’Alba & Sandberg, 2006) that reduces inquiry to positioning the teacher as a questioner rather than deliverer of content. Recognizing faux-inquiry as a possible stage in the development of inquiry-based instruction may assist teacher educators in more effectively supporting novice pre-service teachers in reflecting on the different conceptions of learning represented in traditional and inquiry-oriented instruction.

Teacher-centered inquiry

According to Dreyfus's (2004) model of professional development we consider Mr. Simpson's teaching practice as approaching the standard of ‘expert’ based on his demonstrated ability to make context-based decisions almost effortlessly and support conceptual engagement among students that resonated with the conceptual growth emphasis of inquiry-based instruction. In relation to three of the four core teaching practices (see Fig. 1) identified by Windschitl et al. (2012), Mr. Simpson spontaneously identified a robust conceptual goal for the novice-developed lesson, and led students in making sense of genetic engineering through pressing for evidence-based explanations and eliciting student ideas to make sense of the examples. Unfortunately, in this example he failed to work further instruction around students' developing ideas and extend their thinking into applications of their newly formed understanding of genetic engineering. We suggest his teaching maintained a traditional understanding of the role of the teacher as the holder of scientific knowledge. According to Dall'Alba and Sandberg's (2006) contention that the teacher's definition of the profession influences the trajectory of development of professional practices Mr. Simpson retained a teacher-centered notion that located the responsibility for setting the intellectual direction of instruction solely with the teacher. Thus, he neglected to consider student ideas in his attempt to move the lesson beyond the development of the concept of genetic engineering as it relates to the advantage of traits. Thus, if we only considered Mr. Simpson's practice along a developmental trajectory (Dreyfus, 2004) based on his mastery of inquiry-oriented practices (Windschitl et al., 2012) we would lack language to consider a distinct teacher-centered structure evident in his teaching despite the skill with which he leads his classes.

Adding Dall'Alba and Sandberg's (2006) dimension of the understanding of the professional role allowed us to recognize that Mr. Simpson had retained a more traditional understanding of centrality of the role of the teacher in his instruction, making his practice fall short of a more extensive student-centered, constructivist model of inquiry-based instruction. While he supported student sense-making, he often relied on his own engaging personality to lead students to conceptual connections rather than providing them opportunities to "figure out phenomena" based on their own experiences (Krajcik, 2015). Thus, although we consider Mr. Simpson to be both an effective science teacher and mentor, because the sense making in his lessons was more teacher-directed, we adopt the term "teacher-centered inquiry" to describe Mr. Simpson's teaching practice and suggest that although he is approaching expert performance within his understanding of teaching practice, he too is developing in his enactment of core practices supporting inquiry-based science instruction.

In Fig. 7 we have provided a typology of instruction suggested by our analysis that ranges from traditional to inquiry-based instruction. The categories, Teacher-Centered Inquiry, and Faux Inquiry represent our analysis of adaptations of inquiry-based instruction embodied by participants in our case study. In Fig. 8 we present our model that incorporates the above typology juxtaposed with Dreyfus's (2004) model of professional development as an initial, more dimensional and fluid model of stages through which teachers may pass in developing core practices that support inquiry-based science instruction. We expect that additional research will both refine the model and identify additional stages.

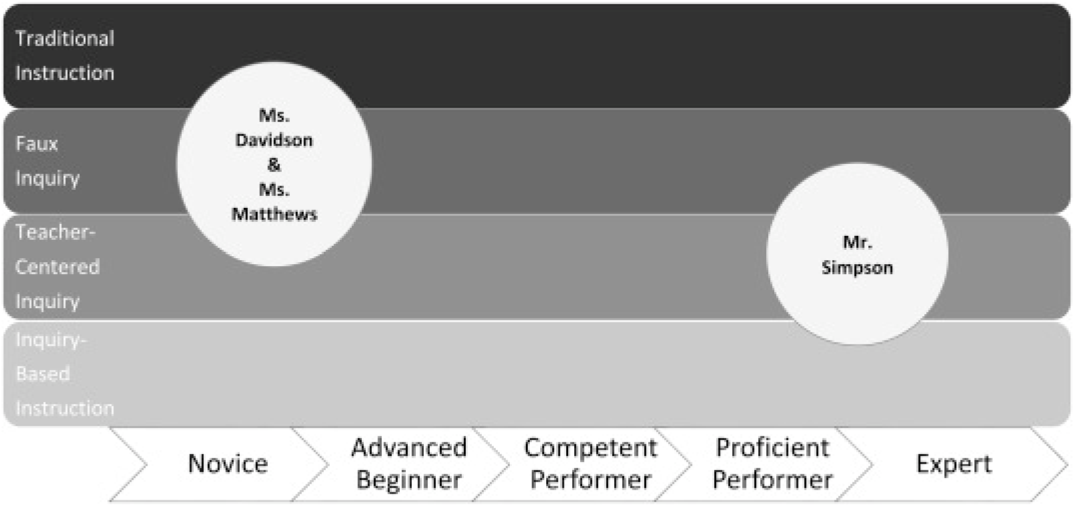

Fig. 8. Two-dimensional model of teacher development.

According to our model of teacher development every instance of teaching reflects a particular enactment of a teacher's understanding of their role in relation to inquiry-based instruction and their development of practices that support inquiry-based science instruction. Through experience and throughout a career, a teacher's practice as depicted by the observation of one lesson might be identified as a shift from previous practice in any direction (more toward the novice or expert, and more or less reflective of inquiry-based practice). While it is generally expected that with increasing experience the teacher's practice will generally trend toward the more expert (Dreyfus, 2004), their fundamental conception of teaching practice may or may not shift in relation to their understanding of inquiry-based instruction as effective practice (Dall'Alba & Sandberg, 2006). Additionally, the inherent challenge of enacting inquiry-based instruction with fidelity suggests that novice teachers with deeper understandings of inquiry still may enact practices consistent with more traditional models of instruction. Such teachers then would be expected to develop along a trajectory of increasingly sophisticated enactment of core teaching practices supporting inquiry-based science instruction as they gain experience and greater ability to implement inquiry in their classrooms.

Conclusions

The results of our study reinforce core teaching practice models claiming that a fundamental characteristic of inquiry-based instruction is the identification of a robust conceptual goal around which to structure every lesson (Hiebert et al., 2007; Windschitl et al., 2012). Our novice pre-service teachers' failure to identify a robust conceptual goal prevented their students from pursuing deeper conceptual knowledge within the parameters of their inquiry-based science lesson. In contrast the mentor teacher intuitively altered the novice pre-service teachers' plan to emphasize complex ideas of genetic variation and natural selection. Having this more robust conceptual goal allowed him to access students' personal experiences and prior learning to help students make sense of why examples of genetic engineering would not characteristically advantage the effected organism. Figuring out this relationship allowed students to analyze the examples in a way that was lacking in the two pre-service teachers' approach, which focused on developing a definition for various terms. However, he failed to provide an opportunity for them to extend or apply their conceptual understanding to additional examples or problems.

Our study suggests that examining and scaffolding the practice of teacher questioning offer powerful tools for teacher educators. Teacher questioning provides an analytical lens through which to assess the depth of conceptual goal and understanding of inquiry enacted by teachers at differing stages of professional experience and development. By recognizing low-press questioning patterns, teacher educators might support novice pre-service teachers in developing more robust conceptual goals for lessons, and a more conceptual understanding of the goals of inquiry instruction generally. Further, by suggesting high-press questions while novices are teaching, mentors may be able to scaffold the practice of more conceptually-rich instruction.

Finally, our two-dimensional model (Fig. 8) of core teaching practice development provides a way of thinking about teaching in terms of both developmental trajectories and foundational definitions of teaching practice. Our model suggests that multiple paths to expert, reform-based teaching are likely and that teachers may develop highly skilled practices that do not reflect all of the priorities of inquiry-based instruction. As Fig. 8 illustrates, the novice pre-service teachers' practice lies to the far left of the developmental trajectory, as expected, while the mentor teachers' practice reflects his experience. However, the strength of the model lies in its specification that the individuals' understanding of teaching is also reflected in each teacher's practice within any observed teaching event. Thus, multiple pathways of development, emphasizing different definitions of teaching are plausible. We contend that teachers can develop skill in their practice within each definition, however, the more challenging enactment of inquiry-based instruction may require continued growth as a teaching professional. Thus, holding expectations that novice pre-service and new teachers can effectively and consistently enact core teaching practices supporting inquiry-based science instruction may be developmentally inappropriate. Rather, we suggest envisioning novice pre-service teacher preparation as setting a foundational understanding of inquiry-based instruction and supporting the initial development of core teaching practices.

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