Defining Learning Progressions in Scientific Inquiry

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Abstract

A learning progression for inquiry describes the increasingly sophisticated scientific practices that students may engage in as they pursue coherent, mechanistic accounts of phenomena. While some science learning progressions have acknowledged the importance of inquiry in science, they are often defined by students' steady progress toward developing the scientifically accepted model of a phenomenon. We offer an alternative framework for a learning progression, where content knowledge does not surpass scientific inquiry as a goal or measure of learning, and the nature of student engagement in inquiry practices is understood to be situation-dependent. In this paper, we illustrate our theoretical framework by outlining an example analysis in terms of one inquiry practice: coherence-seeking. We also address some of the benefits and challenges to defining a learning progression in terms of students' engagement in inquiry practices.

Introduction

Motivation for Studying a Learning Progression in Inquiry

Despite years of awareness of its importance, science education has yet to achieve a systematic emphasis on student inquiry. Often, inquiry is not an objective in itself, but instead is seen as a means to achieving the objective of students' acquisition of correct canonical facts and concepts. Even in research on student learning progressions, which sometimes aims to incorporate multiple strands of scientific proficiency, most work describes "the successively more sophisticated ways of thinking about" one of the "core ideas" in science (NRC, 2007, p. 214). The content-centered approaches to science education deviate from authentic scientific practice in critical ways. For example, when scientists engage in inquiry, the conclusion is never determined in advance (Hodson, 1988). Because inquiry is at the heart of authentic scientific practice, we argue that the development of a learning progression in inquiry—where the objective is developing more sophisticated inquiry practices, rather than just correct canonical understandings—is essential.

Defining Scientific Inquiry

Content as context for inquiry. Instead of treating inquiry as *merely* a vehicle for conveying or assessing scientifically accepted understandings, we argue that inquiry should have equal footing as an educational goal in and of itself. Drawing upon the work by Hammer et al. (2008), we define inquiry as "the pursuit of coherent, mechanistic accounts of phenomena." Complementary to this definition of inquiry, we take reasoning about "what happens in the world and why" as reasoning about "content." Our approach to inquiry learning progressions emphasizes that while inquiry is a primary goal of science education, it is only meaningful when done within the context of scientific content. That is, students must be reasoning *about* something, and we expect the nature of this reasoning to depend on what aspects of the world they are reasoning about.

Scientific inquiry practices. One challenge in our work is to define what progresses during a learning progression in scientific inquiry. We begin by identifying components of scientific inquiry, or *inquiry practices*. Over the course of instruction, we expect students to engage in these inquiry practices both more often and in a greater variety of circumstances. Examples of scientific inquiry practices include modeling, argumentation, mechanistic reasoning, and coherence-seeking. We characterize a learning progression in inquiry by the changes in the nature of students' engagement in inquiry practices over the course of instruction. We do not expect these changes in engagement to be accurately modeled by a taxonomy of stable and hierarchical stages. Instead, we adopt a resources perspective, whereby we expect students to spontaneously activate and coordinate contextually sensitive resources as they engage in tasks.

Conceptualizing an inquiry progression in terms of resources. Other researchers in science and mathematics education have interpreted student reasoning and performance in terms of phenomenological (diSessa, 1993), epistemological (Hammer, 1994; Hammer & Elby, 2002), and even mathematical (Sherin, 2001) resources. Much of this previous work centers on interpreting student learning of scientific concepts, but some of it, in particular the work on epistemological resources and framing, is very applicable to studying student engagement in scientific inquiry practices. For example, children can and do reason mechanistically, but often they do not apply mechanistic reasoning in situations when a scientist would consider it appropriate (Abrams, Southerland & Cummins, 2001; Newton & Newton, 2000). There is some evidence to suggest that the kinds of resources students draw on when reasoning about a situation depends largely on their framing of the activity (Louca, Elby, Hammer & Kagey, 2004;

Hammer, Elby, Scherr & Redish, 2005).

For our work, we find two implications of the resources perspective especially appealing: first, it suggests an alternative to a linear, stage-based description of progression; and second, it helps us recognize productive student thinking that might otherwise be dismissed as inconsistent with scientifically accepted understandings. In particular, the resources perspective leads us to investigate the *situations* in which students engage in inquiry practices. We define *progression* as engaging in an inquiry practice more frequently and in a wider variety of situations. As a result, we conceptualize a learning progression in terms of episodic, rather than steady and linear development. For example, a learning progression in mechanistic reasoning might begin with children using, understanding, and appreciating mechanistic explanations episodically. Over the course of instruction, children might progress toward favoring mechanistic explanations in science discussions, and eventually come to expect such explanations even when none are available.

Our immediate focus is to identify examples of student engagement in a given inquiry practice, identify the conditions under which the engagement occurred, and interpret students' activity in terms of smaller grain-sized components. From this work, we eventually hope to describe examples of resources and their origins, as well as propose an example learning progression in scientific inquiry.

Methods

In this paper we illustrate our approach to characterizing learning progressions in inquiry using data collected during an NSF-funded research project[1]. This project has three major goals: (1) to devise learning progressions for students and teachers in scientific inquiry and energy; (2)

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[1] Learning Progressions for Scientific Inquiry: A Model Implementation in the Context of Energy (NSF DRL 0732233, 01/08-12/09)

to develop model materials and strategies for elementary and middle school curriculum and teacher professional development; and (3) to study how students and teachers learn using the curriculum and professional development materials. We are currently in the first year of implementation and data collection.

For this project, eight participating elementary and middle school teachers attended a week-long summer workshop where they engaged in scientific inquiry activities and interpreted video of students reasoning about scientific phenomena. Teachers also attend biweekly meetings designed to help them attend to student thinking and promote inquiry practices. During the school year, each teacher spends approximately 20 classroom hours using curricular materials developed as part of the project. The curriculum modules seek to promote scientific inquiry practices in the context of a different scientific discipline for each grade level—motion and energy and electric circuits (fourth grade), earth science (fifth grade), and ecology (sixth grade)—but each with opportunities for ideas about energy to emerge.

Video, field notes, and artifacts are collected from professional development meetings, workshops, classroom implementations of curriculum modules, and additional classroom episodes at the discretion of the teacher. These serve as the primary sources of data for our development of student (and teacher) learning progressions.

Sample Analysis of Coherence

Why Coherence?

According to Salmon (1989), "it is explanatory knowledge that provides scientific understanding of our world" (p. 3). Yet, scientists and philosophers have struggled to define the characteristics of a "scientific" explanation. Aristotle held that all scientific arguments are deductive, an idea that has continued to hold ground in modern conceptions of scientific explanation. However, because "not all deductive arguments can qualify as explanations", philosophers have continued the search for a better model to distinguish between scientific and non-scientific explanations (Salmon, 1989, p. 3). Amidst the debate, philosopher Paul Thagard (2000) has investigated ways to distinguish the causal, deductive, and statistical aspects of scientific explanation under the umbrella concept of coherence. His work has influenced science education and cognitive science researchers attempting to understand how students reason scientifically about the world around them (Ranney & Schank, 1998; Sandoval, 2003; Vosniadou, 2000; Vosniadou & Brewer, 1992).

Defining Coherence

Many fields, including philosophy, law, and education, utilize the idea of coherence in determining the reasonableness of an explanation. Despite its pervasiveness, the literature has yet to reach a consensus on how to define coherence, both within and across disciplines. For the purposes of our work, we tentatively define two key aspects of coherence: consistency between elements and meaningful relations between elements. What constitutes an element depends on the context, but in general the term refers to one idea, claim, or piece of data within a larger discussion, argument, or explanation.

Coherence plays at least two distinct but related roles in scientific inquiry. First, coherence is a characteristic of a mature scientific theory, explanation, or model. Second, *seeking coherence* is an aspect of mature scientific reasoning. In considering student progress, we must attend to the ways they seek coherence as well as to the coherence of the ideas they produce. To illustrate our definition of the term coherence and how it relates to a learning progression in inquiry, we present an example taken from one elementary classroom.

Example of a Student Seeking Coherence

One of our fourth grade curriculum modules begins by asking students to think of different ways of getting a toy car to move. In one classroom, students discover that they can make a small toy car move using two attracting magnets. The teacher asks students to explain how magnetism gets the toy car to move, and a discussion ensues. One student, Caitlin, suggests that "magnets have some electricity in them." Later in the discussion, another student responds to this idea:

> Jason: Um, how could it [the magnet] have electricity in it because, because metal conducts electricity. When it hits it it goes through to wherever it is.

Jason appears to have identified an inconsistency between Caitlin's idea that electricity is in magnets, and his own idea that magnets are metal and metal conducts electricity. He draws attention to the inconsistency two more times before the discussion ends:

> Jason: No, how could, how could the magnet be part of...How could it have um, electric in it because if it conducts to metal, electric when it hits it, it would just travel through until, until there's no other metal on it.
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> ....
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> Jason: No, I'm saying how could, how could a magnet have electricity in it because, isn't a magnet metal too? sort of? If it had electricity in it, it would go out. Because once electricity hits metal it goes, it keeps going in the metal until it goes—until there's no other metal on to for it to travel through and then it goes out.

In this excerpt, Jason demonstrates the beginnings of what we tentatively refer to as *coherence-seeking*, drawing productively on at least two sense-making abilities: recognizing inconsistencies and reasoning about cause and effect. Jason recognizes and brings to the attention of the class an inconsistency between three elements: i) Caitlin's idea that electricity is in magnets, ii) his idea that magnets are made of metal, and iii) his other idea that electricity "travels through" and "goes out" of metal. In that sense, he is seeking coherence with respect to the first aspect of coherence—consistency.

Jason also attends to the second aspect of coherence, meaningful relations between elements, in that he appears to be reasoning in terms of cause and effect. Implicit in Jason's thinking is the idea that some sort of *stuff* must remain inside the magnet to *cause* its attractive properties. Since magnets are composed of a material that cannot entrap the proposed causal agent—"electric" or "electricity"—then how can this in fact be the cause of the observed magnetic effects? While Jason's concern is never resolved, we argue that his search for coherence is a productive activity and an important dimension of scientific inquiry.

Working under the assumption that Jason's attention to coherence is sensitive to context, it is important to identify a few key elements of the situation that may have facilitated his coherence-seeking. First, Jason's question was part of a larger class discussion in which students had opportunities to share their ideas. In this context, Jason was able to draw on ideas he already had about magnets and electricity, such as the idea that electricity "conducts." When Jason heard Caitlin's idea and recognized it as contradicting his own knowledge, he drew the inconsistency to the attention of his teacher and classmates. Second, Jason took multiple opportunities to clarify and restate his concern about Caitlin's suggestion that electricity is in magnets, despite being repeatedly misinterpreted by his teacher and classmates. Third, we point out that Jason questions the consistency of a peer's explanation. If, in a different situation, this same explanation had been offered by an authority figure or textbook, Jason may not have sought consistency.

Describing Progress in Terms of Coherence

Jason engages in the activity of coherence-seeking in that he recognizes inconsistencies between Caitlin's and his own ideas and reasons in terms of cause and effect. In the spirit of a learning progression in inquiry, we hope Jason will become more sophisticated in his practice of coherence-seeking over the course of instruction. Rather than define that expected progress in terms of levels, we are pursuing an alternative approach by defining two forms of progress: becoming more stable in seeking coherence, and seeking coherence in a wide variety of contexts.

Our approach implicitly assumes that coherence-seeking is a context-dependent practice involving the activation of finer-grained resources.

As Jason becomes more stable in seeking coherence, we might expect him to draw attention to inconsistencies more often, and let fewer contradictions get by "unnoticed" in the classroom. Likewise, he may show evidence of reasoning in terms of cause and effect more often. Along the second dimension of progress, however, we expect Jason to attend to coherence in a wider variety of situations. For example, he might seek consistency not only among peers' ideas, but also among ideas from authoritative sources such as textbooks and teachers. He might also attend to different kinds of relations among ideas depending on the topic being investigated. For example, Jason recognizes cause and effect relationships in physical science, but in another content area, like ecology, we might also expect Jason to consider part-to-whole relationships. One route we are pursuing in our analysis is to identify if and when students attend to these different types of relations as they proceed through our toy car, electricity, water cycle, and ecology curriculum modules.

Concluding Points and Emerging Questions

In this paper, we argue for the development of an inquiry learning progression that takes as a primary objective students' development of more sophisticated inquiry practices. We outline a framework for defining an inquiry learning progression in terms of students' more stable and varied engagement in inquiry practices as they reason about phenomena, using coherence-seeking as an example. While our work offers an alternative way to conceptualize and define learning progressions, it also raises a number of challenging questions. For instance, if, as we argue, content and inquiry are linked, then can we distill one from the other in a learning progression? We hope that future work will address this and other important questions related to the development of learning progressions for scientific inquiry.

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