The Science Practice of Asking Questions About Phenomena:
Shifting Towards Generating Explanatory Questions

PROBLEM

The ability to construct scientifically oriented questions is an essential science practice, as noted in current and previous science education reform documents (National Research Council, 1996; National Research Council, 2000; National Research Council, 2012); however, the practice is rarely enacted in classrooms (Asay & Orgill 2010; Weiss et al. 2003). Instead, investigations or hands-on activities dominate (Manz, Lehrer, & Schauble, 2020). To center the science practices and make coherent the science experiences of prospective elementary teachers in an undergraduate elementary education program, we implemented a model-based inquiry (Schwarz & White, 2005; Schwarz, 2009; Windschitl, Thompson, Braaten, & Stroupe, 2012) approach across the physical science for elementary teachers and elementary science education methods courses. Prospective elementary teachers constructed scientifically oriented questions as science learners in the physical science course when presented with a phenomenon that would guide a set of investigations and the development of a visual model and written explanation to describe *how* or *why* the phenomenon occurred. The proposed presentation focuses on the questions prospective elementary teachers ask, throughout the semester, upon observing five different phenomena for the first time. They refined questions throughout the inquiry; however, here, we center on the questions the prospective teachers initially create (individually) when they view the phenomenon for the first time. The phenomena cover the topics of matter, force and motion, energy, waves, and electricity.

As stated in Biggers (2018), scientifically oriented questions are sometimes called “driving questions” (Krajcik et al., 1998), “investigative questions” (Forbes & Davis, 2009), or “initial questions” (Kawalkar & Vijapurkar, 2013). Driving questions situate learning across experiences or lessons, whereas investigative questions tend to focus a lesson that may or may not take a day or more to complete. In either case, the purpose of scientifically oriented questions is two-fold. First, the questions provide explicit purpose to the learning experiences, and second, they prompt students’ sense-making of the science (Forbes & Davis, 2009). Elstgeest (2001) identifies questions that ask students to *show* rather than *say* “productive” questions (p. 26).

Hanuscin et al. (2020) identify five categories of investigative questions. “What is…?” questions elicit definitions and isolated facts. Investigations are not necessary to determine an answer. Questions that begin with “How long?” or “How much?” emphasize predictions of outcomes. And, questions that lead to a description of what happened tend to start with “What happens when…?” and “Which…?” “How…?” and “Why…?” questions, on the other hand, elicit explanations. These questions center on cause-and-effect relationships instead of patterns or descriptions of activities.

Explanatory questions are the only type of questions that elicit explanations and enable students to engage in sense-making practices (Forbes & Davis, 2010), which include developing and using models, analyzing and interpreting data, and constructing explanations (McNeill, Katsh-Singer, & Pelletier, 2015). These questions require students to figure out why the phenomenon occurs rather than learning about the phenomenon (Schwarz, Passmore, & Reiser, 2017).

Prospective elementary teachers participate in coherent content storylines that build upon existing ideas through sensemaking events positioning students as co-constructors of knowledge.

The goal is to authentically utilize the science practices to solve a problem—explain why the phenomenon occurs. Unfortunately, the notion that science investigations are for practicing process skills or confirming known outcomes (Lehrer & Schauble, 2015) still prevails. Manz Lehrer, and Schauble (2020) propose a framework for positioning the practice of "planning and carrying out investigations" within a suite of methods to extend its usefulness and align with the work of scientists. Model-based inquiry encourages the use of a collection of science practices organically. In this way, the practices are taken up as scientists would engage with them.

This study was embedded within a more extensive investigation seeking to understand how coherency of the use of the science practices via model-based inquiry across the science content, science education methods, and STEAM methods courses for elementary teachers at a mid-sized state university in the southeastern United States affects their use of the practices in planning and implementation of science instruction during practicum experiences.

To guide our research design, we developed an overarching research question—How do prospective elementary teachers construct scientifically oriented questions of physical science phenomenon throughout a semester?—supported by two sub-questions:

1. What types of questions do prospective teachers generate?
2. If questions change over time, in what ways do they change?

DESIGN

Study Context

All prospective elementary teachers (PETs) in the state enroll in two science content courses for educators before admission to the teacher education program. The study focuses on the physical science content course. The physical science or life science content courses are the prospective elementary teachers' first experience with an integrated (content + pedagogy) course.

The physical science content course is structured around collaborative investigations and sensemaking experiences. Students initially make observations and inferences (Finson, 2010) about a scientific phenomenon. They draw what they see in the phenomenon, ask questions, and write about their observations. Next, they draw what they cannot see (inferences) using their imaginations to describe and illustrate the cause(s) of the phenomenon. This is the observation and inferences model. Then students form small groups to develop an investigation to generate data to help them answer an investigative question. When collaborative discussions occur, they reveal prior knowledge framing investigations. PETs were presented with both guided and open-ended opportunities to engage in initial explorations of the phenomenon. Further, collaborating on data analysis facilitated the construction of an explanation supported by evidence and scientific reasoning negotiated from multiple perspectives. Diversity of perspective increases the quantity and, thus, the quality of explanations. Ideas are analyzed and synthesized to form a consensus view resulting from a process that results from the diversity bonus (Page, 2019).

Although we focus on the initial questions prospective teachers ask after observing a phenomenon, they have experience collaborating with classmates throughout the process of model development for each phenomenon. They and their classmates refine the scientifically oriented question to accompany the revised model and explanation.

Methods and Data Collection

Five times throughout the semester, prospective elementary students observed a phenomenon demonstrated in person or via a video. They were asked to complete a template (Figure 1), including written and drawn descriptions of observations and inferences. We call this the initial model. See Figure 1 below.

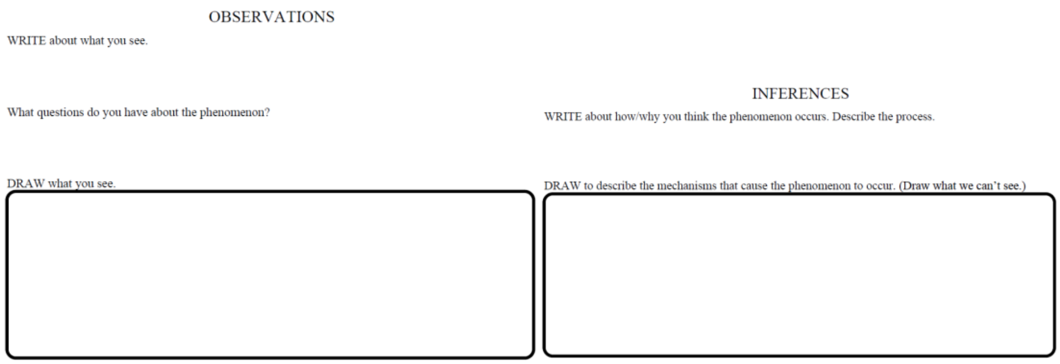

Figure 1. Data collection form to capture initial questions about the phenomenon.

The university's IRB approved the study, and participants consented to join. Eight prospective elementary teachers completed three iterations of five different models and explanations across a semester to explain why the phenomena occur. The following section describes how we analyzed data from their initial models.

ANALYSIS & FINDINGS

Data Analysis

Each prospective elementary teacher's data set was read before coding commenced to gain a sense of all the data. Based on our initial holistic view of the data, we used the Hanuscin et al. (2020) question categories as a guide to determine that there were eight types of questions in our data. A priori question codes included "none," "how," "what," "when," "what causes," "hypothesis," "yes/no," and "why." We consider "how," "why," and "what causes" questions to be explanatory, enabling students to engage in science sense-making. The other questions above elicit facts, descriptions, and outcomes; they are not explanatory questions.

Each phenomenon data was analyzed separately to compare the types of questions across topics and duration of the semester. Table 1 illustrates the number of questions per code. The total number exceeds eight questions per phenomenon because prospective elementary teachers could list as many questions as they wanted to.

The participants generated ten questions for matter and force and motion, eight for waves and electricity, and fifteen for the energy phenomenon. Of the 52 questions, 36 were explanatory, enabling students to engage in sensemaking to figure out *why* or *how* the phenomenon occurs.

Table 1. Number of questions for each code and phenomenon.

	None	When?	Hypothesis	What?	Yes/No?	What causes?	How?	Why?
Matter	2	0	1	0	1	0	1	5
Force & Motion	0	2	0	1	1	3	2	1
Energy	0	0	0	2	2	3	0	5
Waves	0	0	0	0	1	1	1	5
Electricity	0	0	0	1	0	2	1	4

Findings

Research Question 1: What types of questions do prospective teachers generate?

All prospective elementary teachers generated questions that were relevant to the phenomenon. Both fact-finding and explanatory questions were present. Some examples are shown in Table 2 with their code.

Table 2. Codes applied to a sample set of the question data.

Question	Code
Is the other ice cube melting?	Y/N
Why is one ice cube melting faster than the other?	Why
What is keeping the paperclip from falling to the bottom of the cup?	What is causing?
Where does the power that charges the ball come from?	Where
Why are some balloons more inflated than others?	Why
Does it melt because one tray is hotter than the other?	Y/N & Hypothesis

Research Question 2: If questions change over time, in what ways do they change?

The number of questions decreased over time. Initially, the prospective elementary teachers generated ten questions about the phenomenon. Then, for energy, there were fifteen questions. The final two phenomena elicited eight questions each. The first three phenomena (matter, forces, and energy) were more likely to produce fact-finding questions. There were more instances of "when" and "what" questions early on.

Tables 3 and 4 show the questions from Anne and Jane (pseudonyms). Anna did not include questions initially.

Table 3. Anne's questions for each phenomenon.

No Question
What causes the paperclip to remain upright?
What causes one ice cube to melt, and fairly quickly, while the other ice cube doesn't appear to melt at all even though both ice cubes appear to be sitting on the same surface?
What causes the dog's reflection to be shown in the frozen lake?
What causes the ball to light up only when it is squeezed?

Table 4. Jane's questions for each phenomenon.

Why are the balloons being inflated?
What is keeping the paper clip from falling to the bottom of the cup?
What is causing cube #1 to melt? Why isn't cube #2 melting?
Why can we see a perfect reflection of the wolf reflected on the frozen pond?
Why does the ball light up when being squeezed?

The two example question sets above illustrate that some prospective elementary teachers can construct scientifically oriented questions with minimal guidance. The instructor did not explicitly demonstrate how to craft investigative questions during the semester. The presentation will emphasize shifts from fact-finding toward sense-making or explanatory questions such as those shown in Table 5.

Table 5. Reba's questions for each phenomenon.

Is the vinegar amount or baking soda making them grow to different sizes?
Is the rock magnetic?
What causes the one ice cube to melt?
Why does the wolf see the bottom of the pond and himself at the same time?
No question (absent).

Questions like, “Is the vinegar amount or baking soda making them grow to different sizes?” focus on patterns in data rather than an explanation for why a gas appears and enlarges a balloon. Given that the context is modeling and explaining phenomena, a question like, “Why does the balloon inflate?” is a better question. Notice that Reba continues to ask questions that elicit a “yes” or “no” response. It is not until the third phenomenon that she transitions toward scientifically oriented questions.

Only 60% of the initial questions (about matter) were scientifically oriented questions. Except for energy, there was an increase in the number and percent of explanatory questions for each subsequent question set. The last phenomenon—about electricity—had 12% of the questions elicited facts rather than explanations.

CONTRIBUTION

Asking scientifically oriented questions is the first science practice outlined in the *Next Generation Science Standards* (NGSS Lead States, 2013) and *A K-12 Framework for Science Education* (NRC, 2012); however, the practice is not well researched in the context of pre-service and in-service science education. We present the practice embedded within model-based inquiry for prospective elementary teachers in a physical science course for teachers as a way to initiate and guide the investigation of a phenomenon to generate explanations. The findings suggest that prospective elementary teachers produce more explanatory questions with additional experience in explaining phenomena without explicit instruction about constructing scientifically oriented questions. Our next steps include looking horizontally across each phenomenon to determine the ways prospective elementary teachers refine questions throughout a set of investigations.

GENERAL INTEREST

The findings illuminate what prospective elementary teachers can do before entering elementary education programs at the undergraduate level. With a background in crafting scientific questions, prospective elementary teachers are better prepared to learn how to elicit explanatory questions from elementary students when they enter the science education methods course. We feel this presentation may be helpful for content and science education methods instructors and researchers at all levels.

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