MAKING THE GROUNDS OF SCIENTIFIC INQUIRY VISIBLE IN THE CLASSROOM

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ABSTRACT

Teachers can help children develop conceptions of the role and functions of questions, supporting evidence, and convincing argument.  We trace the development of skills of scientific inquiry in a classroom where students designed sustainable aquatic environments and attempted to account for their successes (and failures).

Two hallmarks of scientific practice are posing fruitful questions about nature and developing evidence related to these questions. For practicing scientists, posing questions and constructing evidence are intimately related. Questions are considered fruitful only if one can envision or invent forms of evidence that bear on them, and events become evidence only in relation to questions. As every parent knows from first-hand experience, children are no slouches at generating questions. But the scientific potential in a child's spontaneous question can easily be lost; children often fail to take the step beyond casual curiosity into systematic inquiry. Questioning is indeed, robustly rooted in children's everyday ways of thinking about the world, but serious classroom support is required if these tender shoots are to bloom into productive guides to scientific inquiry. Similarly, children are apt at generating justifications to support their actions or points of view in an argument. However, they often regard their actions or beliefs as unproblematic, even self-evident. In contrast, scientific inquiry demands a separation between belief and evidence, so that each can be considered apart and their relations made explicit. Thus, question posing and evidence-generation go beyond common sense, and so must be nurtured explicitly in science education.

We describe how we supported development of the conduct of inquiry in a sixth grade classroom taught by Ms. Lucas. The general context was the study of aquatic systems. We engaged students in posing questions and generating supporting evidence about two urban retention ponds near the school. We started with some orienting questions: Who lives there? How would you go about finding out? Students elaborated their knowledge of healthy, sustainable systems by designing and testing their own model aquatic systems, including a classroom pond (a tub holding about 30 gallons), and one-gallon jars that were designed and monitored by pairs of students. In their work with these model systems, students attempted first to design, then to generate, and finally to understand what makes a "healthy" or sustainable aquatic system. As we worked with students over the course of a year, we were oriented toward understanding how students would come to define a "good" question. Similarly, we wondered how students would establish evidence. Would they regard it as obvious and transparent, or come to understand that evidence is always tied to methods of study and particular ways of looking at the world?

We first visited one of the retention ponds near the school. Students conducted some systematic investigations of the types of plants, animals, and insects that they observed there. For homework, they generated ten questions about what they had seen. Our assignment was an invitation literally to step back from the new sights and sounds of the pond and take a critical attitude toward these experiences.

When students returned the next day with their questions, they chose one to share with the class. We listed each question and its author told us about what made it worth asking. This identification of qualities of the questions served, of course, to focus conversation on the nature of the questions posed, but also to short-circuit the derogatory comments that middle-school students sometimes generate when asked to evaluate the work of a peer. As you might expect, students' first questions were grounded in things they happened to notice in the pond. "How much blood can a leech suck in an hour?" "Where does the water come from?" "How does the water get polluted?"

We asked students to consider ways of finding answers to the questions posed. In the course of this discussion, several students proposed that some questions were dead-ends because prospective answers didn't fit with anything else. If one found an answer, that was the end of the process. Some noticed that a few questions were connected, so that answering one (e.g., the question about source) might shed light on others (e.g., pollution). A question about over-wintering (Where does everything go in the Winter?) aroused the most collective interest, perhaps because students had never reflected about what might account for the reappearance of animals in the spring. The consensus was that migration was unlikely, a conclusion that left students with a mystery to ponder. We were surprised by the animation of student conversation about these questions, and also by the beginning of an emphasis on the relative fruitfulness of questions, especially on how an answer could potentially participate in a larger network of relationships.

We decided to summarize what students could agree about qualities of good or "cool" questions, which were primarily: (a) easy to answer, (b) meaningful, (c) genuine (we did not already know the answer), and (d) researchable. To illustrate how criteria like these might "do work," we considered one of the questions that we thought particularly good: “Is the animal life in pond 2 more diverse than in pond 1?” We invited the class to assume our perspective: "Why would we say this is a good question?" Several students suggested methods for indexing diversity, such as the number of different animals obtained from one sample to another taken in the same location, or the number of different animals obtained from sampling in different places in the ponds, or even the number of animals obtained over several trips. These suggestions helped clarify for students the important notion that good questions contain the germs of their investigation. As the discussion continued, we re-examined our criteria, and the class now decided that good questions were:

1. Simple/easy to answer; that is, understandable, the investigator would know what to do to answer it.

2. The questioner has an expectation; the investigator is looking for something specific or believes that there is a particular outcome, has a hypothesis, or at least has some idea of an outcome.

3. Genuine, we don’t already know the answer.

4. It tells you what to do; the question is worded so that the investigator knows how to proceed to begin to answer it.

5. Well-thought out, not casual; the question has been considered and revised before beginning to research it.

Our investigations of the pond continued, and when the Wisconsin weather no longer permitted outdoor pond study, students turned instead to the task of engineering sustainable aquatic microhabitats in the classroom. The habitats were designed to answer a question generated by a small group of students working together. This work was more protracted than our initial explorations of the pond, partly because the jars were easy to reach and always visible, and partly because the jars were models that supported a shift beyond occasional observation to more regular observation and eventually, test. Students began to recognize that, for a variety of reasons, some questions were beyond their ability to answer. Therefore, "do-ability" entered the criteria list, and several questions originally posed were eliminated on the grounds that no one in the class could determine a suitable experiment to answer them.

As students eliminated questions by applying the criterion of do-ability, they sought more viable replacements. They were surprised to discover that extending the question of another group could sometimes generate a fruitful question, or by carefully studying the jar designed by another group, perhaps including it in a contrast with one's own. Thus "piggyback" was added to the list of attributes of a good question, making explicit the earlier intuition that related questions was often fruitful. Finally, "sensible" was added, as students responded to the uncanny sense of the absurd that some middle schoolers' questions expressed. Alex's suggestion to put a shark in the jar failed to pass the class's “sensibility” test, as did Brent's idea to put two Bettas in a jar and see which one won.

These attributes suggest that students came to regard inquiry as having both individual and collective aspects. Individuals generated questions guided by collective awareness of the need to participate in a larger social agenda of persuasion and potential fit with related research. Each of these attributes was listed on chart paper, along with accompanying commentary, and was posted in the classroom for the remainder of the year. Both the students and we referred to the chart frequently throughout the year to guide our generation and revision of productive questions. Our collective criteria became a tool for self-assessment.

As the year progressed, we helped students think about the information they might need to answer their questions, how they might develop or get it, what records they should keep, how they might communicate their findings. We kept a library of material available for the class and suggested additional resources for pursuing their questions, including web sites, print and people resources, agencies, etc. There was no possibility that we could be expert in all the areas that students identified as interesting, which included aquatic and prairie plants, water chemistry and pollution, aquatic and terrestrial critters (arthropods, mammals, fish, etc.), soils, weather, interactions among these, and so on. As students researched their questions, they shared their findings and resources with the rest of us. Collective expertise grew. We worked as scientists in a community of inquiry.

The gradual growth and development of expertise, in turn, served as a spur to further inquiry. As mentioned earlier, you have to know something to ask a question, and you have to know and understand quite a bit to ask a good question. Knowing and understanding come from extended experience and are unlikely to grow much in three weeks (the traditional length of a unit) or even nine weeks (the duration of a school quarter). Students need time to develop a baseline of knowledge. In this case, students needed to make several visits to the pond: sampling, collecting, observing, identifying and classifying plants and animals. They needed to design their jar environments with a mind toward interactions among plants, animals, water chemistry, substrate, and environment. They needed time to observe and record their observations. In many cases, initial jar designs "crashed," sometimes on multiple occasions, leading students to question ideas that were initially held uncritically. For example, one group assumed that if reproduction of plants could serve as an index of a "healthy" system, then more reproduction would be even healthier. The resulting proliferation of plants and eventual crash of this jar served as compelling evidence against the assumption that these systems had an unlimited capacity for sustaining organisms. Time was required for students to develop genuine interests, time to detect patterns, make connections, and notice anomalies. Time for something to happen.

Good questions emerged from knowledge, not just from native curiosity. For example, Ellie and Alex set up a jar to investigate a question about the growth of aquatic plants. The substrate chosen by the team was gravel. After four weeks of observation and data collection, Ellie noticed that another group had used soil as their substrate. Her experiences suggested that soil would be a better substrate (all the plants she saw on land grew in soil). Yet, the plants in her jar were thriving, while those grown in soil were not. In fact, the other group's question had shifted to trying to identify reasons for the continuing demise of their plants, which in turn, led to the death of their animals (ghost shrimp and daphnia). Ellie speculated that there might be a "best" substrate for aquatic plants that had something to do with nutrients provided by the substrate. She decided to set up three jars, identical in plants, animals, and environment, and differing only in substrate. She was no longer interested in the original question. She now had enough experience and understanding of aquatic environments and interactions to see an anomaly: Plants should grow better in soil than gravel because there should be more nutrients available, but the opposite was happening. Ellie needed time to detect patterns, make connections, and notice anomalies.

She also needed the freedom to pursue her interests. Yes, she and Alex had developed an initial, legitimate research question that they were documenting, but they had chosen it because they needed to have one. It wasn't compelling. The new one was. In fact, the experiment was still running in the classroom a year later, and only a small difference can be observed in the health of the jars as measured by the amount of duckweed in each. Hence, the time frame for this question may be significantly longer than a single school year. Genuine questions have a way of failing to fit neatly within the prescribed boundaries of topics and units; authentic pursuit of these questions requires both flexibility and an appreciation for what can potentially be gained.

Interestingly, Ellie's three jars were also the site for investigation of a second experimental question "sponsored" by another group, who also had noticed an anomaly by observing the jars designed by other groups. Allyssa, Brent, and Irving were initially struggling to develop a way of measuring humidity in their jar and its effect on the jar's health. In the course of talking to other groups about their dilemma, they noticed that their Dannio (fish) had darker stripes than those in Ellie and Alex's jar (both groups had chosen a Dannio as the animal to be included in their jar). Allyssa's group thought that the Dannios had originally been the same color. They noticed that the major difference between the jars was the substrate (Ellie and Alex's light-colored gravel in contrast to Allyssa, Brent, and Irving's dark-colored soil). They, too, announced a plan to set up a three-jar experiment, in this case, to test whether fish (Dannios) could camouflage themselves by changing their color to match the substrate. We compromised by asking them to observe Ellie and Alex's jars. We introduced Dannios that were all the same light shade. In time, the Dannio in the soil jar became noticeably darker than those in the gravel and sand substrates. Once again, time, patterns, connections, and anomalies led students to deeper and more compelling research.

In summary, students' research questions and their criteria for evaluating questions were constructed on a foundation of long-term inquiry. We began with simple observation. Students' first questions were centered on what they had seen. As we asked students to consider the qualities of questions, their questions increasingly became a matter of collective activity and interest, rather than private enterprise. In the interests of saving time and "getting to the point," teachers might be tempted to eliminate the discussions, student proposals for criteria, and rounds of revision and retuning. Yet we would argue that these discussions and wrestling with ideas played a fundamental role in students' development. First, they pushed students to really look at their questions' viability. The development of students' inquiry skills was prompted not just by having certain experiences, but also by the discourse that surrounded their experiences (visits to the ponds) and their work (questions they developed and identified as good, using these criteria). The discourse was not in any way secondary to student activity and thinking; indeed, we are convinced that it lent shape and interpretation to them. Second, we think it is very important that students imposed these standards on their own work and that of their classmates.  Of course, we want students not just to apply standards, but also to understand why they are valuable and what potential problems they can forestall. The generation of group criteria helped students understand that the adoption of professional standards for work is a part of scientists' work—it is a responsibility for which the community and its members is accountable.

Reflection on the qualities of questions launched our inquiry, but continued inquiry was sustained and generated by students' ongoing involvement in research, so personal agency was enhanced in the context of our classroom research community. Engaging in research for a protracted period of time motivated further inquiry and provided a practical grounding for considering relations between inquiry and evidence. New questions arose by considering new ways of seeing and understanding the world: Evidence and inquiry became coordinated.