Our first contribution to this column is about “Motivating students to ask scientifically productive questions,” and is presented by Robert E. Bohanan, Kevin J. Niemi, and Lisa A. Wachtel of the University of Wisconsin, and the Madison Metropolitan School District.

This contribution is particularly welcome, because encouraging students to construct appropriate questions from their observations of the natural world can often be hard work for the teacher! It thus meets entirely the purpose of this column – sharing good practice to help improve ecological education in schools. So please keep contributions coming; if you have any questions, thoughts, or contributions please contact:

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Motivating Students to Ask Scientifically Productive Questions

We describe a framework for supporting student inquiry in K-16 science classes in the context of student investigation of ecologically or environmentally related problems and issues. The framework was developed based on research from a case study in a 6th grade classroom on how to motivate and support student-thinking about questions and evidence. We discuss how we have applied this framework in professional development for K-12 science teachers and for K-16 instructional materials for students. We describe how this framework facilitated the collaboration of K-12 teachers with scientists, science educators, and cognitive scientists.

Background

Many teachers use some form of inquiry in their classrooms. Our work with teachers and their students, in part, has emphasized inquiry that involves students asking and investigating their own questions about phenomena or observations that they experience, and results in students developing arguments and or explanations that include evidence from data. We show this as a graphic representation of an example inquiry from a Bottle Biology Activity on Decomposition. See http://www.bottlebiology.org/investigations/decomp_main.html
Development of questions is initially grounded in observations or discussion of phenomena. Observations may be in the laboratory or outdoors. Examples of discussion of phenomena may include exploring and analyzing published data (e.g., changes in ice cover on lakes related to changes in climate).

Classroom discussion is used to develop questions and to develop criteria for what makes a good question.

Classroom discussion of evidence is used to refine questions to make questions scientifically productive for inquiry.

Classroom discussion is used to develop criteria for evidence.

Students construct evidence-based models, arguments, or explanations based on...
At the beginning of the case study, we quickly learned that it was very challenging for students to ask scientifically productive questions. After an initial observation of a pair of small urban sediment detention ponds within walking distance of the school, students individually generated a list of 10 questions of interest. We list several examples of these questions below in Table 1.

*Table 1. Questions Posed by 6th Grade Students After Initial Pond Observations*

- How much blood can a leech suck in an hour?
- Are there more fish in our pond?
- Where does the water come from?
- What happens to the animals in the winter?
- How does the water in the pond get polluted?
- Is the animal life in pond 2 more diverse than pond 1?

As you can see, most of these, as written, were not scientifically testable. To facilitate the refinement of their questions, we ask students to develop criteria for what they thought made one question a better scientific question than another. Students negotiated the development of criteria through small group discussions led by the teacher. The initial criteria, agreed upon by the class to evaluate their questions, are listed in Table 2.

*Table 2. Initial Criteria Developed by Students for What Makes a Good Scientific Question*

- Easy to answer
- Meaningful / valuable
- Genuine
- Researchable
- Can not be answered yes or no

To expand upon their initial notions of what made one question a better scientific question than another, we asked students to identify the sources and types of evidence that they would need to provide at the end of their investigation in order to present a convincing argument or explanation. The result of this discussion was a group revision of criteria that they accepted as a class for what made a good scientific question. A scientist facilitated this discussion. We recorded transcripts of this discussion, which provide prompts that were used to guide students’ discussion. Some examples of typical prompts used were something like:

- Could you answer this question just by looking it up?
- How does what you plan to observe or measure relate to your question?
- Do you have the materials or instruments to measure what you need to measure?
That’s a very interesting question, but because we don’t have the materials or instruments that you need, is there another way to make the necessary measurements, or is there another way to ask that question so that you could make your measurements?

Additional transcripts with prompts are available from Bohanan upon request.

Revised class criteria for what makes a good scientific question are summarized in Table 3 below.

*Table 3. Revised Criteria Developed by Students for What Makes a Good Scientific Question after Connecting Questions and Evidence

- Investigator has an expected outcome
- Methods are clear from the wording
- Question is connected to other questions
- Question is a revision of an initial question
- Question is genuine: investigator doesn’t already know the answer
- Research is doable given tools, knowledge, and supplies
- Research is sensible or meaningful and adds knowledge

Through a combination of analysis of student work, transcripts of group discussion, and interviews with individual students, we found that the trajectory of evidence-based reasoning in arguments and explanations, generally began with personal beliefs and by the end of the school year, included careful documentation of empirical results used in explanations. Transcripts of classroom discussions, analysis of student work, and individual interviews with students that reflect changes in their thinking about evidence are summarized in Table 4. Conclusions from the case study are summarized in Table 5.

*Table 4. Change in Student-Thinking About Evidence

- Because I said so
- Because someone told me so
- Because an authority said so
- Because I observed and documented
- Because I conducted an experiment
- Because I communicated my findings clearly
- Because I created a model based on research
- Because I only included evidence specific to my model

*Table 5. Conclusions from the Case Study

- Initial arguments constructed by students were based on personal beliefs
- Initial arguments constructed by students were often based on single undocumented observations
- Classroom discourse and teaching shifted arguments from a basis on personal belief...
or single observations to include scientific evidence in arguments

- Scientific evidence used by students in arguments included documented observations (e.g. dated and documented in a lab notebook), research of others students in the classroom, & empirical results collected directly by students
- Students identified the importance of the repeatability or at least potential for repeatability of results
- Students developed and revised explanations or models based on their research findings and used these to create arguments
- Students developed new questions and experiments based on initial findings from their inquiry


Background, samples of activities, guidelines and forms developed by Lucas in this case study are available at http://www.wisc.edu/cbe/cbe_pubs/aquaticcurriculum.zip

General Framework for Developing Student Questions and Supporting Inquiry

We provide a graphic representation of a general framework for helping students to develop scientifically productive questions and inquiry that results in evidence-based arguments and explanations in Figure 1. We have used this general framework in professional development for elementary, middle, and high school science teachers and instructional materials for K-16 students. The emphasis of the professional development is to help teachers support the development of student investigations that begin with their own questions and result in evidence-based arguments and or explanations. Instructional materials have supported inquiry that may include observations, experiments, and query and analysis of databases and digital libraries. Professional development and materials development involved collaboration among K-12 teachers, university faculty and staff, graduate students, and district science coordinators.

Step 1. Initial observations and subsequent classroom discussions set the context, and to some extent the parameters, for the investigations that students can consider, elicits prior knowledge and content, and establishes personal or local relevance.

Step 2. Additional classroom discussion helps students think about and build new connections to their investigations.

Step 3. Students individually identify several questions (at least 5 and up to 10) to share with the class that they thought about based on their initial observations and possible connections. By thinking of 5-10 questions, we found that most students create a range of questions that typically includes the obvious, the absurd, and a few that are somewhat scientifically testable. See the examples in Table 1.
Step 4. Groups discuss what makes one question a better scientific question than another. Results of their group discussion are summarized as a set of initial criteria that the class will use to evaluate their questions. See the examples in Table 2.

Step 5. Groups refine their questions by thinking about what data they will need to provide evidence for their arguments or explanations. This discussion is a very important part of our instruction to help students to develop scientifically productive questions. Results of this discussion are used in Step 6 to re-evaluate class criteria for what makes a better scientific question and to develop criteria for convincing evidence.

Step 6. The discussion about what makes a better scientific question, in light of the evidence needed to create a convincing argument or explanation, is used to revise classroom criteria for questions. Groups revise their questions, if necessary, based on the new classroom criteria. See examples in Table 3.

Step 7. Groups conduct their investigations. During Step 7, groups share progress reports on their inquiry frequently (e.g. once per week in an investigation lasting a few weeks).

Step 8. Groups construct and present arguments or explanations based on findings from their inquiry. Peers pose questions for clarification and discussion. Classroom discussion is used to re-evaluate criteria for evidence. Groups pose new questions. See Table 4 for change in student thinking about criteria for evidence.
Figure 1. Supporting Inquiry by Connecting Scientific Questions and Evidence. Adapted from System-wide Change for All Learners and Educators (SCALE) http://scale.mspnet.org/

Step 1
Initial Group Questions are Developed During Observations or Discussion of Phenomena
Who lives here?
How many different types of organisms might live here?
Are there other organisms that you think might live here, but that you didn’t see today?
Why didn’t we see them?

Step 2
Groups Discuss Connections of Observations to Related Factors or Analogous Phenomena
What non-living factors might affect who lives here?
What living factors might affect who lives here? (e.g. relationships with other organisms)

Step 3
Students Individually Develop Questions Based on Observations & Discussion
List 5 questions that you have about either some of the organisms that live here or the habitat that we’ve observed

Step 4
Groups Discuss Criteria for Why Some Questions are Better Than Others
What makes a good scientific question?
Which of these are better questions than others? Why?

Step 5
Students Identify Data They Will Collect To Support Their Argument or Explanation
What observations or measurements will you make to collect data related to your question(s)?
How will you collect the data?
After you collect the data, will you have new or additional information related to your question(s) and evidence to use in your argument or explanation?

Step 6
Students Revise Questions and Groups Evaluate Criteria for Questions
Now that you’ve thought about the data that you’ll collect and how you will collect it, do you need to change your question in any way?
Are there new things that you want to add to our list of things that make one question better than another?

Step 7
Students Conduct Their Investigation
Students record their data and describe how they collected their data
Students summarize or describe results
Students interpret results

Step 8
Students Construct Arguments or Explanations and Groups Re-Evaluate Criteria For Evidence
Students construct arguments or explanations based on evidence from results
Groups discuss “Is your evidence convincing”?
What are things that we think as a group make some evidence better than others? Why?
What are some new questions that you have about who lives here and things that might affect them?
For an example of how this framework is applied in instructional materials for middle school science inquiry about the behavior and ecology of an invasive crayfish species see http://www.wisc.edu/cbe/cbe_pubs/crayfishstudy.zip

We have also applied this framework to inquiry using large scale databases as a source of observations and data for high school science and undergraduates to investigate the effects of global warming and climate change on ecosystems. See Bohanan, et. al. 2005, Teaching Issues and Experiments in Ecology Volume 3 in press at http://tiee.ecoed.net/ for the activity and see http://www.lternet.edu/vignettes/ntl.html for additional background on the long-term ecological research on climate change and lakes and on the effects of invasive crayfish.

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