

Ecological Education: K-12

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:

Susan Barker
Department of Secondary Education
350 Education South, University of Alberta
Edmonton, Alberta, Canada, T6G 2G5
E-mail: susan.barker@alberta.ca
(780) 492 5415 Fax: (780) 492 9402

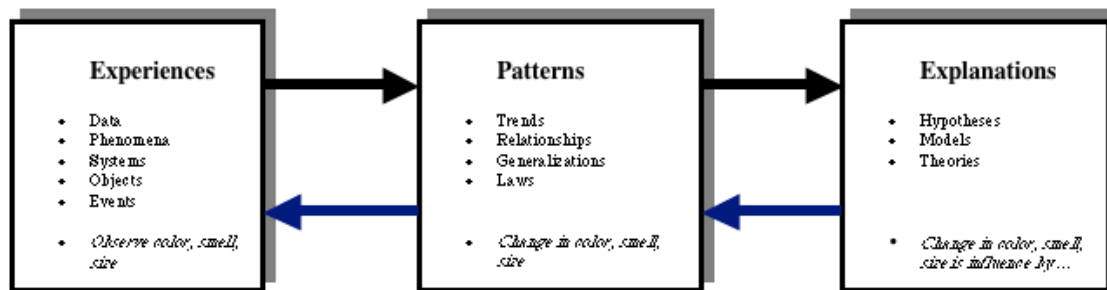
Charles W. (Andy) Anderson
319A Erickson Hall
Michigan State University
East Lansing, MI 48824
E-mail: andy@msu.edu
(517) 432 4648 Fax: (517) 432 5092

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



[Application (Using scientific patterns and theories to describe, explain, predict, design, and make personal and social decisions)]

Adapted from C. W. (Andy) Anderson, National Association of Research in Science Teaching Presidential Address (2003)

Our case study (Lucas, et al., in press 2005) was part of a district-wide middle school science professional development project, SchoolYard Science, in Madison, Wisconsin to improve inquiry-based teaching and learning using habitats at or near schools (see http://www.wisc.edu/cbe/cbe_pubs/schoolyardsciencemodel.ppt for background on our professional development model). The case study was on a year-long field and classroom investigation of aquatic systems in a 6th grade classroom. The teacher (Lucas) was a former elementary grade school teacher who had recently moved to a middle school and was teaching science for the first time in her career. Her goal was to have her students engaged in small groups in scientifically productive (e.g. scientifically testable) investigations of their own questions as a way to address science standards for the nature of science and to emphasize investigations that were personally motivating and relevant to her students.

Scientists, science educators, and cognitive scientists collaborated with the teacher to create an overarching context for research under which students then developed their own related small group inquiry projects. The overarching context was investigation of aquatic systems. In this particular classroom, the specific context was a study of aquatic systems that combined field observations (a pair of ponds near their school) of biological diversity and experimental laboratory investigations (gallon jar microcosms) in which they could manipulate living and non-living factors that might affect aquatic systems.

Scientists provided relevant research vignettes, access to existing data, and other types of background on aquatic systems to add science content for the teacher and students and they advised the research design of student inquiry projects. Science educators worked with the teacher to develop classroom practices (e.g. integration of model-based reasoning by students) and instructional materials (e.g. problem-based materials) to support student investigations. Cognitive scientists helped to design assessment instruments (e.g. rubrics for analyzing student work) and approaches (e.g. observations and interviews) to study change in student learning. See http://www.wisc.edu/cbe/cbe_pubs/aquaticcurriculum.zip for examples of materials that were collaboratively developed by scientists, science educators, and cognitive scientists with the teacher and that were tested with students in this classroom.

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

11

- 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 the 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

*From Lucas, D., Broderick, N., Lehrer, R. and Bohanan, R. (in press fall 2005). Science Scope. National Science Teachers Association.

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.

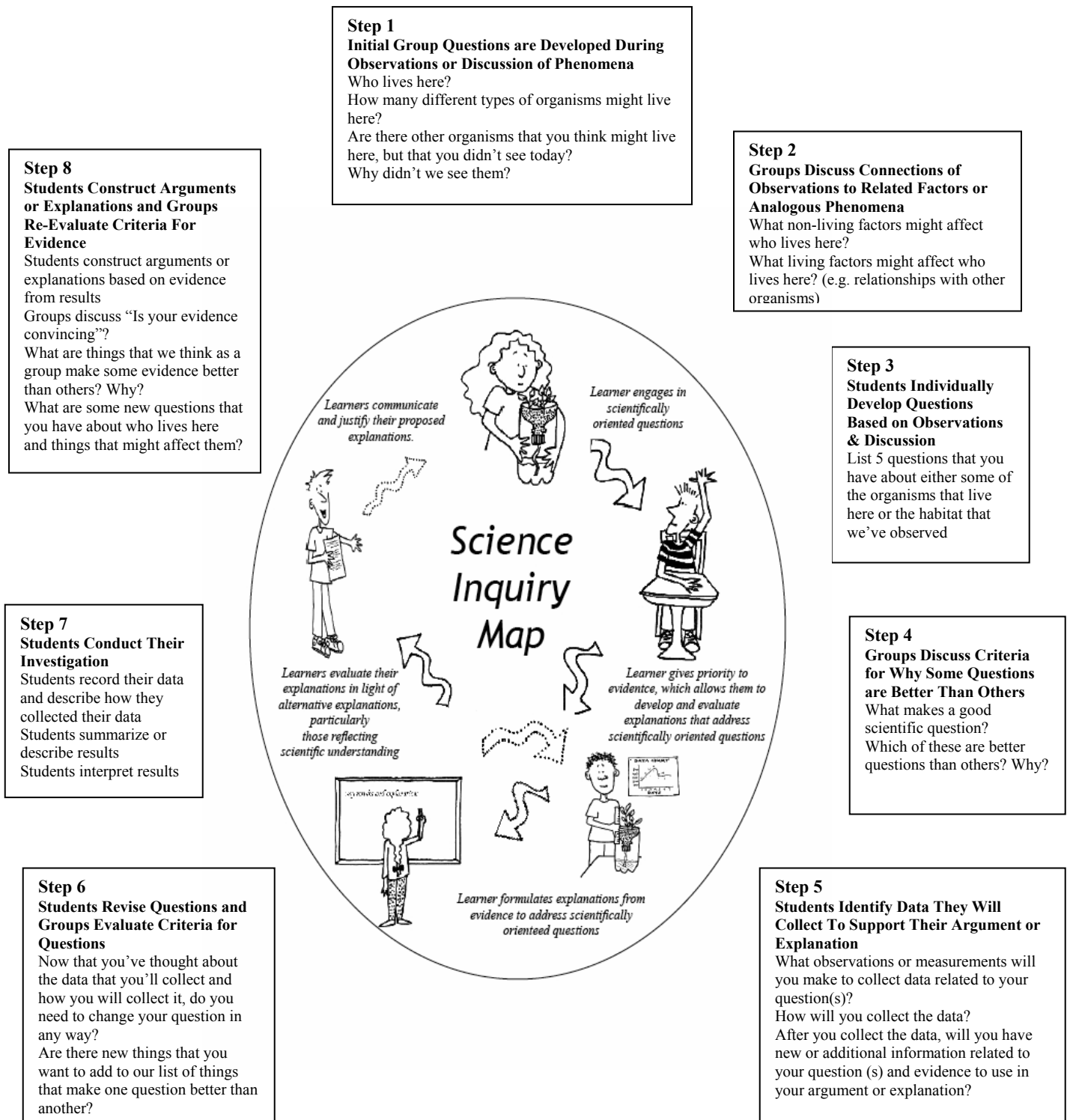
Step 5. Groups refine their questions by thinking about what data they will need to provide evidence for their arguments or explanations. This discussion is a very important part of our instruction to help students to develop scientifically productive questions. Results of this discussion are used in 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/>



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.

Correspondence to:

Robert E. Bohanan, Center for Biology Education and the Wisconsin Center for Education Research, 445 Henry Mall, University of Wisconsin-Madison. Madison, WI 53706 or rbohanan@wisc.edu

Kevin J. Niemi, Center for Biology Education and the Wisconsin Center for Education Research, University of Wisconsin-Madison

Lisa A. Wachtel, Madison Metropolitan School District

Related funding from:

National Science Foundation Long-term Ecological Research Program DEB-0217533 , DEB-9632853, Comparative Study of a Suite of Lakes in Wisconsin, S. R. Carpenter, Principal Investigator

National Science Foundation Math Science Partnership Program Award #: 0227016 System-Wide Change for All Learners and Educators, T. Millar, Principal Investigator

National Science Foundation Research, Evaluation, and Communication REC-9973004, Modeling Nature. R. Lehrer, Principal Investigator

Dwight D. Eisenhower Science and Mathematics. SchoolYard Science. R. Bohanan, Principal Investigator

University of Wisconsin System Elementary and Secondary Education Act Improving Teacher Quality Higher Education Program. Teacher Leadership Development Project: Creating School-based Leadership Cadres to Adapt Exemplary Science Curriculum to Foster Student Inquiry. R. Bohanan, Principal Investigator

Bohanan, R.E., Niemi, K.J., and Wachtel, L.A. Motivating Students to Ask Scientifically Productive Questions. Bulletin of the Ecological Society of America. January 2005. pages 103-108.