Meeting Teachers in the Middle: Designing Handheld Computer-Supported Activities to Improve Student Questioning

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Abstract: Promoting student questioning in science is integral to inquiry-oriented instruction and to conceptual understanding, but it is rare in most science classrooms. This paper describes the development of software for handheld computers that helps teachers capture and use student questions in science classrooms. The paper also analyzes teachers' use of the software to elicit prior knowledge, to engage students in reviewing concepts, and to structure student-led inquiry.

Student Questioning in Science Instruction and Assessment

Inquiry science requires students to learn how to ask good questions. According to the *National Science Education Standards* (National Research Council, 2000), students in grades 5-8 are expected to

> …develop the ability to refine and refocus broad and ill-defined questions. An important aspect of this ability consists of students' ability to clarify questions and inquiries and direct them toward objects and phenomena that can be described, explained, or predicted by scientific investigations. Students should develop the ability to identify their questions with scientific ideas, concepts, and quantitative relationships that guide investigation." (p. 163).

These question-posing abilities should also be the focus of assessment, according to the *Standards;* teachers in inquiry classrooms need to assess students' ability to "generate and clarify questions" and to "evaluate the kinds of questions scientists investigate."(pp.75-76).

Researchers hypothesize that the encouragement of student questioning in science can help students to develop understanding of the nature of inquiry (Marbach-Ad & Sokolove, 2000). As students experience the inquiry process, they are likely to learn to formulate new, more complex questions (Dori & Herscovitz, 1999; White & Frederiksen, 2000). They may also learn to question beliefs and evidence for beliefs (White & Frederiksen, 2000). Students who have opportunities to pose and investigate their own questions develop abilities to recognize what kinds of questions are amenable to scientific investigation (Marbach-Ad & Sokolove, 2000; National Research Council, 2000).

Student questions can also help students develop conceptual understanding, especially during individual encounters with new information such as text reading and lectures. Question posing about science texts helps prepare students for texts they are about to read and clarify passages that they do not understand well after reading (Palincsar & Brown, 1984). Students who ask questions tend to retain material better than those who do not (Davey & McBride, 1986; King, 1989; Marbach-Ad & Sokolove, 2000). In tutoring situations, student question-asking is a key activity that helps students develop conceptual understanding, because through questions, tutors and tutees develop explanations of phenomena (Chi, 1996). In addition, there is some evidence that providing training to students to improve student question-asking during text-reading and oral lectures improves students' problem solving skills and reading comprehension (Dori & Herscovitz, 1999; King, 1991; Palincsar & Brown, 1984). Questioning helps students improve their comprehension because it engages students in more metacognitive processing during learning: researchers hypothesize that questions help students better monitor their own understanding of material (King, 1989) and elicit help from peers and teachers (King, 1991).

The Incidence of Student Questions in Classroom Practice

Despite the importance of student questions in science learning, researchers who have investigated questioning practices in classrooms have found that students ask very few questions. In a study of 27 high school classrooms, Dillon found that two-thirds of all teacher "turns-at-talk" were questions to students; by contrast, just 6 percent of student turns are questions; while teachers asked questions at a rate of two per minute, students asked them at a rate of two per hour (Dillon, 1988). This finding has been replicated in a variety of studies that span fifty years of educational research (Berlyne & Frommer, 1966; Fahey, 1942; Gall, 1970; Good, Slavings, Harel, & Emerson, 1987), leading to the observation that:

> Most pupils in the early grades have become masters at answering questions. Few students, even by late-graduate school, have become more than a novice at asking questions. The remedial status of student questioning appears to be its normative state in past, present, and future schooling. (Dillon, 1988, p. 208).

Several explanations for why student questioning is given such a limited role in science teaching and learning have been offered by researchers. The role of the teacher is important to these explanations. With respect to helping students learn the process of inquiry, teachers need to help students define, focus, and clarify questions for investigation (National Research Council, 2000; Rosebery, Warren, & Conant, 1992). But students' initial questions about a topic tend to be unsophisticated (Graesser, McMahen, & Johnson, 1994); on the basis of these initial questions, some teachers have been found to develop a belief that learners are incapable of asking good questions (Dillon, 1988). At other times, teachers find that student questions push them in directions they had not anticipated; they may feel under-prepared to provide direction to students that would help lead students to scientific understandings of phenomena (Collins, MacLean, Palincsar, & Magnusson, 1999). Teachers in these situations may redirect students' "wonderment" questions into teachers' own agendas to match better their comfort with the material being taught (Gallas, 1995).

To develop students' skill in using questions to support their conceptual development, a different set of challenges arise for teachers. Teachers must learn to allocate more class time for discussion of ideas, rather than recitation or lecture (Dillon, 1984; van Zee, Iwasyk, Kurose, Simpson, & Wild, 2001). Yet discussions are often hard to facilitate, and facilitation skills are difficult to master; moreover, the degree to which student questions are elicited during discussion depends at least in part on teachers' familiarity with the science content being taught (Carlsen, 1988). In addition, many teachers are under increasing pressure to teach to a wide range of standards, a factor that limits their willingness to adopt time-intensive inquiry science activities that focus on fewer content areas more deeply (Means et al., 2000). Professional development providers, for their part, may not see the encouragement of student-led inquiry as central to their mission and goals (Penuel et al., 2003). Finally, there are few available models and curricular materials that teachers can use to guide their students toward more effective questioning, whether to help students improve their conceptual understanding of a topic or to structure inquiry. New materials are needed to help students improve their questioning ability and to help teachers support this essential component of science inquiry learning. These materials, we will argue here, need to "meet teachers in the middle" by helping address teachers' own perceived needs and their own desires for professional growth while helping to advance their repertoire of inquiry teaching strategies.

Designing Handheld Computer-Supported Activities for Improving Student Questioning

In the project described in this paper, SRI researchers worked collaboratively with teachers in a school district to develop both materials and technologies that could be used to enhance the role student questions play in science classrooms. The goal of our project was to develop a set of activities—supported by low-cost handheld computers—that could support student reflection and self-assessment during hands-on science learning. We did not set out to enhance student questioning. This goal emerged through a process of participatory design with teachers.

A chief assumption in our work, borrowed from participatory design, was that we needed to develop more than just new learning technologies; we needed to engage in the design of a *socio-technical system* to support enhanced student questioning (Rheinfrank, Hartman, & Wasserman, 1992). Under this framework, the design of activities in which the software would be used would go hand-in-hand with the design of the technology tools. We therefore worked with teachers to develop a range of strategies for collecting, sharing, discussing, and using data from the software in ways that were consistent with research on learning and assessment in order to maximize the likelihood that the software would be used to benefit students. This paper describes the design and use of the handheld-supported activities designed by one interdisciplinary team of teachers, software developers, and assessment researchers on the project to encourage student questioning in science. In the next section of the paper, we describe the contexts that shaped the team's development of requirements for the software and how the software is intended to support the use of questioning in science classrooms. In the following sections, we describe the professional development program and three different activity formats for using the software. Teachers designed and implemented these activities in classrooms across the district. In the final section, we describe some of the implications of our work for enhancing the role of student questions in science inquiry.

Designing *Boomerang*

Contexts That Influenced Requirements for the Software

In this project, three teams of researchers, software developers, assessment experts, and seven teachers worked together to develop software for handheld computers and study their use in classrooms across a medium-sized district in South Carolina. The goal of this three-year project was to investigate the potential of powerful, low-cost computing devices for improving the frequency and quality of classroom assessment in upper-elementary and middle-grades science classrooms. When SRI researchers first arrived in the district, we understood little about the contexts that would likely influence the design or adoption of new handheld software for assessment, but we learned about them by engaging in a process of participatory design and interviews with teachers. The design team for *Boomerang*, the software program described in this paper, involved two elementary school teachers formed the core of the team that designed *Boomerang*. The teachers were both European American, but they taught in a school where the majority of students were African American and roughly three-quarters of their students are eligible for free or reduced price lunches. One taught a combination fourth-fifth grade class that included both gifted and special education students; the other taught in a fourth grade classroom with lower-performing students. Both had more than 10 years' experience in teaching, but neither was a frequent user of computers to support instruction. Neither had ever used a handheld computer before they began their involvement with our project.

The teachers' own background with technology and teaching assignments suggested important constraints on the requirements for the software. The software would need to be easy for them to learn and require little time to set up, because their time to learn new software and plan for assessment uses of the software was limited by their busy schedules. Neither teacher reported having adequate in-school technical support or the authority to ask for more help, so reliance on the school's network needed to be minimized. Although accepting this constraint meant we would rely on beaming rather than classroom networks for communication, we avoided problems caused by network down-time (see Tatar, Roschelle, Vahey, & Penuel, 2003, for a discussion of this issue). The teachers' own goals for instruction were also important beginning points for developing requirements for the software. When they first got involved in the project, the teachers both wanted to design a tool that could help their students review concepts. They were particularly drawn to the idea of building a program that would be an electronic version of "flashcards" and that could be used by students at the end of a unit to review definitions of concepts they had learned in class. Such a program would have been consistent in its function and emphasis with both teachers' pedagogical styles and goals for science instruction, which focused primarily on developing students' understanding of concepts and on a gradual movement toward more inquiry-based teaching. SRI researchers' goals for the project and teachers' responses to those goals also contributed to the design. SRI researchers suggested that in addition to helping the teachers ask questions of their students, they might create a tool to support student question building. This suggestion was met with ambivalence. The fourth-grade teacher liked the idea in principle, but he argued that students in his lower-performing class could not ask good questions, so using student questions for assessment purposes would not yield useful information. Neither teacher saw an immediate need for focusing more attention on inquiry-oriented "wonderment" questions in science. Both teachers were primarily concerned with pressures to cover content with students they saw as needing to focus on understanding concepts.

Students indirectly influenced the requirements for the design; it was their responses to early prototypes of the software that convinced teachers of the value of developing a tool to support student questioning. Researchers convinced the teachers to try, as a prototyping activity, to reverse (or "Boomerang") the teachers' notions of who asks the questions and provides the answers in a classroom. In this activity, teachers would beam to students the "answers" and then students would create questions to go with the answers in the Palm Memo Pad software. Then students would beam back their questions for whole class review. The teachers likened the process of collecting student questions in response to teacher prompts to the television game show "Jeopardy," a connection that fit a traditional notion of science learning as fact-based but that helped both teachers see how the software could help them meet their original goals and concerns. After just one class with this activity, both teachers were impressed with the student questions and the classroom discussions that happened when the student questions were displayed. The experience revealed to the teachers just how much skill their students already had in developing writing good questions; it helped to convince them that their students could improve the quality of their questions.

Articulation of Key Features of the Software

After this experience and a similar experience with the second teacher on the project, the team was able to develop a set of requirements for *Boomerang* that met both the teachers' goals and addressed researchers' concerns about the need to develop a tool that could support not just traditional instruction but also inquiry instruction in science. The software application, now referred to as *Boomerang,* would need to allow teachers to author "prompts" that students could respond to with questions of their own. These prompts could be used for students to "reflect" back on what they had learned, as in the case of creating questions that might wind up on a class test, or they could be used for students to "explore" some topic further by identifying questions they wanted to answer about the topics covered in a specific science unit. Teachers would need to collect student questions using the beaming feature of the handheld device and aggregate student questions into a single list for presentation or display to the whole class. To ensure students could feel comfortable sharing their questions in public, the team also specified a requirement that the list of questions be able to be displayed anonymously as well as with student names next to student questions. To foster student skills in generating questions, a generic "rubric" (numbers, listed 1-7) was also incorporated, so that students or teachers could categorize the quality of a question that a student had written. Most of the requirements developed for the software also helped support strategies that prior research has found successful in encouraging greater use of science questioning in classrooms. Table 1 shows one mapping of these strategies to the key features of the *Boomerang* software application developed by the design team.

Table 1. Features of Boomerang Mapped to Research-Based Strategies for Encouraging Student Questions

Boomerang Feature	Strategy Supported	Research Studies Supporting Strategy
Teachers can author prompts for student questions	Prompting students to ask questions	(Knapczyk & Livingston, 1974)
Students can write questions on handheld	Incorporating "wait time" to open up space for students to be able to ask questions to deepen their understanding of material	(Rowe, 1974; Swift & Goodling, 1983)
Students or teachers can categorize questions by type or quality	Guiding students in thinking about the quality and complexity of their questions	(Glover & Zimmer, 1982; King, 1989, 1991; Marbach-Ad & Sokolove, 2000; Quellmalz & Hoskyn, 1997).
Questions can be aggregated in a list and presented for discussion	Providing feedback to students on the quality of their questions, to motivate improvement	(Glover & Zimmer, 1982)

Flow of a Typical *Boomerang* Session

Below we describe how a typical Boomerang session in a science classroom might go. We have included descriptions of teacher and student actions, along with a selection of screen shots of the user interface.

Step 1: Teacher Creates Lists of Students within Classrooms. Boomerang allows teachers to create class names and lists of students associated with a class. This function allows teachers to share the same set of handheld devices with multiple classes and students. It also helps teachers associate questions with particular students.

Step 2: Teacher Decides on Prompts for Student Questions. The classroom teacher provides prompts for student questions. These prompts are organized into chapters and subtopics. Prompts could be topics to be studied, concepts, or "answers" for which students might generate questions.

Step 3: Students Write and Categorize Questions. Using graffiti or a detachable keyboard, students compose questions in response to specific subtopics. Students can also categorize any question using a rubric devised for the purpose of the activity, which might be displayed on a board in the front of the room.

Step 4: Students Share Questions by Beaming. Students then share their questions by beaming to peers or to a collector device that aggregates students' questions.

Step 5: Teacher Displays Class List of Questions for Discussion. Once the questions have been collected on a single device, they can be re-beamed to all students, or the teacher can use a document camera to display the list. The list of questions can be displayed anonymously or with students' names.

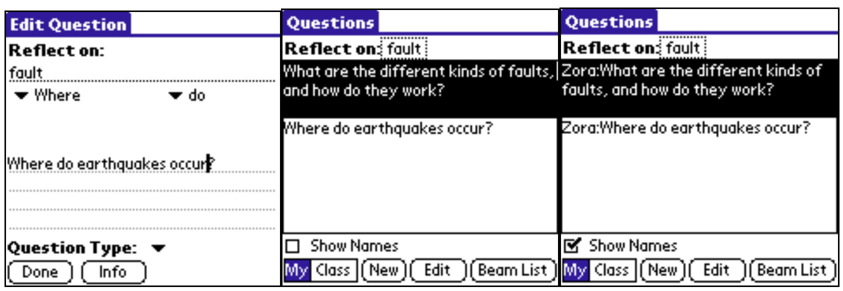

Figure 2. Screens Showing Step 3, Question Editing (left), and Step 5, List of Questions Anonymously (middle) and with Student Names (right)

Designing Activities with the Software to Enhance Student Questioning

Building professional development activities to support software integration

The next year, we made *Boomerang* and the software developed by the other design teams available to a total of 19 teachers in the district as part of a field trial. The insights that we gained from our participatory design experience with the design team teachers coupled with research on best practices in teacher professional development laid the groundwork for our professional development program to prepare teachers to use the software and develop activities to use with them. Teacher professional development literature on technology integration underscores the importance of having teachers discuss lesson plans, review student work, and share challenges of using technology in the classroom (Atkin, 1994; Cochran-Smith & Lytle, 1999; Elliot, 1987; Hargreaves, 1998). We developed three workshops, several by-request after- school sessions (both face-to-face and teleconference), materials for study group sessions for teachers to use to work with their peers, and models for creating assessment activities based on their current curriculum content. In addition, we offered a semester-long course that we offered in collaboration with the Beaufort County School District and the University of South Carolina in Columbia, and 7 teachers enrolled. A chief task in this phase of the project was to engage teachers in the design and testing of assessment activities that could be integrated into their teaching. In this phase, as in the design phase, we built activities from teachers' experience but also provided them with a vision of what might be accomplished with the software (Rheinfrank et al., 1992), drawing on our own understanding of research on effective classroom assessment. To design the activities for Boomerang, we began from lessons we learned from the participatory design work. We knew, for example, that teachers would easily endorse more traditional uses of questioning to probe for student understanding but would need some assistance using our software to focus on using student questions to guide class inquiry and involving students in critiquing the quality of their own questions. In our workshops, we asked teachers to reflect on their own view of student questioning, provided opportunities for teachers to engage in peer interactions in formal and informal meetings, showed teachers models of how to use the questioning software in class, and suggested ideas for standards-aligned uses of the student questioning software. Teachers participated in structured reflections on the importance of student questions and pedagogical approaches that they might try to encourage student questions. The second and third workshop provided structures for reflecting on student assessment work with other teachers. We also promoted informal peer reflection among teachers: teachers joined the project as a school team or were assigned a buddy teacher and encouraged to view each other's classes, to look at student work together, and to rely on each other as resources. To seed ideas about how to use *Boomerang* effectively, we provided models of practice to teachers. At the initial workshop, SRI and design team teachers introduced the questioning software and the other WHIRL applications by engaging teachers in activities they could use with their students. We designed these activities around formative assessment practices that our design teachers had found easy to adopt. We knew, for example, that many teachers used probes of students' prior knowledge and students' interests to begin new science units. We modeled the use of the student questioning software in the initial workshop focused around a process familiar to teachers, namely, gathering student questions at the beginning of a unit to elicit prior knowledge.

Finally, to foster better adoption, we engaged in several activities to align our work more closely with other district initiatives. In our model activities, we drew from science kits that we knew from our research many teachers in the district used. For each of the activity ideas we seeded, we indicated the local standards that the activity could help meet. All workshops were held during the district's already- planned professional development days; we had each of the principal's support, and we minimized the extra time required of teachers in order to participate in the professional development. Local district staff helped plan and lead the workshop sessions and graduate course, and we developed facilitators' guides, user guides, and curriculum integration ideas from each of the professional development opportunities that appear on the project Web site (http://www.projectwhirl.org).

Activities Field Trial Teachers Have Developed and Tested with *Boomerang*

Below we describe some of the teachers' uses of *Boomerang* recorded during the field trial in the 2003-04 school year. As with the design team teachers, uses of *Boomerang* to check students' conceptual understanding are more prevalent than are uses of *Boomerang* to scaffold inquiry.

Eliciting Prior Knowledge (Teacher Assessment)

Because we observed the fourth-fifth grade design team teacher taking time to elicit students' prior knowledge at the beginning of units she taught, we suggested to all field trial teachers try using the tool to support this kind of activity. Teachers sometimes use what is commonly called a K-W-L (Know-Want-Learn) approach, an instructional technique developed by Ogle (1986) that is designed to elicit, among other things, what students want to know about a topic. One teacher new to the project used *Boomerang* before every unit to elicit what students know about a topic and what questions they have about it. She then used this information to guide the course of the unit. Another new teacher, who admitted being initially skeptical of the value of eliciting students' questions, recently used the tool to elicit students' prior knowledge and 'wonderment' questions about Bats. In this short unit, she had invited an expert on Bats. The students used Boomerang to collect, refine, and organize the class questions to ask the guest speaker. When this teacher moved on to a new unit on the human body, students wanted to use Boomerang to show what they knew about the topic and what they wanted to know.

Engaging Students in Developing Test Questions

One use of Boomerang that has become widespread among the teachers is for writing test questions. Teachers provide students with an opportunity to use *Boomerang* at the end of a unit, right before a test. The teachers hope that students will have the chance to review content by writing questions; some teachers select the best student questions for inclusion on the test. In supporting students to develop good test questions, teachers are also incorporating discussions of the quality of student questions as part of their classroom discussions. One teacher recently sent to other teachers a resource she is experimenting with in her classroom for helping evaluate whether questions were "higher-order" questions or factual questions.

Supporting Student Inquiry

So far, only a few teachers in the project have used *Boomerang* in the course of student inquiry in science. One is using *Boomerang* as part of an investigation of electricity; students are using *Boomerang* to generate research questions to guide their own investigations. Another of these teachers recently used *Boomerang* as part of an investigation of ecosystems using a terrarium. She began her first lesson in the investigation with a class discussion about two kinds of questions, "lower order thinking questions" and "higher order thinking questions," as she put it. She then let the students give her examples of each and then wrote them on the board. They then proceeded to discuss sample questions related directly to the growth of seeds in the terrariums which the class had just planted. The students developed hypotheses about what would happen to the seeds and formulated them as research questions. Although this teacher's use of *Boomerang* was not used to plan an inquiry, she did use the tool in the context of investigations to support students' thinking about the possible results of a classroom experiment.

Discussion

The researcher-teacher co-design process was critical in the first phase of our work to build a bridge between teachers' current practice and reform-oriented practice on student questioning. At the start of our project, the design team teachers' classrooms more closely resembled typical classrooms in the incidence of student questions; teacher questions tended to predominate, and teachers were more interested in a quiz program than in *Boomerang*. As researchers, we were reluctant to design software that supported current practice only, but we also needed to consider that teachers might not ever use software that was designed to support only sophisticated forms of inquiry teaching. Had we designed the software in such a way that it forced teachers to adopt an entirely new pedagogy unwittingly, the technology might have ended up "oversold and underused" (Cuban, 2001). In deciding what to include as features of the software, we sought instead to identify areas of "fertile ground" where teachers might be ready to adopt reform practices that could enhance student questioning. Through the co-design process, we chose to introduce more focused additions to teachers' inquiry practice and attempted to reduce the distance that teachers would have to travel to meet our own goals for promoting effective assessment (see Blumenfeld, Fishman, Krajcik, Marx, & Soloway, 2000). During our design process, we made available to the *Boomerang* teachers an existing software tool that would allow them to pose questions to students, as they normally did on quizzes. But we also asked them to try out the idea of having students create questions Initially reluctant, the teachers ultimately decided that student questions could be a valuable source of information about what students know and can do. They discovered several uses of *Boomerang* that fit well with their existing practices, such as the K-W-L process; in addition, they revised some of their quizzing practices so that students could pose questions that they would later answer on a quiz or test. A number of our suggestions for enhancing the role of student questioning and for scaffolding student thinking in the software were not well-received by the design team teachers. We made a strategic decision to leave some features out of the software that might have provided more scaffolds for teachers and students (e.g., to categorize questions) and decided to make these strategies explicit in the professional development to see whether field trial teachers might incorporate them into activities they designed for use with *Boomerang*. We attempted to model assessment uses of *Boomerang*—such as encouraging teachers and students to focus on how the nature and quality of their questions about a topic change over time—that had not gone over well with the design team teachers.

Teachers' use of *Boomerang* lends some initial support for the "fertile ground" software design model. Many of the activities map well onto teachers' existing practices, especially the K-W-L process used by our design teachers. On the basis of our observational study of teachers in the project, we estimate that *Boomerang* is used frequently in class because it is well-aligned with teachers' current practice. For a smaller percentage of teachers, the forms of use we have observed are in part attributable to the kinds of professional development activities and models of use we have provided. For example, despite the reluctance of our design team teachers to consider assessing question-quality, a number of teachers this year have taken up this task with their students. Even the original design team teachers have changed their views on this matter; they now engage their own students in reflecting on their questions as a way to foster more student self-reflection on their own learning process.

Our study suggests that researchers and reformers need strategies to "meet teachers in the middle" to bridge current practice to more reform-oriented practices, especially if we are interested in adoption. It also suggests that a key role for researchers in educational technology is to consider carefully the entire socio-technical system, including teachers' opportunity to learn, so as to produce reforms that are both innovative *and* adoptable.

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