LET'S GO! To the Creek: Co-design of Water Quality Inquiry using Mobile Science Collaboratories

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Abstract—*Learning ecological science content and inquiry strategies should increasingly use the new tools from science – sensors for data capture, information visualization for data-analysis, low-cost mobile computers and mobiles for field-based science. The LET'S GO! project seeks to develop, implement, research, and sustainably scale a new paradigm for fostering high school student learning in teams for ecological sciences. Our "open inquiry" vision uses mobile computing to provide open software tools/resources, participation frameworks for learner project collaboration, mobile media/data capture, analysis, reflection and publishing. We integrate geo-positional data sensing, multimedia communication, information visualization & Web 2.0 tools to create science learning collaboratories, using co-design methods with teachers, learners, developers, learning & domain scientists. The present paper describes the background for our project, related work, goals, and reports on the success of the co-design workshops and school pilots conducted last year.*

Keywords: mobile learning, ecology and science education, science inquiry learning, collaboratories.

I. INTRODUCTION

The LET'S GO! Project (Learning Ecology through Technologies from Science for Global Outcomes) aims to provide educational activities and tools for helping students participate in collaborative science inquiry involving local environmental data. This data is collected, analyzed, reflected on, and reported through mobile and sensor technologies. The activities are co-designed with teachers and administrators at the schools, then piloted to assess their feasibility and students' success. Currently, we have completed these phases of the project and are beginning trials at four schools. The present paper describes the background for our project, related work, goals, and reports on the success of the co-design workshops and school pilots conducted last year.

Educational computing increasingly involves *e-learning*—distributed learning using online courseware or collaborative learning projects. Integration of 1:1 computer-to-learner models with wireless mobile computing provides innovative integrations of indoor/outdoor learning experiences [19] into "seamless learning" across learning contexts [4]. This indoor-outdoor integration introduces *context awareness* and *content adaptivity* into the learning environment. 'Context awareness' means the pedagogical flow and content provided to the learning environment should be *aware* of the situations where learners are (e.g., geo-location). 'Content adaptivity' means different learning contents should be adaptable to the setting where learners are situated, so that time and place appropriate activity supports, information, and technical capabilities are made available. We provide a scenario for implementing the concept of seamless learning spaces to support open inquiry learning by *augmenting physical spaces with information exchanges* and by using *geospatial mappings* between mobile device and physical world that facilitate navigation and context-aware applications [9]. Pea and Maldonado [14] argue that these two features play a vital role in designing mobile applications to support the inquiry processes and socially-mediated knowledge-building associated with learning science by *doing* science. We examine how seamless learning and "open inquiry" create new global opportunities for mobile science learning collaboratories providing open software tools, and participation frameworks for learners' project collaborations, mobile media and data capture, analysis, reflection and publishing. Our next sections describe these ideas by means of an educational scenario and its technological components, followed by implementation and dissemination activities.

In project-enhanced science learning (PESL), students engage in authentic and motivating tasks extending over days that are mediated by various tools and expertise, and that require collaboration and communication within and sometimes beyond school and using data resources outside the classroom [2, 17, 20, 24]. These conditions support the social model of teaching and learning known as "cognitive apprenticeship" [3], where problem definition and problem-solving processes are guided by mentors, with learners gradually taking on increasingly complex tasks and autonomy as support fades. Integral to this model is that learners participate in authentic inquiry where answers are unknown and results matter. This inquiry emphasis advances recommendations from influential science learning standards projects (e.g. [11]). Previous projects using desktop computing for PESL include TERC's pioneering student-scientist partnership studies on water quality (NGS-KidsNet) [23], the environmental science Global Lab Project (TERC, 1996), CoVis [13]; more recent Concord Consortium curriculum projects employing probeware [26], and advances in web-based inquiry environments [8]. The GLOBE Project (http://www.globe.gov/) has also attracted educators and students from 100+ countries to collect environmental data per scientific protocols (e.g., atmosphere, hydrology, land cover, phenology, soil) for web upload to provide aggregate environmental data visualization. Student teams collected data locally and used computer and telecommunications tools for pooling and interpreting results [15].

We are creating new learning opportunities with mobile science learning collaboratories by building on this prior work while also exploiting emerging mobile multimedia technologies, sensors, digital maps and interactive data visualization tools. Opportunities with open platforms and far less costly component technologies make integral use of mobile science learning broadly adoptable in education (see also [7, 25]). The explicit inquiry-support activities and tools we are designing integrate collection of sensor data nearby schools with a collaborative learning system using locally networked mobile devices, and an online community platform for sharing research questions, data and reports across international school sites.

Our major objective is to provide educational activities and tools for helping students participate in collaborative scientific inquiry involving local environmental data. In workshops with teachers from each school site, we are co-designing hands-on, engaging learning activities. These activities offer the students a new environment rich in opportunities for scientific experimentation, systems thinking and opportunities for conceptual change mediated by cycles of scientific inquiry inside and outside the classroom. Handheld-based data-collection probes augment inquiry-based investigations with real-time data and visualizations, increasing students' engagement, enabling concentration on science rather than logistics. Students use probes to collect and analyze data in real time and compare it in near-real time with data from other locations. When students ask their own questions while collecting scientific data, vital opportunities for learning occur [12]. We frame our vision of "open inquiry" as the opportunity to catalyze and sustain global learning using mobile science collaboratories that provide open software tools and resources, and online participation frameworks for learner project collaboration, mobile media and data capture, analysis, reflection and publishing. We are integrating geo-location sensing, multimedia communication, information visualization and Web 2.0 mashup technologies, to create *science learning collaboratories* using interdisciplinary co-design methodologies with teachers, learners, technology developers, domain experts, and learning scientists. This rich type of technological environment provides an experimental arena for learning about complex topics in science through the process of exploring a particular natural phenomenon in its natural setting - as students use sensors and software tools for conducting systematic and collaborative investigations in collecting and analyzing data.

II. Co-Designing The Learning Activities

We share Penuel, Roschelle and Schechtman's [16] definition of co-design as a highly facilitated, team-based process in which teachers, researchers and developers work together in defined roles to design an educational innovation. Educational innovations resulting from the co-design process have been shown to be quite successful in science education, generating a wide range of curriculum materials [6, 18, 21], and specifically in helping students assess their progress in inquiry [1, 5].

The international team co-designing the open inquiry learning activities for the first year consisted of computer science researchers, learning science scientists, school principals, and teachers. All team members had an equal voice; teachers as co-designers have been shown to dramatically impact the success rates of school innovations. Penuel, Roschelle and Schechtman [16] suggest this is due to several factors, including the fact that when developers of innovations are able to match their programs or curricula to teachers' goals for their own students' learning and to their district's requirements, teachers are more likely to implement those innovations. The perceived fit for technology-supported innovations is a function of teachers' current teaching practice, their beliefs about student learning and what kinds of tasks their students are capable of accomplishing, a function of the local context, including the social and technical capacity of schools and districts to support implementation.

Figure 1. Dreamshop Participants Analyzing pH of Different Kinds of Bottled Water

These critical factors are communicated through the teachers' participation and comments during the co-design sessions: "co-design looks at broad reforms through teachers' eyes" [16]. Co-design workshops were conducted first in Sweden and in the United States with the local team, in either one-day or two-half day sessions [22]. We called these workshops "Dreamshops" as they focused on the future of science education. During the first half of the workshop the team started with an ice-breaker introduction exercise, discussed the pedagogical roots and goals of science inquiry learning, and engaged in a showcase of different technologies. Team members walked from station to station, completing a hands-on demonstration of the technologies involved. The technologies demonstrated include geotagging phone-uploaded photos, journaling with interactive digital pens (paper-based computing), exploring different commercially available science education sensors, and others. *Figure 1* shows team members during the technology exploration phase, analyzing the pH and Total Dissolved Salts (TDS) of different kinds of bottled water using PASCO Scientific's SPARK Learning System.

During the second half of the workshop, the team started a brainstorm session with the goal of defining activities or learning scenarios using mobile science collaboratories. We adopted a systematic approach where each team member quickly came up with at least three ideas on their own, and presented them to the full group. These ideas were noted and categorized on a wall by the team. These ideas included an interactive field notebook, climate change (past, present and future changes), restoration of natural habitats, international science data sharing between students, water and soil quality testing, among others.

Nature journal/Latin roots. Multidisciplinary Metacognitive Journaling	
LOCATION	Redwood Highschool, Jasper Ridge, indoor/outdoor classroom
PRIOR KNOWLEDGE NEEDED	Use of Livescribe device, process of reflecting, writing and sharing. Understanding of group norms, respectful environment.
PRIOR MEASUREMENTS NEEDED	n/a
LEARNING GOALS	**Collective (whole group):** active listening, establishing a learning culture **Small Group:** distributing expertise & specializations. Reciprocal teaching. **Individuals:** summative writing, vocabulary building. Improved Observation skills.
GROUPING RATIONALE	
ACTIVITY TYPE	Creating a learning journal, group sharing in a knowledge building community.
RESOURCES NEEDED	Livescribe pen & pads, computer to view entries. Multimedia capture. Projector
DESIRED OUTCOMES	Improved listening skills, hitting target California standards in English writing. Ability to organize & express scientific knowledge.
SUCCESS GOALS	Acquisition of 30 Latin roots, 10 prefixes, 10 sufixes. Ability to form ideas in writing pictorially, transfer them to notes, share in an interactive environment.

Figure 2. Activity Description Template For Learning Latin Roots with an Interactive Nature Journal

Then team members voted on the three concepts they would like to further develop. Team members then chose which of these top three ideas to develop in a smaller group. A template was provided for each of these three groups to describe what a class session where these ideas would be developed would look like (see *Figure 2*).

The template included defining locations, prior conceptual and technological knowledge the students should have, prior technology set-up and measurements to be collected, learning goals, grouping rationale, activity type, resources needed, desired outcomes, success goals, and deliverables at the end of the activity. *Figure 2* illustrates one of the activities developed through the template. As a discussion anchor, this template proved valuable in helping different experts design a feasible activity. It required drawing from the different competencies our team members had to jointly understand the limits of the technology, constraints of lesson plans in limited class time, lesson flow, curriculum standards, etc.

From the three top activities chosen in each country, one was then picked for piloting during the 2008-09 academic year. The Sweden teachers and researchers chose to develop a Soil Quality unit [25], while the US team members focused on the complementary Water Quality unit. This Spring, the two schools in Sweden will implement the Water Quality unit, and the schools in the US will implement the Soil Quality unit. Incorporating the feedback and revisions to both units that will result from these cross-cultural trials will lead to a curriculum whose modules are suitable for implementation in other countries as well, with only the necessary adjustments to the local culture and educational system. Three of the other four activities specified by the workshop participants have been developed since, and will be piloted this year.

III. Piloting a Water Quality Unit

The target group for this activity was 16-18 yr old students from two schools in Sweden and in the US. The technologies we use for these pilots are all commercially available: SPARK science learning systems for the probes and scientific measurements, Livescribe pens for recording both textual and audio discussion, as well as digital cameras. We will now describe the class and activities that took place mid-March 2009, at California high School. During this period, twenty students (eleven male, nine female) agreed to participate in this 90-min Water Quality activity designed and led by the LET'S GO! team as part of an established Environmental Leadership Academy on the school campus.

Figure 3. Starting Class

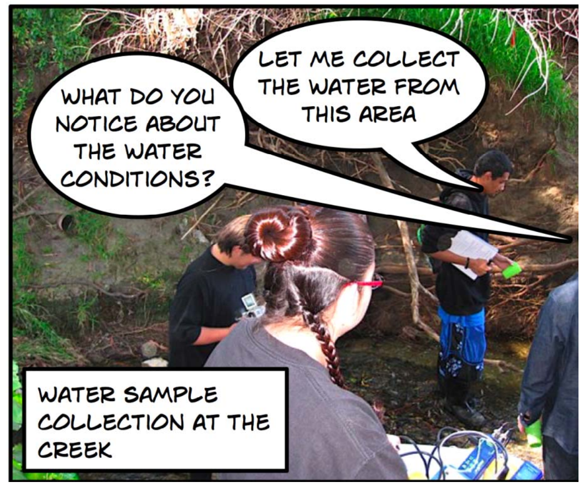

Figure 4. Collecting Samples at the Creek

Two defining characteristics of this school are the creek and pond on the school property, and the students. In this continuation high school students come primarily from underserved populations, and are in school to complete credits needed for graduation. Having a creek on the property facilitates 'learning science by doing science,' as the students do not need fieldtrip permissions or budgets to capture data in the area regularly.

The pond was built by students, as part of the science and leadership academy, and provides a natural contrast to the creek riparian habitat. All images below are drawn from the different student groups that participated, and the text displayed has been transcribed from the video recordings. Every utterance presented as a speech balloon represents a statement made by that participant during the activities.

A. Starting the class:

The learning activity is prefaced by a session with the Principal, called the Gratitude Circle. The students and all staff involved in the lesson activities for the day gather in a circle, take turns introducing themselves and expressing one thing they are grateful for that day, which sets a positive and community tone and spirit. The students then gather at the covered bench area, where the participating Principal introduces the learning activities for the day. While activity centers around Water Quality and scientific concepts (such as pH, TDS, temperature, etc.) the Principal leads the students in thinking through the topic, and ties the weekly units to the main essential question for the classes, involving: "Environmental Justice" (*Figure 3*).

B. Student data collection (activities of inquiry, using the technology):

Students complete a consent form and pre-questionnaire, answering questions about their current understanding of concepts involved in the activity, and break into groups of four. Within the group, the students discuss the purpose of the day's learning activity: to investigate the different quality of water in the pond, compared to the adjoining creek.

Per the instructions, they also discuss what they expect to be some differences in water quality and why. They write their hypotheses and reasoning, then puts on galoshes and head to the adjacent creek to a pre-determined set of GPS coordinates.

Geotagging the data collected allows students to conduct longitudinal research, sampling conditions in the same location during different seasons. Geotagging data also allows student groups to compare measurements taken in different areas of the creek.

As they stand in the creek, each student has a role to play in the data collection process, following Lotan's [10] conception of group-worthy activities: one is responsible for acquiring the water samples, another student uses the SPARK to take measurements on the creek. The other two students record the activity and results, one using the LiveScribe pen and notebook, and another with camera.Per the activity worksheet, the students observe and describe the conditions of the water and surroundings (*Figure 4*). Drawing questions from the hypotheses the students created, they discuss the measurements as the facilitator prompts with leading suggestions and questions, such as the appropriate area to collect samples, or the number of trials to ensure an accurate measurement.

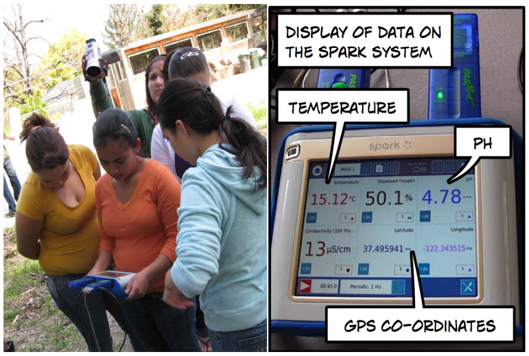

Figure 5. Analyzing the Samples: The Group and The Display of the SPARK

Once back on dry land, the students study the samples (*Figure 5*). They observe the physical appearance of the water (clarity, dissolved solids, etc), insert the probes into the sample and read the data on the SPARK system's screen: pH, temperature, dissolved oxygen, conductivity and GPS sensors.

The procedure is then repeated for the pond location. They record general physical observations (including ambient temperature), and begin comparing *(Figure 6*) the water quality measurements between the pond water (still water) and that of the creek (running water). Guided by the facilitator, the students then suggest possible reasons for any differences observed, making explicit references to the proximity of the creek to a nearby industrial compound.

C. Student discussions and reflections on learning:

The students then return to the covered classroom, where they write out their conclusions and report (*Figure 7*), their theories and reflections about possible explanations for the differences between the samples.

Figure 6. Group Members Discuss Differences Between Creek and Pond Water

Figure 7. Students Writing their Report

Students also complete an individual questionnaire on their understanding of the subject, perception of their learning and reflections on the learning activity. The data collected by all groups in the class, at different locations throughout the creek, can then be visualized on Google Earth or other similar systems for the class-wide discussion (*Figure 8*).

Students' responses were overwhelmingly positive towards the activity and the technology: "a great way to collect data, made it more exciting and much easier" wrote one student. "It is very interesting to get data, I enjoyed doing it and learned a lot" wrote another. Many sought additional visits to repeat measurements during different conditions, and to s tudy other water sources (wells, sea water, tap water).

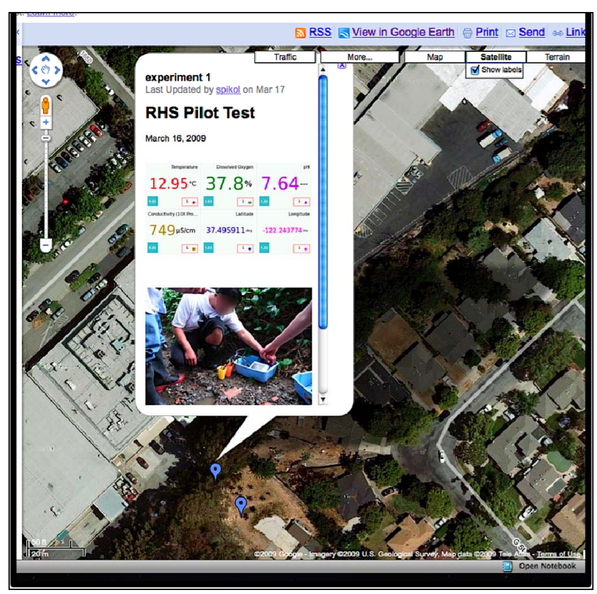

Figure 8. Visualizing Data collected on Google Earth.

Such positive responses are encouraging, and bode well for fostering the students' interest in the subject matter. However, the real question of whether they learned remained.

The students' post-questionnaire responses seem to tentatively indicate that they did increase their understanding of the topic – "the creek moves so more oxygen goes into the creek and the pond just stays in place" wrote a student explaining the difference in O_2 measurements between the creek and the pond. Reflecting on the difference between the total dissolved salts (TDS) measurement, one student stated "The creek moves, so it collects more erosion." Another stated "TDS in the pond is lower because it is rain water, there is nothing flowing into it like the creek … the creek is collecting more things as it flows." A student that had not predicted any differences in temperature between the creek and the pond wrote in their report that "The pond is warmer than the creek because the water stays in the same place and the sun hits [sic] it a lot"

One of the most striking changes in preconceptions came from a student whose entire predictions for the difference between the two locations (over four questions in the pre-test) constituted the line "The creek is much more clear than the pond because the creek flows and the pond not." This was a very common misconception the students faced early on: the belief that the clearer the water, the better. His explanation after the activity reflected an additional understanding of the factors to consider when analyzing water quality: "I think there's a difference because the pond was filled with drain water and the creek is always flowing. The pond is always in the sun and has no cover or shade. The pond water is still and the creek water comes from miles away, from the mountains."

In addition to the students responses in their surveys, we have access to their discussion during the activity: some teams used video cameras to record the process, and all teams used the digital pens that record both written and audio information when the pen tip is pressed down. Through these digital traces we can hear how the students incorporate their classroom knowledge into the inquiry process. For instance, common sense-making conversations on methodology – including how many measurements are needed to comply with the scientific method, or why the values displayed by the probes change rapidly when jostled – would not be captured by the written responses. Yet they remain a crucial part of the learning process.

IV. CONCLUSIONS AND FUTURE WORK:

The results from the pilot are encouraging. Currently we are addressing challenges for the scaling-up phase, aiming to take this water quality inquiry from twenty students in the pilots to four classrooms in the US, and two schools in Sweden. We are also sequencing the water quality inquiry within the academic year with the four other topics that we are developing with the project partners: soil quality, photosynthesis, ecosystems, and biodiversity. Using the sensors over the school year is intended to study longitudinally the effect of different weather patterns on the environment. By tracking students' progress and knowledge – both through the technological traces and through their questionnaire responses – we can study the long-term recall and transfer of the knowledge they discover through the inquiry process.

We are developing an innovative environment to engage learners in exploring and experimenting with multiple representations of causal interactions and functional relationships typical in science, to promote inquiry methods and deeper domain understanding. With sensors, data visualization, GPS and Web 2.0 tools, the components for realizing our vision are available, but they need to be integrated into a scalable system with solid pedagogical foundations and data-driven mechanisms for continuous improvement.

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