AC 2012-4150: THE INTERLACE PROJECT: EXAMINING THE BARRIERS TO IMPLEMENTING COLLABORATIVE, INQUIRY-BASED INVESTIGATIONS

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The InterLACE Project: Examining the Barriers to Implementing Collaborative, Design-Based Inquiry Investigations

ABSTRACT

A growing body of research suggests that inquiry-based pedagogical practices can greatly enhance a student's learning experience in a science/engineering classroom. However, this approach is not widely employed owing to the fact that it is often challenging and time-consuming. To address this problem and to promote cyber-learning strategies that enhance STEM education, the Interactive Learning and Collaboration Environment, or InterLACE, Project is designing, developing, and testing an online collaborative education environment that assists teachers in presenting design-based inquiry lessons to their high school science/engineering classes and motivates students to take a more active role in the learning process. As we construct the blueprint for InterLACE's suite of technological tools, we have conducted design discussions among and classroom observations of the teachers we chose for our Design Team to identify the obstacles that stand in the way of design-based inquiry learning, not only from their perspective but from the students' viewpoint as well. To inform the collaborative aspect of the ways in which our software can support such lessons within the classroom community, we want to examine how shared meanings are built and collective comprehension is reached through various interactions between the teacher and the students and among the students themselves, with an eye toward fostering collaboration across student groups in furtherance of a class-wide goal. By gathering and analyzing such data, our aims are twofold: (1) to create a superior suite of technological tools that can advance

science/engineering education in the high school classroom; and (2) to increase the appreciation of the epistemological benefits and drawbacks of collaborative, design-based inquiry learning with regard to science/engineering education. This paper specifically presents data collected in the fall of 2011 concerning the barriers to meaningful, collaborative design-based inquiry practices that we observed and were reported to us by our Design Team, plus additional data collected in the winter of 2012 regarding the first tool we have created in response to some of these obstacles.

INTRODUCTION

Despite a preponderance of evidence—both anecdotal and statistical—concerning the correlation between collaborative inquiry-based pedagogical practices and substantial student conceptual gains [1-7], the implementation of such methods in the high school science/engineering classroom is sorely lacking [8-10]. Engineering instruction is all but absent, too, according to a 2009 report by the National Academy of Engineering and National Research Council, "Engineering in K–12 Education [11]." These two deficits might in fact share a common cure through the promotion of collaborative, design-based inquiry learning activities.

To explicate what we mean when we use the term *collaborative, design-based inquiry,* we would like to break it down into its three main components: Our use of the word *collaborative* refers to "the process by which individuals negotiate and share meanings relevant to the problem-solving task at hand [12]," not just in terms of the efforts of small student groups but also in terms of the communication across those groups that could help achieve a sort of distributed cognition [13]. *Design-based* refers to "real-world contexts…used to scaffold science learning [14]" in which students design experiments to explore physical phenomena. As students devise these experimental setups within "real world" parameters, they will face the sorts of constraints engineers encounter as they design and build solutions to problems without the luxury of the idealized world often depicted in physics textbooks. These more open-ended design activities need to be carefully constructed to diffuse the "inherent tensions" between science comprehension goals and the success of the student-engineered outcomes [14]. Lastly, *inquiry* refers to the pedagogical approach in which the teacher endeavors to guide his or her students through a process of exploration and interaction with scientific phenomena, working toward the goal of explaining it to themselves and others so they can reach a deeper level of understanding. Inquiry learning requires the teacher to focus on student ideas and reasoning and how they are shaped and developed. The role he or she must adopt is "not simply to keep the students on the right path; it is to find out what paths there are, to scout ahead to see where they might lead, and to make judgments about which ones to follow [4]."

Design-based inquiry learning activities rarely appear in the classroom because teachers often find them hard to implement [15, 16], and attempting such projects typically requires changes in curriculum, instruction, and assessment practices that are new not only to students but to teachers as well [17, 18]. Additionally, students and teachers need guidance through the design-based inquiry process [6] yet lack the resources to integrate and support this approach to learning [19].

To respond to these challenges, various technologies have been developed to buttress design-based inquiry learning. For students, these online tools have offered benefits such as individualized student-centered scaffolding [20, 21], novel ways to visualize scientific concepts [12], and engaging interactive activities and simulations [22]. These technological innovations have also helped encourage class-wide discussion, provided opportunities for students to collaborate with fellow classmates and to receive ongoing feedback from their instructors, and opened up alternate venues through which students can access information and communicate ideas and results.

Extending the RoboBook digital journal prototype developed at Tufts University [23] and building on the aforementioned technological tools with an emphasis on facilitating student discussion and collective sense-making, the Interactive Learning and Collaboration Environment (InterLACE) Project aims to create a flexible, efficient suite of Web-based tools that supports both students and teachers as they attempt collaborative design-based inquiry learning activities based around science/engineering concepts.

THE INTERLACE PROJECT

A diverse group of faculty and graduate students from the computer science, engineering education, and human factors and design departments, as well as five high school science/engineering teachers (the Design Team) and professionals from fields such as collaboration technologies and user-centered design and evaluation, comprise the members of our team. Our goal will be to follow an iterative model of development, design, and testing of a number of Web-based educational technologies and classroom activities. In the fall of 2011, we collected data from our Design Team teachers concerning the impediments they encounter when attempting design-based inquiry instruction in their classrooms. We have analyzed this data to inform the construction of prototypical tools, the first of which has been recently tested several times in the classrooms of our Design Team members. We will continue to augment, evaluate, and fine-tune our software, and soon we will recruit more teachers to gain access to a greater variety of classrooms.

Our Design Team plays a crucial role in our project. The members—three from Massachusetts, two from New Hampshire—come from myriad school settings, in terms of size and ethnic, socioeconomic makeup, and possess varying levels of science/engineering teaching experience. They include Grant, who has nineteen years' experience and works at a small private school in Boston; Kraig, who has six years' experience and works at a large public school in Somerville, Massachusetts; Caroline, who has three years' experience and works at a small public school in Boston; Daniel, who has twenty years' experience and works at a small private school in Sanbornton, New Hampshire; and Charles, who has fifteen years' experience and works at a small public school in Littleton, New Hampshire.

To gauge the Design Team teachers' thoughts on and witness what barriers they face in implementing collaborative design-based inquiry projects in their classrooms, we employed a mix of participatory design discussions and classroom observations. In the fall of 2011, we hosted a total of three design workshops, each of which featured an activity that encouraged the teachers to think about collaborative design-based inquiry learning in the classroom. During the first session, we asked the teachers to list as many obstacles to design-based inquiry learning that they could think of and then rank the ones that presented the greatest challenges. Our goal was to ascertain, from a teacher's perspective, the reasons he or she may use or forgo a design-based inquiry approach to a lesson.

In the second session, we asked the Design Team to view a video clip of fifth graders discussing pendulum motion [21] and then share their thoughts on what they believed the students were thinking based on the comments the children made. Here, we wanted to underscore our philosophical bent: to adopt the stance of inquiry that we defined earlier in this paper—that is, to focus on student thinking and improvise the lesson so that the emphasis remains centered on the students' ideas. This stance not only helps the teacher to better appreciate his or her students' point of view, it also serves as a model of inquiry for the students: As the students seek to learn scientific concepts, the teacher seeks to learn the origins and directions of the students' respective thought processes.

Continuing in this theme, we examined what design-based inquiry learning could look like by asking the Design Team teachers to read "Problem Solving, Modeling, and Local Conceptual Development" [7] before the third session; at that meeting, we discussed the model-eliciting activities highlighted in the paper as possible models for science/engineering activities that InterLACE's suite of technological tools could help implement.

We also conducted fifteen in-class observations in order to see when and how teachers successfully and unsuccessfully engage their students in the sorts of collaborative inquiry that we are hoping to promote. We expected that what we witnessed in the classroom might in fact differ from what teachers reported themselves in the design discussions. The protocol for our observations evolved according to emergent, prominent patterns that we thought deserved more attention and could better inform the development of InterLACE's software. We began with a somewhat strict protocol that attempted to capture the frequency and quality of student-teacher talk, but we quickly realized that the student-to-student talk we were hoping to promote through the use of InterLACE's software was pretty sparse in every classroom. When we realized that focusing on this aspect of classroom interaction would prove fruitless owing to its near nonexistence, we instead decided to direct our attention toward potential organizational barriers—the physical space of each classroom, the respective student populations and school culture, each teacher's style and his or her experience and comfort level with implementing design-based inquiry learning—that could thwart the productive use of InterLACE's software. In November, we developed a Web-based tool that could time-stamp each note taken during our observations, thus helping us keep track of the amount of time that was devoted to various tasks—administrative, lecture, review, discussion, etc.—during a given classroom session (see Figure 1).

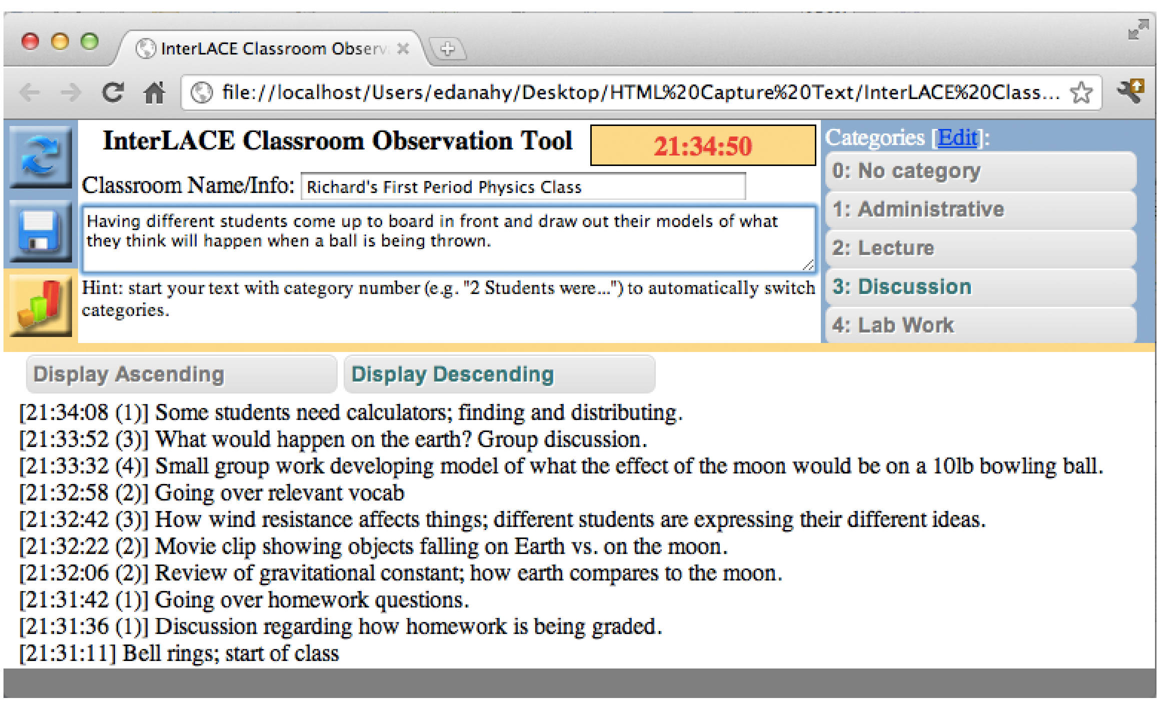

Figure 1: The InterLACE Classroom Observation tool was developed by our technological team so that we could time-stamp our notes, thus helping us keep track of how much classroom time was devoted to lecture, discussion, review, and other instructional tasks.

RESULTS

Several barriers to inquiry learning surfaced during our Design Team workshops. The concerns that Design Team teachers expressed included their students' inability to describe scientific concepts properly; keeping students on-task and motivated; covering the topics necessary for students to pass state-mandated standardized testing; lack of materials and/or technology needed to complete a design-based inquiry project; whether students could connect the engineered outcomes of their projects to the underlying scientific concepts; and giving students choice of the projects they can tackle, an outlet in which they have flexibility in expressing their ideas, and ownership of the data they generate. However, the majority of these barriers seemed to trace back to a common point of concern centered on time: having enough time to prepare students to participate in design-based inquiry activities; losing time when students go off-task as they engage in these types of projects; allowing the students ample time to complete the activities; giving feedback to the students quickly so that they are encouraged to progress through a project's modeling cycle at a faster pace; and granting the teachers autonomy to move through an activity as swiftly or as slowly as they need to.

Perhaps owing to this emphasis on efficient time management in the classroom, in almost all the observations we conducted, we witnessed the use of worksheets. There are other reasons for their ubiquity: They're portable, inexpensive, and easy to implement, plus they keep students on-task. Christine successfully employed worksheets in her classroom to keep her students focused and productive. However, we are concerned that worksheets often decontextualize the problem-solving process for students with content that is static, procedural, narrowly focused on the right answer, weighted toward the mathematical rather than the conceptual process, and often created by someone other than the teacher. Among Kraig's students we observed that some were more concerned with using the proper formulas and entering the correct numbers on their worksheets than with actually understanding the concept the worksheet addressed. If we wish to encourage students to amble along a fertile path to sense-making, it is doubtful that such an aim can be accomplished by a mass-produced worksheet that leads students through a prescribed procedure that elicits merely the "right" answer and does little to spur a student's expression of his or her ideas or reasoning.

Additionally, we observed that many of our Design Team teachers still devote much of their classroom time to the traditional lecture. If students were asked to contribute to the classroom conversation, it was framed in the yes/no, fishing-for-the-correct-answer paradigm, with no subsequent class-wide discussion of the concept at hand. It appeared as though the teachers were working from the position that they needed to bring their students to an easily certifiable level of conceptual understanding before they could engage in an activity, even though such efforts typically reap little reward. For example, in preparation for a lab, Greg's class received a 40-minute lecture; however, the students failed to appropriately apply the concepts addressed in the lecture when they attempted to complete the lab assignment.

Finally, we also found that when students were assembled into groups, though they collaborated within those groups, they would rarely interface with other student groups. In one instance in Charles' classroom, if any of the lab groups had a question regarding procedure or experienced some technical malfunction, rather than consult with their fellow classmates to expedite the issue, they would wait for Charles to direct them through the difficulty. We observed him cycling through the groups, repeatedly answering similar questions, and spending most of his time clarifying the task rather than interacting with students' ideas, reasoning, and justifications. We witnessed nearly the same behavior among Kraig's students: Dispersed among several whiteboards that lined the classroom walls, the student groups largely kept to themselves as they worked out problems and would consult only Kraig if they needed assistance.

DESIGN PRINCIPLES

After reviewing our data, we decided the first issue we wanted our software to tackle was the need for fostering an environment that focuses on student thought and ownership of ideas; thus we generated an initial set of design principles to guide our technological development process:

1. Facilitate student discussion and argumentation with the aim to empower students to share, develop, and build ideas, theories, and designs collectively.
2. Promote collaboration among individual students, student groups, and the teacher.
3. Enable the teacher to act as the facilitator of the above two principles, as well as to allow them to focus on student thinking.

A key goal of the InterLACE software will be to allow teachers and students to create a scientific "community of practice" in the classroom. Within this community, teachers and students will emphasize the pursuit of ideas through inquiry, communication, and collaboration. These practices will foster scientific argumentation and design justification in which students will discuss, listen to, and critique ideas and provide evidence for their hypotheses and designs, thus advancing toward more stable conclusions. Students will be encouraged to value the design of experiments and how that design relates to the appropriate testing of hypotheses; they will also be enabled to see the reasons for an experiment's failure and possible sources of error. Finally, students will come to think of data collection and analysis as a collaborative endeavor rather than an individualistic pursuit by contributing to a classroom culture in which the collection of larger and more varied data sets transparently supports the acceptance or rejection of hypotheses. This culture will hopefully lead not only to improved design solutions but also to a greater collective understanding of scientific concepts. However, we are cognizant of the fact that these design principles speak to an idealized view of the classroom, which we realize will be subject to the various constraints that we have previously outlined regarding the need to reduce the time it takes—or at least the time teachers perceive that it takes—to implement design-based inquiry projects.

The first step in expediting this aim was to design a simple aggregation and sharing tool that makes student thinking readily visible. Students are asked to type up their ideas on a science/engineering concept (soon they will be able to express themselves pictorially as well) and upload their contributions to InterLACE's Web-based platform. Via an administrator dashboard, the teacher can monitor, manage, and then visually display the students' contributions on a centralized projection screen to encourage a subsequent class-wide discussion (see Figure 2). The teacher or a student can also rearrange these thought bubbles on-screen so that he or she can group them in terms of a certain emergent pattern of ideas, agreement vs. disagreement, etc. Most important, the tool grants students and teachers a visual artifact of everyone's thoughts. Rather than having to rely on their memories to recall who said what in an earlier conversation, they can refer to the archive of a class session for a more exact account.

Our trials of the tool in our Design Team members' classrooms have so far yielded fairly good results. Both teachers and students have responded to the tool rather positively. Daniel said he liked that the tool allowed him to discover how far off target some of his students were in their reasoning. Kraig observed that the tool encouraged his students to contribute more to the classroom discussion than they normally would have. And, on the whole, students have greeted the tool with excitement and approval. In fact, a student from Kraig's class claimed that he would come to school every day if his lessons involved interacting with the tool.

The classroom conversations we have observed still leave room for enrichment. We have noted that care must be taken in how the questions presented by the tool are worded; they need to be open-ended enough to spark rigorous thought and spirited discussion but clear and accessible enough to avoid confusion and detachment. We also need to continue shaping our Design Team teachers' inquiry stance so that they can gain a level of comfort with the awkward pauses that can often precede lively conversations and pose the questions that can really probe and reveal student thinking. Additionally, we feel many more observations of the tool in action need to be made before we can declare its success or failure.

This inaugural tool is one of many we will create to support teachers in instigating rich conversations centered on student-generated ideas. Further add-ons and tools will emerge as we develop and evaluate this first iteration. Chiefly, these tools will address the lack of emphasis on student discussion and collaboration by giving every student a conspicuous voice in classroom discussions and grant them ownership in the class-wide quest to collectively make sense of the concepts presented to them. It will also provide teachers with a dynamic data set—their own students' thinking.

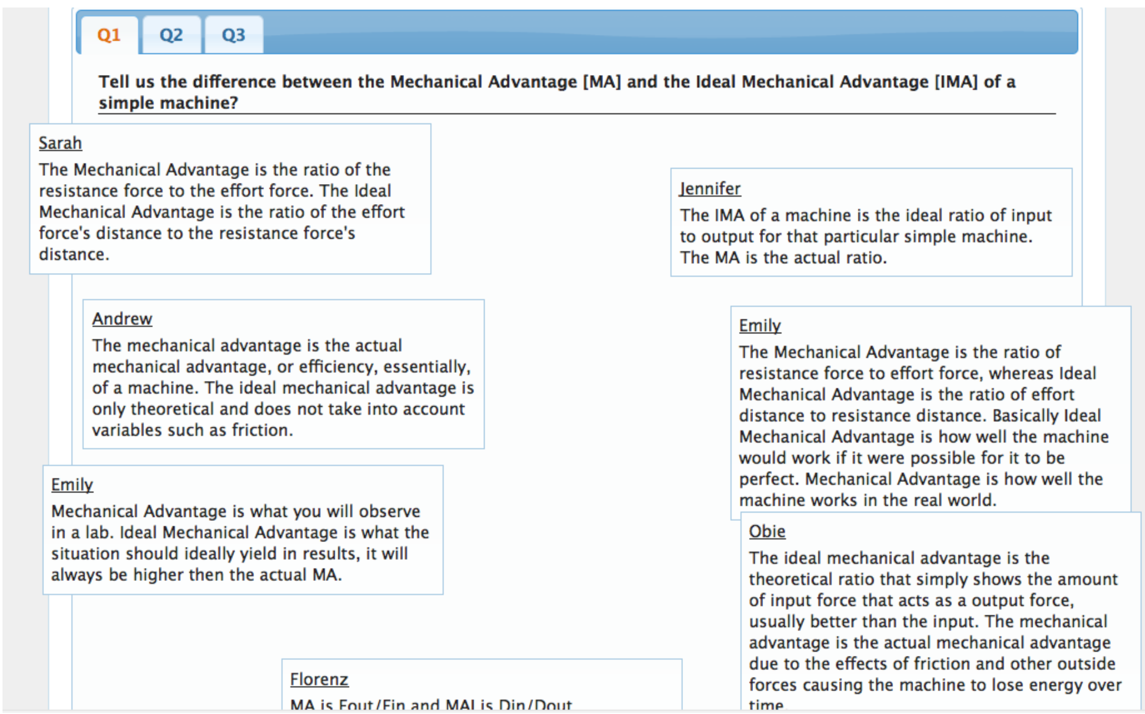

Figure 2: The first tool we have developed for the InterLACE Project allows students to seamlessly share their ideas with their fellow classmates.

CONCLUSION

The invaluable data that we gathered from our Design Team teachers in the fall of 2011 has allowed us to create a technological tool that shows real promise. As we've identified several barriers to, concerns surrounding, and enablers of design-based inquiry learning, we've established design principles that will guide us through the refinement of this initial tool and the construction of others. With the first few steps behind us, we realize that there is much more left to do to facilitate design-based inquiry learning in the classroom, and our hope is that InterLACE will contribute a great deal to this effort.

REFERENCES

1. Beatty, I.D., et al., *Designing Effective Questions for Classroom Response System Teaching.* American Journal of Physics, 2006. **74**(1): p. 11.
2. Crouch, C.H., and Mazur, E., *Peer Instruction: Ten Years of Experience and Results.* American Journal of Physics, 2001. **69**(9): p. 8.
3. Hake, R., *Interactive-Engagement Versus Traditional Methods: A Six-Thousand-Student Survey of Mechanics Test Data for Introductory Physics Courses.* American Journal of Physics, 1998. **66**(1): p. 11.
4. Hammer, D., *Discovery Learning and Discovery Teaching.* Cognition and Instruction, 1997. **15**(4): p. 45.
5. Heller, P., and Hollabaugh, M., *Teaching Problem Solving Through Cooperative Grouping. Part 2: Designing Problems and Structuring Groups.* American Journal of Physics, 1992. **60**(7): p. 8.
6. Kolodner, J.L., et al., *Problem-Based Learning Meets Case-Based Reasoning in the Middle-School Science Classroom: Putting Learning by Design™ Into Practice.* The Journal of the Learning Sciences, 2003. **12**(4): p. 54.
7. Lesh, R., and Harel, G., *Problem Solving, Modeling, and Local Conceptual Development.* Mathematical Thinking and Learning, 2003. **5**(2/3): p. 33.
8. Becker, H.J., *Internet Use by Teachers: Conditions of Professional Use and Teacher-Directed Student Use*, 1999, Center for Research on Information Technology and Organizations. University of California, Irvine, CA.
9. Chinn, C.A., and Malhotra, B.A., *Epistemologically Authentic Inquiry in Schools: A Theoretical Framework for Evaluating Inquiry Tasks.* Science Education, 2002. **86**: p. 43.
10. Driver, R., et al., *Young People's Images of Science.* 1996, Buckingham, England: Open University Press.

11. Katehi, L., Pearson, G. and Feder, M., *Engineering in K–12 Education: Understanding the Status and Improving the Prospects*, National Academy of Engineering and National Research Council. 2009, Washington, D.C.: The National Academies Press.
12. Roschelle, J., and Teasley, S.D., "Constructing a Joint Problem Space: The Computer as a Tool for Sharing Knowledge," in *Computers as Cognitive Tools,* S. Lajoie (ed.). 1993: Hillsdale, NJ, Lawrence Erlbaum Associates.
13. Bell, P., and Winn, W. "Distributed Cognition, by Nature and by Design," in *Theoretical Foundations of Learning Environments,* D.H. Jonassen and S. Land (eds.), 2000: Mahwah, NJ, Lawrence Erlbaum Associates.
14. Leonard, M., and Derry, S.,*"What's the Science Behind It?" The Interaction of Engineering and Science Goals, Knowledge, and Practices in a Design-Based Science Activity* (WCER Working Paper No. 2011-5). 2011. Retrieved from the University of Wisconsin–Madison, Wisconsin Center for Education Research website: http://www.wcer.wisc.edu/publications/workingPapers/papers.php
15. Edelson, D.C., Gordin, D.N., and Pea, R.D., *Addressing the Challenges of Inquiry-Based Learning Through Technology and Curriculum Design.* The Journal of the Learning Sciences, 1999. **8**(3/4): p. 61.
16. Gallagher, S., and Stepien, W., *Content Acquisition in Problem-Based Learning: Depth Versus Breadth in American Studies.* Journal for the Education of the Gifted, 1996. **19**: p. 18.
17. Lehtinen, E., et al., *Computer-Supported Collaborative Learning: A Review of Research and Development*, in *The J.H.G.I. Giesbers Reports on Education.* 1999, University of Nijmegen, Department of Educational Sciences: Netherlands.
18. Lipponen, L., et al., *Effectice Participation and Discourse Through a Computer Network: Investigating Elementary Students' Computer-Supprted Interaction*, 2001: University of Maastricht. p. 421–428.
19. Darling-Hammond, L., et al., *Powerful Learning: What We Know About Teaching for Understanding.* 2008, San Francisco: John Wiley and Sons.
20. Gudzial, M., *Software-Realized Scaffolding to Facilitate Programming for Science Learning.* Interactive Learning Environments, 1995. **4**(1): p. 44.
21. Gudzial, M., et al., *Integrating and Guiding Collaboration: Lessons Learned in Computer-Supported Collaborative Learning Research at Georgia Tech*, in *Proceedings Computer Support for Collaborative Learning '97.* 1997. p. 91–99.
22. Linn, M.C., Clark, D., and Slotta, J.D., *WISE Design for Knowledge Integration.* Science Education, 2003. **87**(4): p. 22.
23. Danahy, E., Goswamy, A., and Rogers, C. *Future of Robotics Education: The Design and Creation of Interactive Notebooks for Teaching Robotic Concepts*. In *IEE International Conference on Technologies for Practical Robotic Applications*. 2008.
24. Hammer, D., and Van Zee, E., *Seeing the Science in Children's Thinking: Case Studies of Student Thinking in Physical Science.* 2006, Portsmouth, NH: Heinemann.