Online Representations That Promote Inquiry in Physics

Andee Rubin

TERC

Cambridge, MA

Andee_rubin@terc.edu

Paper presented at the Annual Meeting of the American Educational Research Association, New Orleans, April 2002

The work reported in this paper was funded in part by the National Science Foundation Grant ESI-9911770 and in part by the Fund for the Improvement of Post Secondary Education (FIPSE) Grant P116D990066A. These organizations are in no way responsible for the views or claims expressed in this paper.

Community building in an online environment is influenced by, among other things, the general social culture of the online experience and the more specific knowledge culture and community of practice that students are encountering. Recent research has focused primarily on the first of these - the determinants and effects of the interactions among students and teacher/facilitator from a situated perspective, which sees learning as occurring within an activity and a context. (Brown, Collins, & Duguid, 1989; Lave & Wegner, 1991) Such studies analyze the activities and approaches students need to appropriate to become members of a learning community; they also identify and address such issues as the changing roles of instructor and students as the course progresses and the students take more responsibility for their own learning (Collison et al, 2000; Graham et al, 2000.) This paper focuses on the second influence on online community building: what I am calling the "knowledge culture" to refer to the subject matter about which students are learning, (in this case physics), and the tools and scientific stances that members of the community of practice (in this case, physicists) use.

Investigating Physics is the second in a series of six online courses that make up a fully online master's program for elementary and middle school teachers in Science Education, developed collaboratively by TERC and Lesley University. The program seeks to "re-open the door to science" by providing teachers with a safe environment where they can think hard, work collaboratively, and extend their science understandings. Totaling 33 credit hours, the program helps teachers increase their knowledge of physics, biology, earth science, engineering and ecology, while exploring new ways to support their students' science learning. As they develop their own expertise with computer-based technologies, they learn ways to enhance their students' learning with technology as well.

The courses are designed to be solid science courses, but written for an audience that has often had negative school experiences with science. In the case of physics, people's memories were especially painful and some began the course quite tentatively. The Investigating Physics course is on forces and motion—especially Newton's Laws.

The aim of the course is for participants to see Newton's Laws in their own everyday actions by taking the perspective of a physicist. We set as our goal in designing the class that students would understand F=ma with some significant depth - a much more difficult tasks than it would seem from its four-character equation. To guide the students in their scientific thinking, one of the two instructors for each class is a scientist.

In each course in the program, there is a dual emphasis: on science and on pedagogy. In the Investigating Physics course, the pedagogical emphasis is learning how to conduct interviews with children to understand their scientific ideas. During the course, each student conducts interviews with several children on the same topics they are studying themselves, and transcribes and analyzes portions of each interview to share with other participants. In order to support this aspect of the course, there is a second instructor, who is a science educator. Both instructors interact with the students in the three forums described below.

Each course is designed with an explicit focus on inquiry as a tool for learning – and teaching. This is not a simple task; it is easy to give lip service to inquiry, but more difficult to ensure that understanding develops through inquiry - especially online. This is where the learning community fostered by the course is most important. As explained in more detail below, participants' interactions with one another, which are carefully supported by the course structure, are the major places where understanding unfolds from the investigations carried out by each course participant. To facilitate focused conversation, students are divided into "study groups" of five or six people; it is these people with whom they will explore the science, share their interviews and offer personal support, although they are welcome to "visit" other study groups as well.

This paper will describe briefly some of the characteristics of the course that are influenced by the knowledge context and that promote an online inquiry-based community, then analyze in more depth one particular aspect of the course that supports this community growth.

Integrating scientific and personal perspectives: One of the areas researchers have chosen to examine in online contexts is the relationship between course-relevant conversation and more personal conversation (as much as these can be separated). (Kerr, this session). In this course, we wanted students to look at their world with a physicist's eye, to see and appreciate the physics of motion everywhere they went. To this end, we established three separate "forums," separate threaded discussion spaces, to encourage students to bring their personal experiences into the course. In the Physics Forum, students discuss the data they have collected, their analysis of it and further questions it evokes. This is where students also share graphs and sketches to illustrate their analysis. In the Learning Forum, the conversations center on interviews with children, including bits of transcript and analysis. Because all participants asked similar questions in their interviews, they were able to compare both their interviewing techniques and what they discovered about the child they interviewed.

The third and most innovative forum was "Motions in Your Life," in which we asked students to connect their daily life to the concepts of the course. In this way chores (driving kids to school), athletic events (playing volleyball or soccer), vacations (swimming or diving) and relaxing (watching a pet cat jump on the sofa). For example, in the very first week of the course, we asked students to post in the Motions in Your Life forum places in their lives in which they could find constant motion, speeding up motion, slowing down motion and crashes. Here is one of the student's posts.

Speeding up: occurs when the dryer is turned on; the more mass (due to more clothes or more moisture in the clothes) the slower the speeding up process.
Slowing down: occurs when the dryer door is opened; the more mass, the longer it takes to slow down [My opinion here is different from Joyce's.]
Constant: occurs after the dryer reaches its peak speed. I did wonder if the "balance" of the clothes in the dryer may cause changes, albeit slight, in the constant movement
Crash: occurs if you open the dryer door and use your hand to stop the motion.

Thus, while in most courses personal interactions add to (or detract from) the social structure in a context-independent way, we were able to make use of the <u>content</u> of students' everyday life experiences. The particular connections we were able to create were shaped by the scientific content of the course, the physics of motion.

<u>Viewing a scientists' perspective first-hand:</u> In order to better understand the intellectual stance of some physicists' (certainly not all) community of practice, students had the opportunity to watch a practicing physicist doing the same experiments they were doing and asking some of the same questions they had asked. Luckily, while we were videotaping these experiments, something happened that surprised and temporarily perplexed the physicist, who reacted with just what physicists do. He tried the motion again, varied it and saw what happened, looked at it from a different perspective and finally had his own "Aha" experience.

In order to encourage students to attempt to "get into the head" of the physicist, we asked them to compare the physicist's, their students' and their own understanding of F=ma. for a final project. The fact that the course was about elementary physics, in which the phenomena of interest are accessible and potentially surprising, even to a practicing scientist, made this piece of the course feasible. As one student said in his final essay, "When considering the diverse range of experiences between Gary Goldstein [the physicist] the students that I interviewed and my own, it was amazing to see how we all were surprised by things just outside of [our] realm of understanding." He went on to describe where these boundaries lay for each "scientist."

Preserving a hands-on experience: One of the design principles of Investigating Physics was to consider carefully when a high-tech approach would work well and when a low-tech approach had real advantages. Thus, while many online courses ask students to keep an online journal, students in Investigating Physics keep an offline notebook - just paper and pen. We had many reasons for this choice. First, the subject matter of force and motion required students to do many of their investigations away from a computer - in some cases, outside or even in a car or bus. Second, much of what we wanted students to draw were diagrams and graphs which would have been difficult if not impossible to draw on the computer. Third, even though it seems old-fashioned, we felt that a physical notebook was, for many students, more conducive to personal and informal journal keeping, which we were trying to foster as a scientific habit of mind.

Having an online course doesn't mean that all of students' experiences have to be online. As hinted at above, much of a student's work in Investigating Physics takes place with real objects. Students receive a kit of materials before the course begins - it contains a low-friction cart, several balls, and some spring scales - simple materials that cost little and could be used in a classroom as well. Each course session begins with first-hand experimentation that demands close observation; participants record their results in their journals, which then form the basis for their online conversation during the week.

In one case, students construct an instrument to measure acceleration from a jar, a cork, some string and enough corn oil to fill the jar.. (See picture of the accelerometer about to go for a ride on its cart). This instrument indicates acceleration by the position of the cork relative to the jar; if the jar is accelerating, the cork will lean in the direction of the acceleration.) Many of students' explorations during that session involved observing the accelerometer as they moved it - including watching how it behaved in a quickly moving vehicle such as a car or bus. (One student related how she took the accelerometer for a ride one evening and reassured us that her husband was driving and she was watching the accelerometer by flashlight.) There is no substitute for this kinesthetic sense of motion – speeding up and slowing down – that can then be connected to symbolic and mathematical representations of motion.

It might seem that all this offline activity might undercut the online community, that students would get involved in their own work and ignore their online colleagues. In fact, just the opposite was true. Students' conversations were enlivened by their individual experiences; rather than all talking about a shared online experience, they brought their own stories to the table. The sense of storytelling made for some energetic and humorous exchanges, for example:

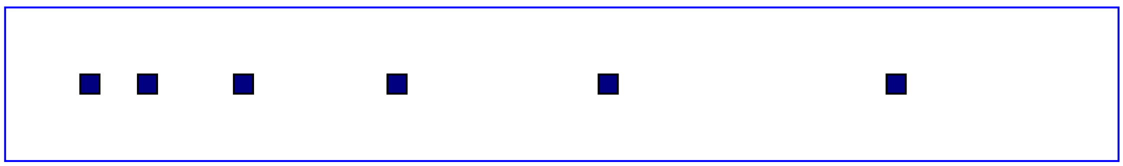
> "Diving!
> Why is it that none of us have brought up diving so far?
> I was out and about shopping on Saturday when I had to make the most dreaded purchase of all time - the bathing suit. As I was perusing the racks I was going over my bathing suit criteria, one of them being that I must stay intact and be also comfortable when diving overboard and climbing back on board the boat. Well, didn't you know it, the little physics bell, which has suddenly appeared above my head, started ringing. A diver in the course of a dive exhibits many of the forces and changes in acceleration and velocity that we have been discussing"…(And a detailed description of the act of diving follows.)
> How did I do?

> I usually have to draw the visual first before writing it up. I am going to put my write up to the test of now trying to create the visual. Take a peek at my attachment and tell me if I scored a 9.0 or an 8.0. Being that it is my first time I am not expecting a perfect score!!!!

Using representations as the basis for collaborative inquiry

Given that many of students' experiences are offline and personal, it is important that they have some kind of shared representation that both captures their experience and moves it toward more conventional mathematical representations. Investigating Physics uses two such representations; one especially designed for the course and one a more common graphical representation. The following sections will describe both representations, discuss which characteristics of them support collaborative inquiry and the formation of community and give examples of how these representations became shared objects of inquiry.

Strobe Pictures: Attempting to observe motion closely presents one major problem: it is over almost as soon as it begins. Most of the motions students in this course studied lasted one second or less. To deal with this problem, the students used videotapes of the motions which they could view one frame at a time. (These videos were viewable over the Web.) This helped, but students still needed some representation they could see all at once, a record of the passage of time on a single image. Classically, scientists use graphs for these purposes, since a graph of change over time has time on the X-axis and allows us to follow the motion (or growth, etc.) by scanning left to right across the graph. But we felt this was too great a conceptual leap - from video to graph - and designed a transitional representation we called a strobe picture. Students make strobe pictures by placing an overhead transparency on their computer screen and marking on it with an overhead pen. A student creates a strobe picture of, for example, a cart, by marking the position of the cart in one frame of the video, advancing the video one frame, marking the position of the cart in that frame, etc. When they are done, students have a representation of the motion of the cart in subsequent frames - all on one transparency. Constant speed is represented by equally spaced dots; speeding up is represented by dots getting further and further apart; slowing down is represented by dots getting closer and closer together. The strobe picture below shows an object speeding up, since the dots get progressively farther apart.



The role of strobe pictures in the course pulls together several design principles, which emerged as we continued to develop the course. 1) Students' observations began with motions they created themselves. 2) Then, students all viewed the same motion on a Web-based video. 3) Students each created a representation of the shared video that allowed them to talk about it in more explicitly mathematical terms. In a sense, the strobe picture gave them a common language with which they could communicate about details of the motion. Below is a message a student sent during the session in which strobe pictures were introduced. Other students were able to comment on and/or disagree with this woman's observations, since they were so explicit.

> My understanding is that the accelerometer measures change in velocity. I think that the angle measures the change in direction, like when I took it out and drove on a curvy road, the speed didn't change but the cork kinda moves on like with the road. That is what I think so far……
> My strobes:
> 1-6 middle --constant v
> 7-10 back --or forward depending on what you see ---acceleration
> 11-13 middle---constant v
> 14-19--back or forward again what you see--acceleration

20-30 --middle --constant v

31-32--slight forward or back how you look at it acceleration

33-middle is constant v

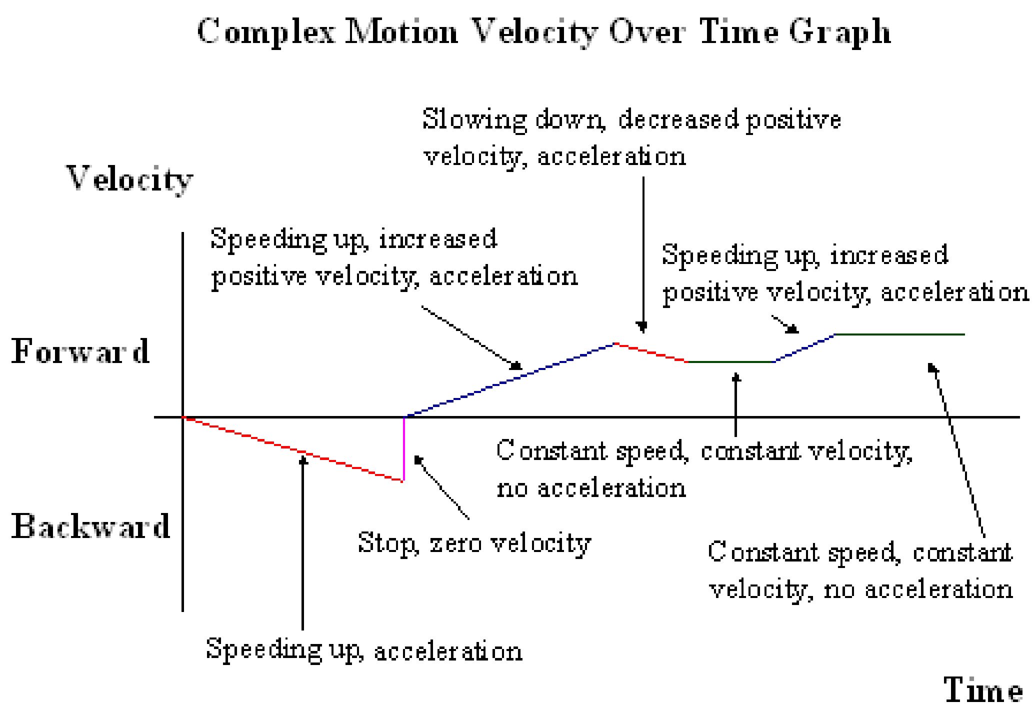
That is what I got!

Thus, while students did not actually view one another's strobe pictures, they had enough experience (watching the same video) and language (strobe pictures) in common to have a scientific dialogue and to support the growth of their online community.

Graphs of velocity over time: A more conventional representation of motion is a graph of velocity over time. Students in the course learned how to draw these graphs in the second session, after already having had experience with strobe pictures. The progression from verbal descriptions of motion, which they had shared in the first session, to strobe pictures, which they constructed in the second session and finally velocity over time graphs represents a move from more "common" descriptions of motion to more mathematical representations. This shift, however, did not undermine the community that had been forged out of highly personal descriptions such as the one above about diving. Rather, students continued and even increased their participation in the physics forum. This would not have been possible if they had not been able to share their graphs. While many online courses allow participants to share only text, we realized that without these shared representations, students would not be able to continue their scientific dialogue. Therefore, we provided students with PowerPoint as a drawing program and they attached their graphs to their posted messages. Given this tool, rather than a more constrained graphing program like Excel, students were able to continue to integrate their personal and scientific conversations.

For example, one student created the graph on the next page to describe a complex motion of an accelerometer on a cart. Notice her color-coding (if you are viewing this online!) and labeling of individual segments of the graph. In addition to the comments she wrote on the graph, Irene included the following text:

> I am not sure what would be negative acceleration and positive acceleration. I think that positive acceleration would denote an object that is speeding up, and negative acceleration would denote an object that is slowing down. I also believe that this holds true no matter what direction the object is traveling, but I am not positive about the conventions physicists use. If I am correct with this, then how is acceleration that takes place with negative velocity differentiated from acceleration during positive velocity? Or is it?????



The conversational tone of these remarks is obvious; this student was working out her thoughts about negative and positive acceleration in public, hoping to get some response from other students (or, rarely, one of the teachers). This message is the kind that occurs in a learning community, where a sense of trust has been built up among the participants. In fact, this student got many responses

Other fundamental physics questions arose as students attempted to create graphs that represented complex motions. One of the most hotly debated topics was how to represent motion that quickly changed direction. Here is a brief exchange between two students in Session 3, when they were working with velocity over time graphs for the second week:

> Jill: The line I found most difficult to interpret and draw was going from motion to a stop or change of direction. I noted your line for this movement is drawn vertical up to the "X" axis. Did you see it as an immediate change in motion? I drew a slanting line because I thought the motion was a change in direction and didn't involve a stop over time. At this point I'm not sure I'm being very clear but any help is appreciated.
>
> Irene: I see the vertical line on my graph as representative of an abrupt change in direction from negative velocity to positive velocity. Because this switch is so fast, that I feel is best represented as an immediate change, hence the vertical line. This makes sense to me because when I look at the motion of the cart as it changes velocities, I observe that it experiences a 180-degree change in acceleration! This is a substantial directional change, so I would expect it to be a very profound point on the graph. This is simply my understanding at this point, and I could very well be off track here.

Students also engaged in some "metarepresentational" thinking, in which they compared the information they could glean from a strobe picture with the information a graph provided:

> I liked that the strobe gave very specific variations in movement. I could see when the forward (or backward) speed changed, even slightly. The graph seemed to give more of an overall trend. The last motion graph that we looked at had a meandering feel to it, but it was hard to know what the specific movement

> variations were. The graph gave an organization to the movement. The strobe picture got very complicated quickly when the movements were linear and were back and forth. The graph gave a better way to visualize more complicated movements.

What role did these graphs play in supporting collaborative inquiry? These publicly shared representations took their power from a confluence of characteristics of both the graphs and the online space in which they exist.

- They required explicitness. A graphical representation forces a student to take a stand in a way that words do not. In drawing the graph above, Irene had to make decisions about the spacing between changes in motion, the slope of lines indicating change in velocity, the height of any line and the width of the entire graph. A verbal description would never need to or be able to include this detail. This is an important point for developers of online courses in any area where text alone is insufficient - which, I contend, is just about every area. One of the potentially negative effects of online courses is the "textifying" of communication; while the course material can include fancy graphs, video and sound, many courses limit students to text or Web-based objects which they can connect to. This is not a difficult technical issue; course delivery systems should include drawing and graphing capabilities as a matter of course.
- In the on-line environment, much of the communication is public - and graphs are no exception. Students attached their graphs to posted messages, which were read at least by the other members of their study group, if not by the rest of the class. This is actually different from what happens in an offline class, in which students are less likely to see and comment on one another's graphs or other scientific representations.
- Other students' comments were focused and shaped by the graph as a common referent. Rather than talking in general about "graphs of accelerating motion" or

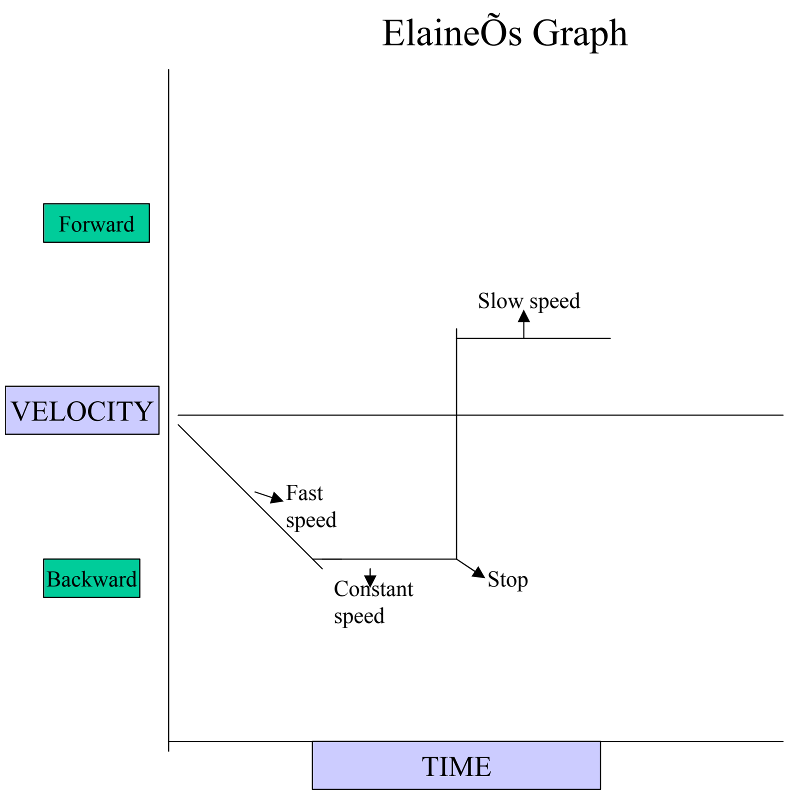
"the place where the ball stopped," students could refer with much more specificity to one another's graphs.

- Because these online graphs could be easily modified, students were encouraged to reflect on their graphs, incorporate feedback from other students and post a revised theory in the form of a new graph.

The following series of messages and graphs illustrates the kind of collaborative meaning making that these graphical representations can support.

E. posted this graph to the forum, with a short comment:

I think I did it! Hope it works.



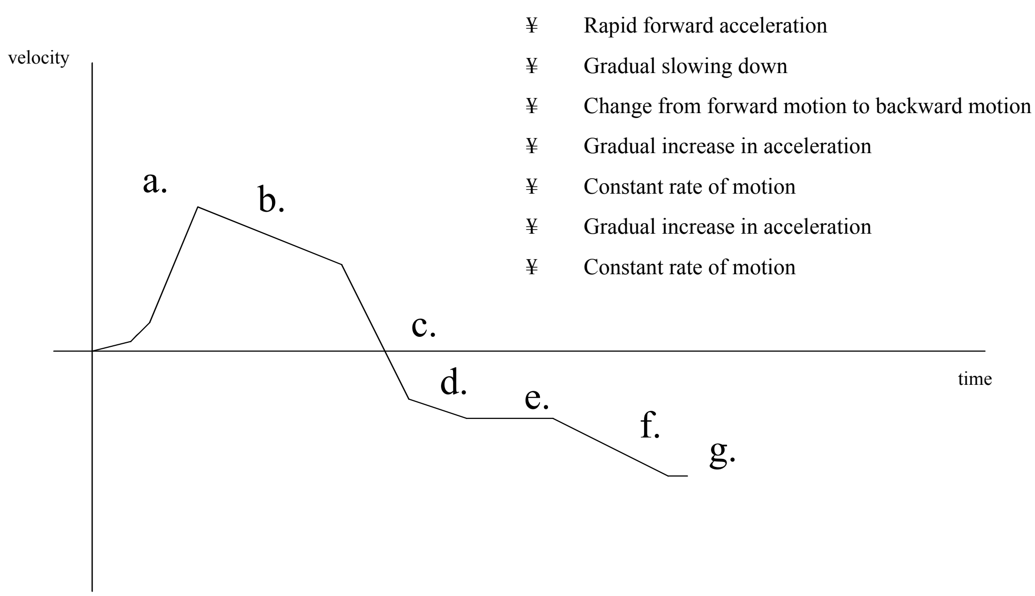
Then M. posted her graph, accompanied by the following message:

While graphing my strobe sketches, I kept getting confused over how I was to measure (graph) velocity. Should I factor in the length between each frame to determine velocity, or do I look at how much the cork is leaning to determine the velocity? We haven't talked about measuring the distances between each frame so I based my graph on the cork movement alone.

Another area I'm not sure about is the direction change of the motion. I feel somewhere there should be a graph point at o on the y-axis, because the forward motion stopped, so there is 0 velocity. But instead, the next graph point (taken from my strobe sketch) is below the x-axis.

All this being said, I gave it my best and can't wait to compare results.

MarieÕs Cart and Accelerometer Graph



M.S., who had been less than confident about her own graph, commented with relief:

Dear N., R., E. and M,. I am relieved to find our graphs look similar. I love to see the text directly place on your graphs, and will do the same on the next one. I found following the cork to be extremely difficult. Did any of you? I also found interpreting the movement to be difficult as well. For example, when the cart is pulled back to the other direction (backwards) I interpreted that to be a slanted line through the baseline of the graph. I see that N. and E. show it as a straight line through the base. Which is correct? S.

P.S. I did notice that E's graph is the opposite of my own. I assumed that E. saw the cart as moving backwards first, and then pulled forward, so I just looked at it backwards myself. Interesting interpretation, E.!

E. confirmed S.'s observation, noting that, indeed, a difference in assigning "front" and "back" accounted for their different graphs. In fact, this conversation about frontward and backward, as well as how to graph motion as it changes direction, were a theme throughout this and the next several sessions.

Through interactions such as these, graphs in the Investigating Physics course became objects to think with, a common representation (although this continued to be negotiated) and the source of a common language. These uses mirror those that graphs play in professional scientific discourse, as both shapers and products of scientific community. An intriguing continuation of this analysis would entail tracking the extent to which students converged on a common theory of the two seemingly most problematic aspects of representing motion: representing motion in two opposite directions, and representing motion as it changes from one direction to another.

References

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. Educational Research, 18, 32-42.

Collison, G., Elbaum, B., Haavind, S., & Tinker, R. (2000). Facilitating online learning: Effective strategies for moderators. Madison, WI; Atwood.

Graham, Charles et al 2000 *Teaching in a Web Based Distance Learning Environment*. Center for Research on Learning and Technology Technical Report #13-00. Bloomington, IN.

Kearlsey, G. (2000). Online education: Learning and teaching in cyberspace. Belmont, CA: Wadsworth.

Lave, J. & Wenger, E. (1991). Situated learning: Legitimate peripheral practice. NY: Cambridge University Press.

Ong, W. (1982). Orality and literacy: The technologizing of the word. New York: Methuen.

Palloff, R.M. & Pratt, K. (1999). Building learning communities in cyberspace: Effective strategies for the online classroom. San Francisco: Jossey-Bass.

Preece, J. (2000). Online communities: Designing usability, supporting sociability. NY: Wiley.

Smith, M.A. & Kollock, P. (eds.) (1999). Communities in cyberspace. NY: Routledge.