Bootstrapping a Community of Practice: Learning Science by Doing Projects in a High School Classroom

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Introduction

Researchers and theorists have extolled the promise of learning achieved through participation in the activities of a community of practice. Although he did not use the term "community of practice" in his seminal work *Mindstorms*, [Papert, 1980] described intergenerational learning that takes place in the preparation for a Brazilian festival. Experienced adults work with novice children on teams over an extended period of time, supporting learning and passing on expertise naturally through the construction of displays and the production of street theater. Similarly, [Lave & Wenger, 1991] describe how apprentice tailors gradually learn their craft by aiding master tailors in ever expanding portions of work they are hired to do. [Brown, Collins, & Duguid, 1989] have described the general processes of modeling, coaching, and fading as important means by which more experienced members of a community help novices learn to contribute to activities.

For educators interested in fostering meaningful learning in school classrooms, however, models such as the samba school and classical apprenticeships can seem frustratingly distant from any reality they face or can create. In this paper, I describe the "bootstrapping problem" for teachers interested in making novel approaches to teaching work in classroom communities of practice. Then, I briefly outline the school setting where this research was conducted, as well as my research methods. In the main portion of the paper, I explore a range of scaffolding strategies adapted to the school setting by one teacher, and the results and implications of his efforts to enable students to construct scientific inquiries. Two initial problematic strategies are examined. Then, a constellation of more successful strategies the teacher developed to support student learning are discussed.

The "Bootstrapping Problem"

For teachers' and students' daily work in high schools, the most salient community is found in the individual classrooms that change on a period-by-period basis. One obvious difference between traditional apprenticeship models and classroom communities is that the group which the teacher leads is entirely reconstituted at the beginning of each year. At any one time in an apprenticeship, most of the members of the community have some experience and a few are novices. In a high school class at the beginning of the school year, only one person in the classroom has experience in the specific practices of that specific class—the teacher. As one teacher put it, "when you start out a new year you have a whole new group of kids, and they have no idea what happened the last year."

Although the classroom group may be new at the beginning of the year, students are familiar with common school practices from previous years' experience. Thus, teachers who conduct their classes in the most typical fashion can take advantage of the shared experiences students already have, even though they don't know the students. Such teachers using the most "typical" pedagogy will have an easier time at establishing shared understanding of what is expected in the class than those whose pedagogy departs from the norm. Teachers who "swim against the flow" not only lack the shared understanding of how school works that more traditional teachers use—they must also actively *resist* students' assumption that the class is or should fit their accustomed model.

The lack of experts and the opposition to the standard culture of schooling create a unique problem for teachers leading reform-oriented classrooms: they must create an environment in which students can take actions to begin to "pull themselves up by their own bootstraps." Strategies for creating and maintaining such an environment are the subject of this paper.

The Research Setting and Methods

Rory Wagner teaches earth science using project-based methods in a high school where most science teaching follows a traditional "lecture-lab-demo" model. In the fall of 1992, Rory was introduced to the idea of conducting a project-based science by members of the Learning Through Collaborative Visualization (CoVis) project at Northwestern University. CoVis created a testbed of internetworked classrooms in which students, teachers, and other adults collaboratively conduct authentic scientific inquiry [Pea, 1993]. Rory became interested in students "learning science by doing science," rather than simply learning facts about what other people have done in science. For the past three and a half years, he has been trying to help his students to work together in groups on research questions that they have posed themselves. He wants his students to learn to work with scientific data, and use that data to support a claim about how the physical world works.

I will use data from a larger ethnography I am conducting on Rory Wagner's earth science class to describe the range of design issues and choices faced by educators interested in introducing project-based science to students in a standard format high school. Given the problems discussed above of creating a classroom community of practice outside the norm, I believe valuable lessons are learned from Rory's experiences.

I have been working with Rory during the past three years. During the first one and a half years I acted as an in-class technical assistant and interested research colleague, and in the subsequent one and a half years I have acted as a participant observer specifically conducting this study. My participation in the class during the study has primarily been in the form of conversations with students and teacher about the progress of their work and plans, but it has also included sharing knowledge and advice on issues related to the use of computers and the Internet. My participant observation during the 1994-95 and 1995-96 school years (completed in February) has included half-time attendance at one of Rory Wagner's Earth Science classes, recorded with handwritten field notes and periodic videotaping; four formal and more than 50 informal interviews with Rory about his history of project teaching, issues of running a project-based classroom, and the guidance of specific student projects; two formal interviews with each of six students in the class being observed in 1995-96 about their understandings of and reactions to project-based science; and informal interviews about ongoing project work with all students in classes I observed during both years of the study. My analysis also includes handouts created by Rory, written assignments created by his students, and written feedback on those assignments given by Rory.

Setting the Students Free

Rory Wagner, a teacher for nineteen years, tried many variations of the standard science class format of "lecture-lab-demo." He "really hadn't been feeling for a long time that lecture-lab-demo was the way to go" and for the first time saw a viable alternative in project-based science. He was so eager to try the kind of new ideas he had been reading about physics teachers trying in the LabNet book [Ruopp, Gal, Drayton, & Pfister, 1993] that he altered his curriculum and instruction in midyear. The question was, where and how should he begin? He was convinced that "if students are involved with doing things that they pick and design, they're more apt to be ... more energized by that, and take more interest in and ownership in it" as opposed to cookbook labs and lockstep textbook and lecture learning. But he wasn't sure how to "describe [projects] to them without telling them exactly what to do."

So in the late fall of the 1992-93 school year, Rory stopped giving lectures, reading assignments, tests and "cookbook" labs. Instead, he assigned students a quarter-long, open-ended project with no formal requirements other than originality. He himself had only a vague sense of what he wanted his students to accomplish, but felt they would enjoy the freedom. As he tells it:

> "I thought that I was setting them on top of Mount Everest and saying 'look, the whole world is here for you to look at. Isn't that great? Look what you can study.' ... And they felt like 'Oh my God, I'm gonna fall, I could die up here, this is horrible, I'm gonna freeze to death, I'm gonna fall off the mountain.' ... I thought I was setting them free and they felt like they were being abandoned."

Rory's initial swing away from teacher-directed pedagogy to a student-directed version is well-described in a study by [Rogoff, 1994]. As Rogoff describes, lecture-based classrooms depend on transmission of knowledge from an active teacher to a passive learner. In contrast, unguided discovery depends on acquisition of knowledge by an active learner with the teacher remaining passive. However, the model of community of learners "is based on the premise that learning occurs as people participate in shared endeavors with others, with all playing active but asymmetrical roles." (p. 209). Since that first frustrating project in his class, Rory Wagner has been designing and refining *his* unique role of structuring and guiding student activities in the classroom so that they can learn to conduct scientific inquiry.

Modeling projects

In the literature on cognitive apprenticeship, *modeling* is discussed as an important aspect of how experienced practitioners can help novices learn new skills and ideas [Brown, Collins, & Duguid, 1989; Collins, Brown, & Newman, 1989]. In the 1993-94 and 94-95 school years, Rory implemented a form of modeling projects that he eventually decided did not meet the desired results.

Since students had never conducted projects before, it seemed that leading them through a whole-class project of his own design would provide them an opportunity to "observe and build a conceptual model of the processes that are required to accomplish the task" [Collins, Brown, & Newman, 1989, p. 481]. These model projects were completed before the first student-designed projects were begun. In the first year, he directed the students in mapping and measuring the size and extent of a local sand beach, collecting historical maps and data, and analyzing how the beach had eroded and changed. In the second year, he directed the students in collecting data on the size, texture, and composition of the sand grains from different beach locations and environments.

Each of these model projects included students working on vital parts of the process, such as systematically collecting and organizing data, and creating graphical representations of the data. In Rory's appraisal, these model projects did not motivate the students.. The projects fell into the same kind of trap traditional labs do—students never took interest or ownership, and were able to go through the motions without thinking. Students' lack of engagement in the model project prevented them from building a "conceptual model" through which they could learn and remember the parts of the process in subsequent projects. During the 1995-96 school year Rory decided to forgo complete model projects and rely instead on modeling subskills and scaffolding support for the students in the midst of the projects that they direct themselves.

Giving the Students Raw Materials and Glimpses of their Crafting

The 1995-96 school year is the fourth in which Rory Wagner has been teaching using projects. He currently employs a constellation of scaffolding strategies to help students learn how to conduct science research projects. Not only are most students entering Rory Wagner's earth science class unfamiliar with the project-based method; most of them are unfamiliar with the subject matter of earth science. This relates to the tug-of-war many teachers experience between balancing "content" and "process." Rory said, "There are 2 parts to what scientists do: the body of knowledge, and how they go about getting that knowledge. Most classes concentrate on just the body of knowledge. In this class, I'm more interested in the process—how you go about getting knowledge." Nonetheless, in order for students to get started on building their own research projects, they need some raw materials. Specifically, to design and conduct in-depth projects on earth science questions, they must have some basic familiarity with the scope and issues addressed by geology, meteorology, oceanography, and astronomy. Thus, Rory includes a series of lectures and films primarily concerned with the "body of knowledge" that constitutes earth science.

However, this preliminary work is also concerned with the crafting of those raw materials in the "process" of science research. For example, Rory showed a video which described Halley's comet through the history of how the comet was discovered and it's return predicted by increasingly accurate models. After stopping the video, he emphasized the process of work conducted by a scientist in the video: "Yeoman came up with a model. That's what scientists do ... He used supporting data to prove that his model was correct."

As evidenced through student interviews and classroom observation, lectures and videos have provided Rory's students (1) an awareness of the topics in earth science so that they are better prepared to choose one for their later projects, (2) a familiarity with the basic terminology that is beneficial in students' initial project research on their chosen topics, and (3) an inkling of some of the crucial aspects of the process of science. Even though this approach is promising, its effectiveness is limited by common problems associated with lectures and videos. In interviews, students mentioned their own tendency to disengage from these traditional presentations. They explained that their interest and engagement increased later when they were doing projects. Lectures and videos at the beginning of the year also tend to make the class seem like "business as usual" in school. This can undermine the points made during lecture leading toward the teacher's ultimate goal of students doing scientific inquiry themselves. Despite these weakness, lectures and videos may be the best choice for teachers moving toward projects, especially if they include interactive discussions.

Providing a Structure on Which Students Can Build

Giving students an overall "conceptual model" of how projects can be conducted remains a necessity. Rory achieves this in part through a written project paper format adapted from two other CoVis teachers at his school. The process includes the following milestones: (1) choosing a group to work with and a general research topic, (2) collecting and writing up background information on the area of research, (3) submitting a research proposal which includes a research question and methods for addressing the question, (4) collecting data to answer the research question, (5) analyzing the data to answer the question, and (6) submitting the final paper with the previous sections and a conclusion and abstract.

The format of the paper gives students a framework to structure their work, so that they are not cast completely adrift for ideas on how to proceed. Having the students turn in milestones has the additional benefit of breaking down a long ten-week project into manageable increments. At the same time, the format challenges the students to come up with their own questions and ways of addressing them—as Rory told the students when he was introducing the projects, "I'm trying to get you to solve problems, but *you create* the problem." It provides a framework for the students to work and thoughtfully engage in. As one student put it,

> "In [classes with traditional labs], it doesn't really teach you anything about what scientists really do. 'Cause scientists don't sit there with, like, an instruction manual. They kind of, like, figure stuff out ... So this is more of us ... coming up with our own questions, our own theories ... And having to do the research and having to get the statistics to back up the research ... And so, I have like a better understanding of what people actually do, instead of 'nice experiment, kid.'"

However, using the project paper format as a framework for conducting projects had not been without problems and pitfalls. In past years, the most problematic aspect of projects proved to be the selection of a research question. Rory originally expected students to turn in a research question as the first milestone, *before* doing background research on a general topic. But he found that students with little previous background were simply unable to come up with much beyond what [Scardamalia and Bereiter, 1991] term "basic information questions," such as "why does a comet revolve around the sun?" In order to come up with more ultimately productive "wonderment questions" such as "how does a comet's core size affect its tail size?" students needed a little more background on the topic area than they typically had. Therefore, Rory adjusted the milestones such that Step 1 did not include deciding on a research question, but instead a general topic area which students then collect background information on in Step 2, and *then* come up with a focused research question based on their newfound knowledge. The other problems with the project paper format as a framework are yet to be solved. One is that the framework can become too much like a template. Rory concurs with researchers such as [Feyerabend, 1993] who demonstrate that any one process is not definitive of how all science is or can be done. But even though Rory doesn't want the framework to be restrictive of students' creatively approaching problems, students who want the best possible grade may prefer to take the path of least resistance.

Coaching Students in the Course of Inquiry

Rory's work is far from done after providing students with a basic framework. He supports students in many ways during their projects, most of which can be considered aspects of coaching.

Appropriation

In Rory Wagner's class, a "project" has a particular meaning, but students usually come in to the class with other meanings for projects that do not match the goals Rory is striving for. In Rory's class, he wants students "to ... observe some scientific phenomena, take measurements or collect information on it, and try to come to some conclusion about how it worked." Students confirmed that in other classes, projects simply referred to extended group work, but the question was often supplied, and students were required to collect information from library books and summarize it. They were reporting what others had already explained about a phenomenon.

Despite its limitations, Rory recognizes the kind of work students are already familiar with can be a building block for the research that he intends. He uses a process of *appropriation* [Newman, Griffin, & Cole, 1984;

Pea, 1992], which refers in this case to seizing meaning and transforming it through conversation. For example, a group of students chose the plesiosaur, a dinosaur resembling a sea-faring brontosaurus, as their topic, because they found it interesting and "cute." In the process of doing their background library research about the plesiosaur, one of the group members, Susan, discovered a problem. "Mr. Wagner," she said one day, "Do you know whether the plesiosaur moved by rowing its flippers or flapping them like wings? These books don't agree." Rory told her he didn't know, and asked to see the books. It turned out that one book claimed the plesiosaur swam by a rowing motion, and the other claimed it was essentially "underwater flight." But neither mentioned the other possibility. Susan's intention when she went to Rory was to get *the answer*, assuming it was a simple fact. A fact is all she would have wanted for a library research report. But Rory helped her fit the issue into a science research process to which *she* could contribute, when he interpreted her query as a potential research question. The question could be "Do plesiosaurs swim by rowing their flippers or underwater flight?" Although Susan hadn't yet realized it, *they* could look for evidence to support a claim about the answer. Rory's interpretation did not match Susan's, but it allowed him to scaffold her into the activity she had not yet learned, and perhaps extend her own interpretation of what questions arising from literature review imply.

Providing Feedback to Students

Another form of coaching that Rory Wagner performs daily includes evaluating students' actions and products. One of the ways Rory provides feedback that scaffolds his students into a better understanding of how to "do science" involves negotiating the topics and questions the students work on. Allowing the students to choose their own topics and define their own research questions turns out to have significant motivational benefits attested to by both the teacher and his students. But Rory must find ways to help students transform and channel their initial interests into productive scientific investigations, without taking away the need for them to think, and without taking ownership of the process from them. Because of the need to balance these goals, Rory sometimes makes strong suggestions about paths the students are considering, but leaves the ultimate decisions about what they choose to them. Leaving these decisions ultimately to the students does not mean that they are completely free, of course, because of the authority the teacher holds and the fact that the teacher assigns grades.

Students are most frequently attracted to topics that are spectacular, threatening or destructive. While some of these topics such as earthquakes, volcanoes, hurricanes, and tornadoes often lead to interesting and productive projects, others have proven problematic time and again. The most frequently encountered problematic topic is worth mentioning: aliens and UFOs. Rory made the case with several project groups (3 out of 11 groups in the class wanted to do something about aliens) in the 1995-96 class that such projects tended to degenerate into empty rhetoric about the government covering up files, with no data to use for an analysis. After these discussions of the problem with projects on aliens, one of the groups switched to another topic. Two groups decided to try and make something of the topic. One of the two groups encountered the expected problems and concluded in their final paper that "there is not enough 'real' information" to prove anything," but the other group managed to develop an unexplored angle. The students pointed out that the government had published a document in the 1960s explaining away many UFO sightings through understood events such as meteor showers, the aurora borealis, and airplanes. In a discussion during class, Rory suggested they take a cue from this strategy, and try to prove the government wrong by attempting to replicate their findings, or using similar methods to explain recent sightings. Such a sequence of events required Rory to entrust his students with more control over their own learning than is customary.

Rory also offers feedback in written form. When students turn in milestones and drafts of their papers, Rory makes detailed comments and suggestions on the text, and also assigns numeric grades to portions of the paper. In some cases, perhaps due to students' unfamiliarity with the process of writing and revising drafts, students fail to respond to Rory's feedback on their interim papers. In cases where Rory tries to ensure students will act on his comments, he has had more success when the students are given notice with the lowest grade possible. For example, in order to make the distinction between simply collecting the findings of others, and coming to one's own new findings, Rory has found it useful to focus on whether or not students have data and analysis. Data in earth science is often in the form of numbers or charts of descriptive categories, and analysis in the form of graphs or visualizations. He has found that many students think they have data, but have little they can analyze to answer their question. For example, the group who researched plesiosaur locomotion initially had little data from the fossil record to support their claim that plesiosaurs swam by flapping their wings like birds. They cited modern-day sea turtles in their report as swimming with the same motion, however, and Rory pushed them to find skeletal records on these turtles to use in a comparison and bolster their case. In other cases, students have voluminous data and make graphs of every conceivable variable, but form no coherent argument with the graphs. Rory offers such groups commentary on shortcomings, and suggests ways of focusing and organizing their analysis. All the written work and the discussion it spurs provides an opportunity for Rory and his students to come to a mutual understanding about what they have done and where they could go.

Learning from the Archives of Student Work

In addition to the means documented above to scaffold students into a new classroom community of practice, Rory has attempted to carry what he can of the community from one year to the next. The legacy of previous years' classes to an incoming class is the archive of student project reports. Rory makes the archive available for reading and reference. Students initially used the archive to mine for project ideas and get a sense of how projects are done. Later, when students were getting ready to turn in their research reports, Rory gave them an example of a particularly good research report from another student group. The example helped the students to understand how they should write up their results, in a way that his descriptions of the report could not. As one student put it, "I found that it really helped me see what he wanted, 'cause I had all the information ... I just didn't know how to put it in the right form." Although useful in the current undocumented form, students have pointed out that commentary and assessment of more past projects from the teacher would be helpful.

Conclusion

Although project-based teaching like Rory Wagner's is not widespread in schooling today, it is a method with a long history and theoretical appeal from John Dewey [Dewey, 1902] to recent work on apprenticeship learning [Lave & Wenger, 1989]. Many educators are interested in creating environments where students can learn by working on projects, but it is a complex task. Educators unprepared to help students "pull themselves up by their bootstraps," and extend beyond the students' preconceived notions of schoolwork developed in other classes may become frustrated and return to more familiar ways. Unfortunately, this is far too often the case [Cuban, 1986]. The ideas presented here are intended to serve as frames [Schön, 1983] and sources of inspiration for other educators to use in their own planning and implementation of reform efforts.

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