Patterns of Student Collaboration and Reflection

in a Sustainable Culture of Learning through Design
Abstract

This paper addresses the role of students in creating a sustainable classroom culture of learning through design, a technology-rich science inquiry curriculum. Existing research suggests that one of the challenges for teachers in persisting with innovations such as learning through design is their difficulty scaffolding students’ transitions into technology-supported and open-ended activities. This study examined two mixed-grade classes of 4th-5th grade students and focused on the ways in which older students with previous experience in this curricular approach took on many socializing functions, effectively apprenticing younger students into the practices of learning through design. Within this environment, we also examined emergent collaborative patterns among students and the affordances of those patterns for effective learning. Individual interviews with all sixty-three students in the project revealed that both fourth-grade and fifth-grade students were highly reflective about their respective collaborative roles, and that experienced students benefited as much, if not more so, than inexperienced students from this arrangement. Our results have implications for existing research and practice in collaborative learning and project-based technology-integrated curricula, and also for theory and scholarship on children’s roles within learning communities.
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Project-based learning is a highly promising kind of learning environment, in which
students engage in collaborative, technology-integrated, sustained inquiry (Blumenfeld,
Soloway, Marx, Krajick, Guzdial, & Palincsar, 1991). Yet despite recommendations by
standards movements and national organizations (National Council of Teachers of
Mathematics, 1989; National Research Council; 1995), this sort of curriculum still represents a
significant departure in practical terms from the traditional norm for most students. In fact,
research reveals that the first project-based unit students experience is often the most difficult,
given students’ unfamiliarity with inquiry practices, tools, and ways of thinking (Kolodner, Hmelo,
& Narayanan, 1996). This unfamiliarity represents a significant challenge for teachers. Those
who want to implement project-based learning must guide new cohorts of students every year
through the rough terrain of building these expectations and understandings. To address this
challenge, this article presents a sustainable classroom culture of collaborative learning through
design, a particular type of project-based curriculum, wherein fourth and fifth-grade students
perform among themselves many of the socializing and guiding functions for which a traditional
teacher is usually responsible.

Describing the nature of students’ collaborative experiences in socializing and guiding
one another through the design process is no small matter, however, which brings up the other
goals of this article. Systematic studies of collaboration in open-ended, project-based
environments are rare (Cohen, 1994), and rarer still are those which not only document student
collaborative behavior but also consider students’ perspectives on their experiences. This study set out to address both these goals through qualitative analysis of video footage of two classrooms’ daily learning through design student collaborations and videotaped interviews with every student in the project (n = 63) about their experiences. In this paper we describe our sustainable classroom culture of learning through design, the means by which children socialize one another in specific behavioral terms into the process and skills of this complex curriculum, and children’s reflective understandings of their own experiences. We conclude with implications of our findings for teaching and designing project-based learning environments, for interpreting the roles of children in community participation, and for further research on student collaboration in open-ended contexts.

**Review of Research**

The classroom community we worked with and studied was engaged with a particular approach known as learning through design. Learning through design is part of the larger family of project-based learning, and is based on a model in which students simultaneously learn new information and design a relevant product reflecting their knowledge (Harel, 1991; Harel & Papert, 1990; Kafai, 1995). In our projects students simultaneously learn science content and use Logo Microworlds™ object-oriented programming to create educational software products aimed at younger users. Previous efforts in this vein have been situated in mathematics, specifically fractions, (Harel, 1991; Kafai, 1995), and several areas of science, including astronomy and neuroscience (Kafai & Ching, 2001; Kafai, Ching, & Marshall, 1997).
Researchers who develop and study project-based and design-based learning environments have articulated the need for students to engage in authentic tasks (Brown, Collins, & Duguid, 1989), create meaningful artifacts and use technological tools (Blumenfeld, et al., 1991; Kafai, 1995), iteratively revisit their designs and ideas (Kolodner, Hmelo, & Narayanan, 1996), and reflect on their own learning processes (Edelson, 2002). Studies have documented how students construct meaning through inquiry discourse (Kafai & Ching, 2001; Roschelle, 1996), master authentic and sophisticated scientific tools (Edelson, Pea, & Gomez, 1996), and use data to make predictions and marshal arguments (Bell, 2004; Sandoval, 2003). Existing studies have also demonstrated that students engaged in learning through design can make significant learning gains over matched cohorts of students learning via traditional classroom methods (Harel & Papert, 1990; Kolodner, Camp, Crismond, Fasse, Gray, Holbrook, Puntambekar, & Ryan, 2003)

While the project-based family of curricular approaches holds much potential, research reveals that it is sometimes difficult for teachers to adopt or persist in these innovations (Kolodner, et al., 2003). Teachers and students can become so focused on learning the procedures and mastering the technologies of design projects that they lose track of the scientific content to be learned (Hmelo, Holton, & Kolodner, 2000). Various technology tools and “ramping up” units have been designed by researchers to assist students and teachers with these new ways of thinking and doing (Kolodner & Nagel, 1999; Reiser, 2004). We want to argue here, however, that an alternative means of supporting project-based learning is to create a sustainable learning culture, in which experienced students scaffold new students through collaborative learning.
Student collaboration has been a focus of research on project-based learning for many years. The literature contains analyses of successful and synergistic collaborative designs (Roth, 1995), rich student discussions (Brown & Campione, 1994), gender differences in collaborative tasks (Ching, Kafai, & Marshall, 2000), and long-distance student collaborations via telecommunications (Songer, 1996). Barron, in particular, has recently tackled the critical topic of how student groups begin the inquiry process and collaboratively determine strategies for project-based work (Barron, 2000; 2003). The kind of peer-to-peer helping we describe here has not been investigated before, however, in either project-based research or the traditional collaborative learning literature.

Educational research for the past 25 years contains a rich body of empirical studies on collaborative learning in the classroom and the laboratory. Questions addressed included: how well did collaboration work compared to learning alone (Johnson & Johnson, 1974; Slavin, 1983), what sorts of students sought help and gave help when it was needed (Ryan & Pintrich, 1998), what student status characteristics contributed to their collaborative roles (Cohen, 1982), and how different interactions during collaboration were linked to learning outcomes (Webb, 1989). Researchers evaluated whether it was better to assign strict roles and protocols to students working together, as in peer tutoring (Swing & Petersen, 1982; King, 1993), or better to not confine them but rather teach all students how to effectively ask for and give constructive help (Webb & Palincsar, 1996). Help-giving and help-receiving has certainly received attention in this research; however, the tasks in which students have been involved in these studies are typically short-term problems. Largely, students in traditional collaborative learning tasks give and receive help with obtaining right answers, rather than with mastering learning practices for
long-term engagement; thus their results are not directly transferable to a project-based environment. We draw on this literature for informing what behaviors we might expect to see, however, in our examination of peer socialization in learning through design.

The work on apprenticeship learning addresses the role of previous experience in students’ collaborations (Lave & Wenger, 1991; Rogoff, 1993). The most prominent approach is cognitive apprenticeship as a model for K-12 teaching in academic domains (e.g., Collins, Brown, & Newman, 1989; Scardemalia, Bereiter, & Steinbach, 1984). Other studies in education have opted for placing students in laboratory apprenticeships with practicing scientists (Hay & Barab, 2001; Richmond & Kurth, 1999; Ritchie & Regano, 1996) or appropriating scientists’ tools for use in classroom communities (Edelson, Pea, & Gomez, 1996). In all these diverse efforts, however, there is one constant: teachers and scientists are always placed in the role of experts, and students are always beginners. At no time are students configured as experienced collaborators in the learning contexts and cultures they inhabit. Within this context the learning through design project also offers a viable alternative to the apprenticeship models that have been the staple of most educational implementations.

In addition to the role of collaborative experience in socializing and guiding one another into learning through design, there is the issue of student perspectives. Traditional collaborative learning research rarely queries students’ perspectives on their own experiences (c.f. King, 1993). Additionally, all too often research on apprenticeship uses participant interviews as a means of informing an ethnographic framework or providing textual support for researchers’ assertions; however, participants’ voices themselves are rarely given full treatment in the final publications. Hodges’ (1998) critical and insightful reflection on her own failed apprenticeship
into early childhood education illustrates the importance of first-person narratives in understanding the experience of participants in communities of practice. We are not aware of any larger scale studies, however, which critically investigate and present an entire community of first-person narratives.

Our work focuses on children as both beginners and experts collaborating in the learning through design project. The classroom teacher and researchers in this study do not function as the resident experts but only facilitate the overall curricular intervention. This study will thus be able to examine multiple aspects of children’s collaboration in project-based learning, in how they work with inexperienced peers, and how students’ reflections of their own interactions and experiences contribute to a sustainable learning culture.

**Context and Methods**

**Participants**

Two classes of fourth and fifth grade students, located at a laboratory school in a west coast urban area, participated in this study. Both classes were taught by the same teacher using the same curriculum activities. The focus classroom contained 33 students: 16 fifth graders and 17 fourth graders. All of the focus fifth grade boys (n = 9) and girls (n = 8) participated in a software design project on the brain during the previous year (see Kafai & Ching, 2001). The 15 focus fourth grade boys (n = 9) and girls (n = 7), on the other hand, had no previous experience with long term inquiry in learning through design. The comparison classroom contained 30 students: 15 fifth grade boys (n = 8) and girls (n = 7) and 15 fourth
grade boys (n = 10) and girls (n = 5). The main difference between the focus and comparison classrooms is that none of the comparison students had previous experience with learning through design. Comparison fifth-graders had, however, approximately three weeks of exposure to the programming environment used in this study during the previous year. (This distinction between the fifth graders in both classes in terms of previous participation in the culture of learning through design versus limited technical knowledge becomes crucial later on.) Ethnic breakdown of the children in both classes was as follows: Caucasian=30, Latino/a=14, African American=8, Asian=6, and mixed ethnicity=5. We selected these two classes for our study because they had the same science teacher; she had worked with us on previous design projects.

The focus class had nine mixed-gender teams which each included at least two experienced fifth graders and two to three inexperienced fourth graders; the comparison class has also nine mixed-gender and mixed-grade teams with similar distributions. The teacher and researchers decided on the composition of teams for each class according to principles of best practice: ensuring a balance of gender and experience among team members, as well as attempting to avoid known personality clashes within teams.

**Classroom Setting**

The classroom for focus and comparison students featured eight computers distributed within clusters of desks throughout the room; two more computers were located on the sides of the room, not designated for any particular workstation, but rather for general use. All computers were Power Macintosh with Internet access and assigned hard disk space for students to save
their design work in team folders on a daily basis. A big-screen television monitor, a whiteboard, and a rug area were located at the front of the classroom. Colorful bulletin boards displayed a mural of ocean animals and fish along the length of the far wall. Each team was assigned a computer with surrounding desks as their work station.

**Curriculum Activities**

The project started for both the focus and comparison class with an inquiry component, in which students posed individual questions that interest them within a curricular topic. The topic for the project reported here was marine biology. Some student-generated questions included: “how do tidepools work,” “how do whales in pods cooperate,” and “why do fish swim in schools?” Students were also introduced to the software design environment, Logo Microworlds™ in three sessions in which they learned the interface to use text and graphics for creating a food web presentation. Students then conducted information research to answer to their questions via on-line and print resources and outside experts, and they programmed simulations that displayed what they learned about their questions (see figure 1 for a screen capture from a student’s whale simulation). But these activities did not all occur in linear sequence. The iterative cycle of question posing, research, design, programming, and continued research and revision is one of the hallmarks of design learning (Perkins, 1986).

<insert figure 1 about here>
A planning board consisting of three panels was used by each team to keep track of screen ideas, allocate computer time, and printouts from information searches (see Marshall & Kafai, 1998 for a more extensive description). The teacher conducted whole class sessions with students introducing and discussing particular aspects of marine biology such as habitats, different life forms, and food webs. She also met with individual students and teams to review their research questions and provide feedback and pointers to relevant information sources. This project-based unit took approximately ten weeks to finish.

Scheduled throughout the project were demonstrations and usability testing sessions that focused on presentation and evaluation of teams’ software products. In the demonstration sessions in weeks 3 and 7 of the project, all teams gave an approximately five-minute presentation to the rest of the class, in which they walked through what they had programmed so far and asked for feedback from the teacher and their classmates. Usability testing sessions in weeks 4 and 8 brought in third-grade students and provided an opportunity for students to test the pedagogical value of their products; that is, to see if third-graders actually learned anything from their simulations. In preparation for this event and in the discussion process after the third-graders left, students in the marine biology project process “user” reactions and turn user comments into constructive suggestions for product development.

All of these activities together — the use of planning boards and creation of instructional software designs, classroom and team sessions with the teacher, and the usability and demonstration sessions conducted by students — constituted the curriculum of the learning science by design project.
Data Collection and Analysis

We used several qualitative and quantitative methods to document classroom activities and team interactions and interview students about their project experiences. In the following sections, we describe those procedures and instruments that pertain to the analyses in this paper.

*Classroom and Team Observations.* Two video cameras and two remote, wireless microphones were used to collect the data for the investigation of collaboration patterns. Two teams were videotaped and recorded each day for all ten weeks as they collaborated at their workstations, one with each camera and microphone. The camera captured all activity at a given team’s workstation: all programming and other work on the computer, drawing or reading research material at the adjacent desk space, and working on the planning boards. In addition, we kept daily field notes documenting classroom activities and discussions with students.

Our main focus for this article was the everyday team interactions during the crucial “middle” phase of the marine biology design project, weeks 3-6. During this middle phase, all students were supposed to have completed their initial inquiry research on their questions, although some additional research was necessary later in the process for some designers, and most teams had finished their introductory screens (table of contents, title screen, etc). Students were then supposed to begin work designing and programming their individual simulations that would address their inquiry questions and teach third-grade users what they had learned. The combination of independent and collaborative work that occurred during this time, with all students ostensibly having a high degree of ownership over their own simulation
ideas yet fourth-graders needing help with manifesting their design screens, made these weeks particularly fruitful for this analysis.

We used a combination of qualitative methods to create a descriptive framework for the collaborative patterns that emerged. Erickson’s (1992) method for microanalysis of video was used to create video annotations and a comprehensive list of the kinds of fourth-fifth grade collaborations we saw. We were interested, however, in not only documenting various kinds of peer-to-peer helping but also tracing trajectories of interaction and the flow of collaboration. After the list was created, we drew on grounded theory (Strauss & Corbin, 1998) and hermeneutic phenomenology (see Laverty, 2003 for review) to develop what ultimately emerged as a descriptive flow-chart of the progression of helping practices in collaborative episodes. The hermeneutic methodology is meant to facilitate an understanding and interpretation of our video data by creating a conversation between the collaborative patterns contained in the footage—the helping practices that are revealed in individual episodes as well as within and across groups—and our own researcher perspectives that are situated in traditions of sociocultural, constructivist, and constructionist perspectives on educational technology and classroom practices. Thus while the results of our video analysis are highly grounded in the data, as is consistent with grounded theory, our interpretation and organization of those results are necessarily colored by the theory and practice that informs our work. Since the framework that arose from this process is a result, rather than a coding scheme or rubric, it will be described in the next section.
Interviews. At the end of the project, debriefing interviews were conducted with all students. Students were asked the following three questions that gave them opportunities to reflect on their own situation as well as that of students in the other grade level: (1) Can you think of any differences between fourth and fifth graders in terms of how they worked on the simulation design project? What are they? (2) What does it mean to be a fourth grader working on this simulation design project? And (3) What does it mean to be a fifth grader working on this simulation design project? Focus fifth-graders are distinct in that when answering the second question, they can draw on their own experiences as a newcomer to design during the previous year, in addition to reflecting on the perspective of fourth graders in the current project.

One might wonder why these three questions were designed in such a seemingly vague manner, when research has demonstrated that more structured clinical interviews designed to support reflections on metacognitive properties of learning experiences can affect students’ content understanding (Ackerman, 1995; White & Frederiksen, 1998). In this analysis, rather than prompting students to talk about specific issues, we wanted to find out what skills and practices they would spontaneously mention when considering the nature of experience in learning through design. The focus here is not only on how fourth and fifth-graders conceive of design “experience” as a property of individuals, but also their awareness of how this experience comes into play in their design collaborations with others. Lave emphasizes the importance of attempting to “locate learning throughout the relations of persons in activity in the world,” (1996, p. 27). It is this directive that influenced the choice here to ask students to reflect not about skills or competencies in the abstract, but on the different ways of knowing and doing.
exhibited by individuals with varying amounts of design expertise as they worked in the design project.

All interviews were conducted by the authors or a graduate student who had been present in the classroom weekly throughout the project; thus, students spoke candidly to interviewers with whom they were already acquainted and who were also participant-observers in the design classroom. The interviews were videotaped, transcribed, and analyzed using interpretive methods to create an emergent coding scheme reflective of the variety and complexity of student responses. This scheme was then used to code the entire corpus of interviews, and counts were made of students’ breadth of understanding in their discussion of various aspects of the project experience. These counts were then used in an analysis of variance to determine statistically significant differences among students at various levels of experience with learning through design and programming.

Results

Patterns of Student Collaboration

The community features described earlier provide opportunities for socialization among students with varying levels of experience. Equally important as these occasional events, however, are the everyday practices students engage in as they work on their design projects. It is to these everyday collaborations that we now turn to investigate how students interact with one another within this classroom community. Following is an example of the kind of interaction we examined for this investigation.
Sarah, a fourth-grader on team four, is sitting alone at the computer at her team’s workstation. She is working on her screen about sharks, which uses a submarine to navigate through the water, while fifth-grader Daniel (also on team four) talks with members of team six. Daniel leaves his discussion with team six and walks behind Sarah to observe what she is doing on the computer, just as Sarah opens up an object command window and begins to type a procedure that will animate the submarine she drew earlier.

Daniel: What are you doing?
Sarah: I want this [the submarine] to float down to the bottom, like this. ((drags the submarine down with the mouse)) Then the shark will come along!
Daniel: Why are you typing it in the window?
Sarah: Ummmmmm. . . . What?
Daniel: It’s easier if you use the procedures page.
Sarah: ((looks at Daniel quizzically, says nothing))
Daniel: That way you can make it a bigger procedure for the shark too.
Sarah: Oh. So I can do it all at once? ((long pause)) Well. . . where do I type it then?
Daniel: Click here ((pointing on the screen to the icon for procedures)), and write it there. Use a “wait,” and then write what you want for the shark after.
Sarah: Okay. ((clicks on procedures)) Where should I write it?
Daniel: Well you can, I mean, anywhere, really. But let’s put it on the bottom, because it’s new.
Sarah: Okay. ((voice-over as she is typing)) “Tooo shaaaark…”

In the sequence above Daniel points out for Sarah the difference in Logo Microworlds between programming objects using their command windows, where only short command strings can be entered, and programming using the procedures page, where the designer can write longer procedures and link them together (separated by “wait” commands) to control
multiple objects at once. Procedures page programming represents a more sophisticated level of skill than embedded object programming, a leap which Sarah might not have attempted without Daniel’s guidance. The discussion begins with Daniel questioning Sarah about her goals for the animation and then suggesting a fundamental change in Sarah’s approach, a strategy which ultimately results in a more sophisticated solution to the problem. This interchange and its question-suggest format bears some resemblance to the conversations documented by Schön in his examination of novice/expert relationships in the architectural design studio (1986). The discussion between Sarah and Daniel contains several different kinds of peer-to-peer helping, and we will return to it as an example after the framework is presented.

In creating a framework of interaction patterns for the focus class, a dichotomy of team organization was revealed. In both classrooms, team interactions seemed to be structured in one of two broad ways: clustered work or independent work. Clustered work describes a pattern wherein all or the majority of team members hover around the workstation computer and contribute physically or verbally to screen creation. In independent work, students in a given team simultaneously perform different activities such as programming, researching, working on the planning board, and drawing screen ideas. Independent team members are within earshot of one another, however, and are often at the same workstation while doing these different tasks, so communication and collaboration among members still occurs. Initially, we decided to look at these two kinds of groupings and their constituent interactions separately; however, subsequent analysis and interpretation led us to bring them back together after their respective frameworks emerged.
The next step in analyzing interaction patterns after establishing general group organization was to determine what fifth-graders were doing to help fourth-graders learn to negotiate the terrain of beginning their own simulations. At this point in the project, students divided up their work time such that multiple students in a given team had the opportunity to work in Microworlds during a single class period. Consequently, in each team session on video, there were sufficient opportunities to examine extended episodes of fourth-graders working in Microworlds. Because we were specifically interested fourth-fifth grader interaction patterns that would help newcomers learn about software design, this particular analysis was limited solely to video footage involving fourth-graders making their simulations.

During the process of moving from a list of interaction patterns to a descriptive framework, what emerged was not a list of discrete categories, but rather a sequence of potential fourth-fifth grader exchanges. For both clustered and independent teams, fifth-graders responded in multiple ways to fourth-graders’ work. These sequences are represented by a flow chart showing the multiple collaborative patterns seen in the data. Figure 2 displays the flowchart depicting the framework for clustered and independent teams.

As is evident from the flowchart, some patterns (such as “fix” and “aesthetic opinions”) are represented twice in the framework. This is due to the fact that we originally had two separate frameworks for clustered and independent configurations, in which some of the same helping patterns were observed. Upon repeated viewing and comparison of episodes, and
continual reflection and comparison of frameworks, however, we found that the framework structures were highly similar, and common patterns occurred in both. These common patterns, however, were ultimately found to be very different not in terms of the interaction structure, but in terms of their discursive content and their affordances for fourth-grader learning. Thus in our description of the differences, we have chosen to outline a trajectory for clustered teams first as a baseline, and we then move to the independent configuration in order to better illustrate these affordances.

In clustered situations, the entire team (or the majority) were seated or standing around the computer workstation. Consequently, when fourth-graders worked in Microworlds, fifth-graders on their team had immediate visual access to the screen and its contents as well as easy physical access to computer controls at all times. This immediate and continual monitoring typically resulted in fifth-graders performing one of two initial patterns: immediate intervention or responding to questions. It should be pointed out that episodes for each team contained some amount of both types; as individuals and teams rarely stuck exclusively to a single pattern.

Immediate intervention consisted of two kinds of sub-behaviors. Aesthetic opinions described an interaction wherein fifth-graders would provide their own, often unsolicited, opinions about the look of what was being created, such as, “don’t make the octopus blue or you can’t see it, ‘cause the water’s blue.” Fourth-graders might then change their screens to suit fifth-grader preferences or argue for their own ideas. In either case, aesthetic discussions conveyed the importance of considering the appearance of the design. The other pattern was directing, in which fifth-graders would provide verbal directions for fourth-graders on how to
perform specific actions in Microworlds. For example, fourth-grader Ivan was attempting to animate a starfish moving across a tide pool. When Ivan had the starfish’s command window open and was beginning to write the animation commands, fifth-grader Therese directed exactly what to type in the window without being asked: “type ‘glide,’ . . . (pause while Ivan typed) then space, . . . whatever distance you want, like 50, . . . space, . . . then a speed, like 2.”

In contrast to the above two patterns, which both involve fifth-graders’ unsolicited input, the second main pattern for clustered teams describes exchanges in which fifth-graders respond to direct questions. Types of fourth-grader questions varied from interface (“where’s the stamps box?”) to graphics (“how do you make it transparent?”) to programming (“what comes after ‘set’?”). Again, because the whole team was seated immediately around the workstation, fourth-graders typically received quick answers. Two main fifth-grader strategies emerged for responding to questions. One method was to direct fourth-graders’ actions via verbal instructions and pointing on the computer screen in response to a specific question. The second method was to simply fix the problem themselves by taking the mouse and keyboard and opening windows, clicking in the correct location, or typing in commands for the fourth-grader. This fixing may or may not have been accompanied by a verbal explanation of what the fifth-grader was doing.

There are some obvious advantages and disadvantages to employing a fix in response to fourth-graders’ questions. On the plus side, it is much more efficient for a fifth-grader to simply perform the action him or herself, rather than taking the time to tell the fourth-grader how to do it—a course of action often accompanied by misinterpretations, mistakes, and necessary clarification on both sides. From the perspective of novice learning, however, fixing does not
allow the learner to physically perform the correct action and thus get the feel of doing it right. Furthermore, if the fix is unaccompanied by a verbal explanation, the learner has to rely on merely watching in order to gain any knowledge of how to perform that action the next time. In fact, when fourth-graders were on the computer, clustered teams as a whole seemed to be characterized by a functional over-reliance on fifth-graders’ input, opinions, and occasional computer control—a pattern which did not afford learners very much self-direction in decision making or problem solving in Microworlds. We turn now to the independent configuration and examine how some helping patterns which look very similar on the surface are actually fundamentally different, and how other patterns seem to only be afforded by the periodic absence of more capable others.

All or the majority of students in independent teams worked on their own endeavors most of the time. Team three, for example, had an extended episode in which fourth-grader Karen worked in Microworlds on her manta ray screen, fifth-grader Kelly used the planning board to organize a priorities schedule for the week of what should be accomplished before the third grade visit, fifth-grader Michael read and took notes on a whale book at the workstation desk space, and fourth-grader Martin talked with the teacher about how to find information on viper fish. Despite working on separate tasks, however, members of independent teams were still within relatively close proximity to one another and thus available as resources. Indeed, as the analysis of interaction sequences will show, even when fifth-graders were engaged with their own activities, they took an active role in supporting fourth-graders’ Microworlds work.

The first main way fifth-graders contributed to fourth-grader learning when they were engaged in separate activities was to respond to fourth-grader questions, which is on the
surface similar to the clustered pattern. The way in which this interaction was initiated, however, differed greatly from that previously described. In clustered teams, a fourth-grader could merely utter a question he or she was pondering, and it would be immediately addressed by a fifth-grader right next to him or her. In independent teams, however, a fourth-grader with a question would have to call out the name of the fifth-grader he or she wanted to ask, or leave the workstation temporarily to physically retrieve the fifth-grader from another location in the classroom. In either case, responding to a fourth-grader’s question required fifth-graders to cease their own activity temporarily and attend to the fourth-grader working in Microworlds. Once the fifth-grader being sought arrived at the team workstation and could see the screen, the subsequent exchanges unfolded in much the same manner as in clustered teams: fourth-graders asked questions, and fifth-graders would either direct or fix.

In addition to the way questions were initiated, a crucial difference emerged between independent and clustered teams in the types of questions being asked. Fourth-graders in independent teams often asked debugging questions, whereas this issue almost never came up in clustered teams. A debugging question would arise from a situation in which a fourth-grader had typed a procedure or some portion thereof incorrectly, tried to run the procedure, failed, and thus had to find and correct the error. Fourth-graders often had difficulty finding the bugs in their own procedures, and would thus ask fifth-graders for help. In contrast, bugs almost never occurred in clustered teams, because under fifth-graders’ continual watching and direction, fourth-graders’ programming mistakes were usually caught as they happened rather than as a result of a failed program run. Consequently, fourth-graders in independent teams had more of an opportunity to build debugging skills—an important aspect of programming expertise. The
same sorts of advantages and disadvantages of fifth-graders directing versus fixing these bugs also arose in the independent configuration.

The second main way in which fifth-graders in independent teams supported fourth-graders’ learning was through periodic monitoring. This pattern was unique to the independent configuration and describes a situation in which fifth-graders would occasionally leave their own activities voluntarily and go investigate how fourth-graders were doing on the computer. This voluntary monitoring provides evidence that fifth-graders in independent teams, despite performing other tasks themselves, took their socializing responsibilities seriously and were concerned with fourth-graders’ progress and activities. Upon arriving at the workstation computer and watching the screen for a while, fifth-graders typically initiated one of three types of exchanges. They sometimes provided unsolicited aesthetic opinions or directions, much the same as fifth-graders in clustered teams. The third type of exchange was different, however. Fifth-graders monitoring fourth-graders’ activity would often ask a question of the fourth-grader, such as, “what is that supposed to be?” These questions would initiate a dialogue between fifth-grader and fourth-grader about the contents of the screen or fourth-graders’ ideas. The exchange between Daniel and Sarah at the beginning of this section is an example of this kind of conversation.

These discussions were important because they gave fourth-graders opportunities to justify their own design decisions and talk about the process of implementing their abstract ideas with more experienced others. These dialogues, as well as the greater opportunities for debugging afforded by the independent collaborative structure, represent significant steps on a trajectory toward full simulation design practice in this classroom community. Dialogues
between fourth and fifth-graders on the same team also bore a greater resemblance to the kind of conversations we observed between members of different teams. It was not uncommon for children to look at one another’s screens as they traversed the classroom, stopping occasionally to talk about what they saw. Sometimes helping occurred in these interactions as well; however, these across-team patterns are beyond the scope of this study.

While both focus and comparison classes displayed these same patterns, there were some across-class differences that are worth pointing out. Recall that comparison fifth-graders had three weeks of Microworlds programming exposure during the previous year in math class, while focus fifth-graders completed an entire design project the previous year. This meant that while comparison fifth-graders certainly knew more programming than fourth-graders on their teams, their knowledge was not extensive, and thus their solutions to fourth-grader questions or programming dilemmas were occasionally wrong. Additionally, comparison teams seemed to spend more time in a clustered configuration than independent, although there was certainly a good distribution of both configurations across classes. Comparison fourth-graders thus had fewer opportunities to engage in debugging and dialogues about their screens during the middle phase of the project.

**Student Voices on Collaboration**

The wide variety of helping patterns described in the previous section lead one to wonder about how students perceived their actions and the actions of others. How aware were students of their differences, not only in terms of interaction patterns, but also in general? Below are two segments of interview transcripts, provided to give the reader examples of the
way students talked about their roles. The first segment is from an interview with Brian, a fifth-grader in the focus class, and the second is from an interview with Ivan, a fourth-grader in the focus class. The interviewer in each case, CCC, is the first author.

CCC: What does it mean to be a fifth-grader working on this project?
Brian: Well, we have experience, so sometimes we help them with the simulations.
CCC: How do you mean?
Brian: Well, programming (pause). But it’s not just programming, ‘cause Melody [a fourth-grader on Brian’s team] is pretty good at that. But, like, if I see something that’s not planned well, or maybe over-scheduling, then I’ll say something about that.

CCC: What does it mean to be a fourth grader working on this project?
Ivan: Well, um, it’s (pause). . .to know that there’s people older than you, who know more and are more experienced at it.
CCC: Mmm. What else?
Ivan: Well, you know that you can always get help from them, because of what they’ve done before on it.

In each case, both Brian and Ivan discuss their respective roles as fifth-grader and fourth-grader in social terms; the experience of each is inherently defined by collaborating with the other. Further, the relationship between fifth-graders and fourth-graders in both responses is configured as that of not just collaborating, but specifically giving or receiving help. Additionally, Brian first describes a general type of help and then expands his response to include the more specific skills of programming, planning, and scheduling. Ivan’s description, on the other hand, also focuses on the difference in previous experience, but when prompted to elaborate, he
describes helping but doesn’t specify help with what. These characteristics of the student interviews — a focus on help and a more fine-grained articulation by fifth-graders — are reflective of just some of the compelling overall patterns we found in our analysis. In reporting results from the interview analyses, we first describe the coding scheme that emerged from student interview transcripts and then move to our analysis of students’ awareness of role differences by class and grade level.

A decision was made to treat all three questions about fourth-fifth grade differences and identity issues as one unit of analysis, due to the nature of student responses. Rather than limiting their talk to only fourth-graders or only fifth-graders in response to the corresponding questions, student answers to any, and sometimes all, questions contained information relevant to differences (question 1) and the meanings of their own and others’ roles (questions 2-3). Consequently, it made sense to code the entire conversation as one unit. The main categories that emerged from student responses were knowledge differences, affective differences, and social role differences. There was also a fourth code for “no difference.” The descriptions students gave of knowledge differences were more multifaceted than could be captured by a single code, however. Students cited several different types of knowledge differences: (a) general or unspecified knowledge [e.g., “fifth graders seemed to know more”], (b) knowledge about programming specifically [e.g., “they were newer to Microworlds than us”], and (c) knowledge about specific aspects of design other than programming [e.g., “fourth-graders didn’t know how to spread out the work”]. Students also mentioned affective difference [e.g., “you feel kind of dumb at first”]; this was a single code and not broken down further.
The social roles code refers to differences students mention in regard to how fourth and fifth-grade students interacted with each other. Most often students phrased this difference in terms of giving or receiving help with some aspect of project work, as with Brian’s and Ivan’s responses at the beginning of this section. Like knowledge differences, the picture painted by students was more complex than the initial category. They cited the following types of social roles: (a) general or unspecified giving and receiving help [e.g., “we had to help the fourth graders to know what to do”], (b) giving or receiving help with programming [e.g., “you could always ask a fifth grader if your animation wouldn’t work”], and (c) giving or receiving help with other specific aspects of design [e.g., “we always helped, ‘cause fourth graders couldn’t make the schedule by themselves”]. Although some students also mentioned “no difference,” these were typically comparison class students. A few focus students who claimed that there were no differences in response to the first question later contradicted themselves by talking about differences in response to the “what does it mean?” questions. These sub-codes—knowledge, affective, and social role differences—make up seven types of observations students spontaneously cited as distinguishing fourth and fifth-grade designers. That students could spontaneously discuss differences in such a complex and sophisticated manner supports the argument that design provides students a rich context in which to learn and interact with tools, artifacts, and with each other.

In order to assess the breadth of characteristic differences students cited between fourth and fifth grade designers, each student’s entire set of responses for all three interview questions was examined as the unit of analysis. Student interviews were analyzed for the total number of difference types students mentioned. For example, a student who mentioned receiving help
with programming, fifth graders knowing more, and it feeling harder as a fourth grader would receive a total score of three. Fifth-graders spontaneously generated more types of difference (M = 4.893, SD = 1.368) than fourth-graders (M = 2.800, SD = 1.082), comparison fifth graders (M = 2.933, SD = 1.387), or comparison fourth graders (M = 3.200, SD = 1.265). Analysis of variance and a Tukey post-hoc revealed that fifth-graders’ breadth of awareness was significantly greater than that of any other group (MS = 4.713, F = 2.855, p < .05).

These results demonstrate several things. First, there clearly existed a dynamic in the comparison class wherein students perceived differences between fourth and fifth-graders, despite comparison fifth-graders’ limited previous experience with Microworlds. Even though comparison fifth-graders had only three weeks of programming in mathematics during the previous year, which was not at all comparable to the long-term design experience of focus fifth-graders, this difference was noticed and became highly salient in comparison students’ reflections. Additionally, the existing age dynamic in both classes may have also affected students’ perceptions of general knowledge differences. Focus fifth-graders, however, were able to talk about differences between those with experience and those without in a much more sophisticated way.

Discussion

Summary of Findings and Contributions

Our goal was to describe and understand the nature of everyday collaborations between experienced and inexperienced students in a project-based environment to illustrate how a
sustainable learning culture can be instantiated. We identified patterns of collaboration through which more experienced students provide some of the socializing and guiding functions previously assumed by the teacher. Our comparisons drawn between independent and clustered teams have implications for understanding the nature of collaborations, both in classroom communities and apprenticeship contexts at large. First, the issue of fourth graders’ participation is further defined by these findings. Access for inexperienced students clearly means more than immediate participation with experienced students in talk and other activities, or hands-on proximity to the physical means of software production. Inexperienced students in both the clustered and independent teams in our classroom community experienced these phenomena. As shown by our analyses, however, access to learning in classroom communities also means access to making and fixing mistakes. In existing studies of apprenticeship, researchers describe how in traditional vocations or tribal cultures, economies of production make errors costly or prohibitive; consequently, newcomers are rarely allowed to fully participate in the most crucial phases of craftwork (Lave & Wenger, 1991). In our classroom community however, as well as in professional software design, the trial and error cycle of code writing and debugging — making mistakes, in the most basic sense — is an inevitable and important part of the creation process. Existing work in mathematics education has demonstrated similar findings in the area of student-teacher interactions: opportunity to learn is enhanced when students have access to the entire problem-solving and problem-posing process (Lampert, 1990; Gearhart, Saxe, Seltzer, et. al, 1999). Our work extends these findings to the areas of peer collaboration and educational technology as well.
Another contribution of these findings deals with the wide variety of collaborative helping interactions we observed. Students in both classes displayed many different ways of helping and working with one another — a much richer variety of interactions than that documented by traditional collaborative learning research (see Webb, 1989). The motivations behind these actions, however, are not discernable from the behavioral data. Questions arise regarding how experienced students think about their interactions with beginners, and the choices experienced students make regarding how they helped beginners and engaged them in design. The categorical distinction between clustered and independent teams represents only one such choice. Why did fifth graders in clustered teams choose to hover over fourth graders shoulders, while experienced students in independent teams retreated to a greater distance away? Certainly these interactions were likely co-constructed, however, we did not observe beginners in clustered teams needing more guidance or asking many more questions than their independent counterparts. On another level of detail, why did some experienced students direct beginners in fixing their own mistakes, while other experienced students jumped in and did all the fixing themselves? Why, for that matter, did some experienced students give unsolicited opinions to beginners while others engaged in design dialogues? The functional outcomes of these decisions are clear — some fourth graders gained access much more fluidly to full design practices, while others struggled — but fifth grade students’ motivations are less so. It could be that all fifth graders acted in ways they genuinely believed to be most helpful. Equally likely, however, is that experienced students’ interactions with fourth graders were more a function of their own preferences than any specific pedagogical intent. An examination of how students
viewed their roles as fourth and fifth graders, or as inexperienced and experienced students, provided some insight into these questions.

Fifth-graders’ greater breadth of understanding shows that fifth-graders continue to develop knowledge, insight, and a more reflective perspective on the design project and its apprenticeship interactions through their experience during their fifth-grader year. Recall that the interviews took place after project completion; thus, the insights shown by fourth-graders in the post interviews potentially represent the level of design knowledge and understanding with which fifth-graders enter their second year in the project. Yet by the end of that second year, fifth-graders have developed reflections on the project that far surpass their fourth-grader classmates and their same-age comparison cohort. Thus learning in the classroom design community does not end with a fourth-grader’s attainment of skills sufficient to participate fully. Rather, fifth-graders continue to learn about the nature of practice by observing, working with, and helping fourth-graders. Thus the old adage that one never really learns something as fully as when one has to teach it holds true yet again. Existing studies of collaboration and communities of practice, however, have not examined this aspect of learning; much potential for future research resides here.

**Implications for sustainability and the structure of schooling**

These differences in students’ collaboration patterns and reflections indicate two ways through which sustainability was achieved in a classroom community. The first one deals with the modeling of collaborations provided through experienced students, while the second one focuses on the structural features of the team composition. In the learning through design
project, focus fourth graders begin by observing experienced fifth graders program and providing occasional support. Mature practice is attained when students can independently design and program their simulations with only occasional help; this is how many fifth graders spent their time on the computer. The space between these two phases, however, is wide and difficult to cross. Successful collaboration interactions require that fifth graders understand and accept the goal of eventually yielding their higher-status positions, as newcomers become more skilled and more independent. The implications of these collaboration interactions go far beyond the actual learning situation, because fourth graders not only experience in their own learning but also see a model of interactions in what it means to be an experienced fifth grader — a position which they will assume in the coming year.

This modeling function is greatly enhanced by a structural feature of the learning through the design project: the composition of mixed-grade teams. This feature guarantees that there are always students who come with previous project experience. More importantly, students know that in the following year it will be their turn to assume the roles held previously by their fifth-grade team members and to apprentice the new generation of fourth-graders into project practices. Such a mechanism insures that the collaboration learning has a history and future, and it also allows for change, as new students enter and leave the classroom community. In the analyses of previous projects, we have found evidence in teams’ planning meetings that experienced fifth graders explicitly reference their prior experience when helping other team members in their software design decisions (Marshall, 2000). We realize that the structure of most school organizations is not set up to support such long-term curricular implementations. But the difficulty alone should not be reason for exclusion; rather it should invite educational
theorists and practitioners alike to rethink on how we can organize collaborative learning environments with such reproductive features (Barab & Duffy, 2000).

**Implications for children’s participation in learning communities**

With these modeling and structural features, the learning through design project has much more in common with apprenticeship learning than with traditional collaboration approaches. Existing literature provides a variety of perspectives on apprenticeship: how experienced members (or oldtimers) structure beginners’ (or newcomers’) use of particular artifacts (Rogoff, 1993), how participants negotiate and co-construct shifts in different phases of activity (Wenger, 1998), detailed descriptions of particular apprenticeship interactions at isolated moments in time (Hutchins, 1996; Schön, 1986), and even instances of failed apprenticeships and their shortfalls (Hodges, 1998; Lave & Wenger, 1991). In all of these documented studies, the extent to which newcomers have access to full participation and are guided in a smooth trajectory toward more mature skills and understandings is often a determinant of an apprenticeship’s success. Lave and Wenger in particular describe a cohort of apprentice butchers with varying levels of physical and social access to full participation in the practices of meat cutting; many of those with less access dropped out or never transitioned to becoming master butchers during the course of observation. The clustered teams interactions observed mostly in the comparison class provide a striking similarity. While authors such as Lave and Wenger and others have argued that apprenticeship cannot take place in formal education because the process of identification and the structure of discourse are problematic (Linehan & McCarthy, 2001), we found that the reproductive features and the patterns of collaborations
observed in the learning through design project carry many of the same characteristics found in apprenticeship learning. Our other analyses of student discourse (Kafai & Ching, 2001) and students' identification with their roles (Kafai & Robert, 2002) also support the argument that learning through design projects can provide a context for apprenticeship in schools.

**Implications for roles of teachers and students**

In this last section, we turn to the role of teachers and their significant challenges in implementing project-based approaches in classrooms. We have argued that one of the difficulties in implementing approaches such as learning through design is that each year teachers must initiate a new cohort of students into project practices. In an analysis of teachers’ issues in learning how to implement project-based learning, Mintrop (2001) noted that “[m]ost often, students turned out to be the strongest obstacle of success when they did not behave according to the expectations of the pedagogy” (p. 233). He identified some of the problems faced by teachers when implementing the “Fostering of Communities of Learners” approach developed by Brown and Campione (1994). Creating a fusion of ideological commitment, mastery of the model, clinical tryouts, and reflection that was commensurate with the founders’ original implementation turned out to be problematic. These observations come from a teacher education program that tried to incorporate project-based teaching and learning in its curriculum, but the findings most likely also apply to challenges faced by experienced teachers bringing these approaches into their classroom.

The presence of fifth-graders in our project illustrated how peers can carry out some of the socializing and guiding functions needed to support teachers in the classroom.
implementation. But the presence of older students alone did not make the difference, as indicated by our observations from the comparison class. It was the presence of experienced older students having participated as fourth-graders in a previous learning through design project and having seen modeled more advanced forms of project practices by fifth-graders. In addition, the teacher’s interactions with students, their teams and the whole class also facilitated various project practices, and this is where more research is needed. How does a teacher know when further work with individual students is needed or when team members can take over some of this responsibility? How do teachers decide when to call for whole class sessions and to address project issues that pertain to all and not just some groups? How do classroom teachers balance curricular goals with those of research questions developed by individual students? None of these are trivial questions, because they pertain to the creation and implementation of the classroom community that makes the learning through design project possible for all participants.

Conclusion

Questions about the patterns of collaborative interactions in project-based learning were the driving force behind this study. On a basic level, this work contributes to the growing body of research on project-based learning and the larger research literature on collaboration by providing a detailed account of how collaboration between students can be configured to create sustainable classroom communities. On a theoretical level, the patterns of collaborative interactions observed in learning through design provided evidence for the possibility to locate
apprenticeship learning in classroom communities. The learning through design project has affordances for creating a classroom culture rich enough to foster highly contextualized practices with embedded knowledge and skills. This study suggests that an apprenticeship system that shares many of the key qualities of other documented forms can be found in formal schooling, within the context of learning through design. More importantly, the results from this study offer an opportunity to rethink approaches to curricular reform efforts that so far looked only at institutions and teachers, rather than at students, as carriers of change. Sustainability can and needs to be implemented on all levels to be effective and long living.
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FIGURES

Figure 1. Screen capture from student-created whale simulation

Figure 2. Grounded theory framework of teams’ interaction patterns
Figure 1. Screen capture from student-created whale simulation
Figure 2. Emergent framework of helping patterns within team configurations