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ABSTRACT

This paper discusses a case study of the implementation of the computer software, "Boxer," in a single sixth-grade classroom. The paper reports on the process of teacher learning accompanying the assimilation of a new technology into this classroom. A case study approach was used because the teacher taught a 4-week class using Boxer to study geometric figures in the plane five times during a single school year to different groups of students. This repetition was used to study change in the teacher's instructional practices over time. Based on the evidence from this single case, three conclusions are drawn that can serve as starting points for further research. First, the use of technology can serve as a resource that helps to increase the presence of student thinking during classroom instruction. Second, new technologies such as Boxer can be assimilated into a teacher's familiar and productive class routines and serve as a resource. Third, the use of technologies that serve as open toolsets (A. A. diSessa, 1997) can support change in the classroom by allowing for flexibility in response to long-term or emergent goals. Contains 26 references. (Author/AEF)

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The Assimilation of Technology in a Sixth-Grade Classroom:
Teacher Learning from the Use of an Open Toolset

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Abstract

This paper discusses a case study of the implementation of the computer software, Boxer, in a single sixth-grade classroom. We report on the process of teacher learning accompanying the assimilation of a new technology into this classroom. We use a case study approach because the teacher taught a four-week class using Boxer to study geometric figures in the plane five times during a single school year to different groups of students. We use this repetition to study change in the teacher's instructional practices over time. Based on the evidence from this single case we draw three conclusions that can serve as starting points for further research. First, the use of technology can serve as a resource that helps to increase the presence of student thinking during classroom instruction. Second, new technologies such as Boxer can be assimilated into a teacher's familiar and productive class routines and serve as a resource. Third, the use of technologies that serve as open toolsets (diSessa, 1997) can support change in the classroom by allowing for flexibility in response to long-term or emergent goals.

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Introduction

Changes in the classroom that result from the use of technology are far less well studied than the impact of technology on the activities of the individual, perhaps because software design is most often informed by consideration of individuals (diSessa, 1997). In this paper we examine patterns of appropriation and resulting changes in classroom practices when a new technology, the computer software Boxer[1], was introduced to a sixth grade classroom for the study of geometry. We focus on the relationship between pedagogy, learning, and technology during the introduction of a new computational medium.

Boxer is a computational medium that allows students to construct and explore their ideas in a dynamic representational environment (diSessa et al., 1991a). The design of Boxer incorporates the principle of *open toolsets* (diSessa, 1997). Open toolsets is a design principle for educational software that recognizes agency by providing tools, flexibility by allowing for many tools to be combined as sets and openness by allowing for an infinite combination of tools to be used in activity. In the eye of its designers Boxer provides a programming environment that enables the investigation of topics across a number of domains. In the classroom discussed in this paper the teacher employed the turtle geometry features of Boxer during his initial use of the technology.

We report the development of one teacher's knowledge and practices during his initial experiences teaching with Boxer in the classroom. The teacher taught a sixteen-day course five times in succession over the course of six months revising the curriculum plan in response to his evaluation of its success. During this period the teacher (second

[1] Boxer is a flexible computational tool developed by the Boxer Project at the University of California, Berkeley (diSessa, Abelson, & Ploger, 1991a).

author) and the researcher (first author) met on a regular basis and discussed the design and revision of the curriculum. Classroom instruction emphasized the development of students' competency using Boxer as a tool for experimentation and inquiry in the domain of geometry. We view changes in the instructional unit that result from the teacher's assessment of his students' performance as evidence of changing teacher knowledge. These changes provide evidence of the types of knowledge that teachers need to acquire as they assimilate technologies into their classrooms.

Previous studies have identified the need to study classroom instruction in light of the sociocultural influences on classroom activity, including the influence of the representational tools that are available to students for the development of their ideas (Cobb & Bauersfeld, 1995; Erickson & Lehrer, 1998; Goodman, 1976; Lehrer, Schauble, Carpenter, & Penner, in press; Olson, 1994; Schwandt, 1994; Wertsch, 1998). Numerous studies report that the presence of technologies provides a catalyst for change in students' beliefs and conceptions of themselves, the subject matter, and the nature of knowledge (diSessa, Hammer, Sherin, & Kolpakowski, 1991b; Erickson & Lehrer, 1998; Lehrer, Lee, & Jeong, 1999; White & Frederiksen, 1998; Wilensky & Reisman, 1998). Balacheff & Kaput (1996) argue that the changes in the classroom resulting from the introduction of technologies are largely epistemological. An epistemological shift occurs because the representations that are possible in the presence of technology are sufficiently different from those in a pre-information age classroom to enable new ways of thinking and learning (Lehrer, 1992).

Several researchers studied how children learn to use the representational capacities of new technologies. Nemirovsky, Tierney, & Wright (1998) report that during early experiences with a dynamic computer-based representational tool children are engaged in the development of a tool perspective. A tool perspective involves sensitivity to the important aspects of a computer's operation and interface, understanding when and how the computer is a useful aid to activity, and recognizing the significance of the different forms of representations that the computer produces. Erickson & Lehrer (1998) discuss changes in middle grades students' ability to represent their ideas in a hypermedia environment over the course of two years of classroom activities focused on the design of Web pages. They identify changes in the sociocultural norms in the classroom related to the design of hypermedia documents. These studies highlight the changes in the ideas and practices of students and in classrooms as new technologies are incorporated into intellectual activity.

During the introduction of a new technology in the classroom the teacher also needs to acquire a tool perspective. The teacher's tool perspective requires understanding not only the technology but also the pedagogy and tasks that foster a tool perspective amongst his/her students (Balacheff, 1993). The study of this form of teacher knowledge requires research into the pedagogical content knowledge (Shulman, 1986) associated with the use of particular technologies in classroom learning environments. Pedagogical content knowledge includes knowledge of the purposes for teaching a subject, knowledge of students' understandings and potential misunderstandings, knowledge of curricular materials, and knowledge about strategies and representations for teaching particular topics (Grossman, 1990).

Research on the study of teacher knowledge identifies the importance of treating teacher knowledge as an integral whole and studying teacher knowledge in instructional

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contexts (Calderhead, 1996; De Corte, Greer, & Verschaffel, 1996; Fennema & Franke, 1992). The study of teacher knowledge requires recognition of the dynamic nature of teacher knowledge that results from a teacher's dual role as teacher and learner in the classroom. In this paper we describe the development of one teacher's knowledge and practices during his initial experiences teaching with a new technology in his classroom. We capitalize on a sustained collaboration between the teacher and the researcher portraying change resulting from experiences with technology in light of general norms and practices in the teacher's classroom.

Research Questions

In this study the research questions focus on the beliefs and the practices of the teacher as he experimented with the uses for and usefulness of the technology. Three questions guided inquiry in the classroom. What are the teacher's goals for the use of Boxer and how were they evidenced during classroom instruction? What teaching methods does the teacher employ to capitalize on the use of Boxer in the classroom? What does the teacher learn from successive implementations of his instructional unit and what are the influences upon his learning process? The goal of this research is to study the teaching and learning activities in the classroom focusing particular attention upon the apparent changes in the teacher's knowledge and beliefs.

Context of the Study

The site for the study was the classroom of a sixth-grade teacher in a suburban middle school in the Midwest region of the United States. The teacher, Doug McFarlane, participated in a Middle School Design Collaborative (the Collaborative) supported by the National Center for Improving Student Learning Achievement in Mathematics and

Science (NCISLA).[2] The teacher and researcher began to work together in January of 1998 and continued their work together with the Collaborative until June of 1999. The primary forms of interaction during this period were monthly professional development meetings sponsored by the Collaborative and periodic classroom observations. The Collaborative focused its efforts upon the reform of mathematics and science instruction in the participating teachers' classrooms, emphasizing the exploration of topics in algebra and physics.

Professional development related to mathematics instruction focused on the teacher's implementation of selected algebra units from the NSF funded middle school curriculum *Mathematics in Context* (National Center for Educational Research in Mathematics and Science & Freudenthal Institute, 1996-1998). The Collaborative's initiative in science education employed Boxer as a resource for the investigation of topics in physics related to simple motion in space. Professional development in the domain of science included an introduction to Boxer through the exploration of microworlds and curricula prepared by The Boxer Group at the University Of California-Berkeley.

The teacher in the study, Doug, is a mathematics teacher within a team of subject matter specialist in one of five sixth-grade houses at his school. In addition to classes in the traditional subject areas Doug's house sponsors a Connections class during which each teacher offers an extracurricular unit of instruction. The Connections period is the first hour of the day four days per week. The students within the house rotate from teacher to teacher in four-week cycles so that each teacher repeats his/her instructional

[2] In the body of this paper I will use the term "research collaborative" to refer to Middle School Design Collaborative.

unit five times in a school year. Each teacher chooses a topic that is of personal interest and that is not included in the sixth-grade curriculum.

Doug chose to use Boxer in his Connections class, a decision that reflects his personal interest in technology as well as his participation in the Collaborative. Throughout his participation with NCISLA Doug demonstrated a strong interest in the use of Boxer in his classroom, an interest partially motivated by his concurrent participation in a master's degree program in educational technology. In collaboration with NCISLA researchers Doug developed and revised a curriculum for his connections class that focuses on the exploration of geometric ideas (McFarlane, 1999). Doug chose to focus on topics in geometry because he believed that this was an area of weakness in the sixth-grade mathematics curriculum. Because of Doug's strong interest and background in technology and the special circumstances of repeated implementation, this study was undertaken to investigate the process of teacher learning associated with the introduction of Boxer in a classroom.

Methodology

This qualitative study focuses on a single, unique case in order to identify particular characteristics of learning how to teach with technology. Doug's classroom was chosen as a site for this study because he repeatedly expressed a strong interest in learning how to use technology as a resource in his classroom, and because repeated implementations of the Boxer course during a single school year enabled the study of change. Participant observation, semi-structured interviews, documentary evidence, and videotape of classroom activities were data sources.

Data collection for this study occurred during the period from February 1998 to June 1999. Doug's classroom was observed thirty-six times during this period. Twenty of these observations occurred during the Connections class and sixteen occurred during Doug's sixth-grade mathematics class. In January and February of 1999, during the third of five rounds of Doug's Connections class all sixteen-class meetings were observed and videotaped.

Three interviews were conducted with the teacher. The first two interviews were conducted by the first author at the conclusion of each of the first two rounds of the Connections class. A second NCISLA researcher conducted the third interview in June of 1999. Each interview was recorded and transcribed for analysis. During the third round of the connections class students saved their work in Boxer on a regular basis and e-mailed their programs to the teacher and the researcher. Analysis of the data was conducted using a Constant Comparative Method (Strauss & Corbin, 1994). The qualitative data management software NVIVO (Qualitative Solutions and Research, 1999) was employed as a tool for analysis.

Results

The discussion of the results is divided into three parts. First we describe Doug's goals for the use of Boxer in his classroom. In the second two segments, we portray his instructional practices demonstrating how he pursued his goals for the use of Boxer and we describe Doug's acquisition of knowledge relevant to the use of technology in his classroom.

Doug's Goals and his Agenda for Change

Although Doug possessed a strong general interest in pursuing uses for technology in his classroom, one of his primary instructional goals for the Connections class focused on understanding student thinking. The data suggest that the primacy of Doug's focus on student thinking results partly from his participation in the Collaborative. In his reflections on his classroom teaching Doug emphasizes cooperative activity, communication, and sharing ideas as changes in his instructional practices that derive from his participation in the collaborative.

Figure 1: Examples of Change

> Interviewer: Sure. Has your participation in the collaborative changed the way you teach math?
>
> Teacher: Yah. Definitely.
>
> Interviewer: Would you give some examples?
>
> Teacher: Just the way that I do my groupings now. The way I promote and *provide time for students to do more working together* the way that I even have begun to assess and do a lot *more listening to the discussion as a form of assessment*, more informal, but then focusing more on *helping kids to communicate their mathematical ideas* and to develop and appreciate other people's ideas. So I have done a lot more of that instead of, not all the time, but I know a lot more. In the past I would be much more, this is the way you do it, now practice this out of the book. And the book has your grade. Without a lot of discussion. *Time to share ideas in small groups* or within the class. Doing a lot more, letting the children, *the students try to develop their own sense of understanding* by experimenting and building their understanding with working with Boxer, for instance [italics added] (Interview 3, Paras 119 to 122).

Assessment of student's thinking and communication of ideas were primary topics during the professional development meetings held by the Collaborative. These discussions often occurred during meetings focusing upon the challenges of teaching with a reform mathematics curriculum (i.e., *Mathematics in Context).*

Doug mapped the Collaborative's goals for instructional change in mathematics onto his efforts to implement Boxer. Issues raised during professional development focusing on curriculum implementation led Doug to think about change in his instructional practices. Gaining an understanding of student thinking in the classroom

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became more prominent in Doug's instructional decision-making. Observational data suggest that these changes were evident in Doug's mathematics class as well as in his Connections class. Doug deliberately employed instructional methods that provided opportunities for students to communicate their ideas in small and large group settings. He reflected upon their effectiveness as he prepared for the third Connections class:

Figure 2: Emerging Goals

> Interviewer:.Huh, hum. How have your goals for student learning changed, since you first taught the unit?
> Teacher:.Well, I think I've seen, ah, how powerful the...the sharing can be and the communication component has become a more critical, ah, aspect of how I like the class to run.
> Interviewer:.Ok.
> Teacher:.Um...I...*first time I wasn't really sure,* I was kind of (?) this and (?) geometry ideas here. Um, as I saw how the kids were working with them, um, *I saw that when they did take time to reflect and share, um to demonstrate what they did and for the kids to communicate, that it was really a...I think, it helped them, you know, understanding, and it gave other students a chance to see how the other students were thinking* and it was a more, ah, a better learning experience in the fact that they...they developed a clear understanding, and... [italics added] (Interview 2, Paras 312 to 329).

This passage suggests that Doug was unclear about the forms of activity that would enable student thinking to become a resource in his classroom when he first began to use Boxer. Doug identified an increase in the amount of sharing and communication about student work as a positive change because it increased the presence of student thinking in his classroom as a resource both for the other students and for him.

In describing his goals Doug also expressed concern about his students' hesitancy to take risks in sharing their strategies and ideas in his mathematics class. He identified promoting new habits of mind among his students as a second goal for his Connections class. These habits of mind include the willingness to experiment with ideas and to take risks as a learner.

Figure 3: Habits of Mind

> Interviewer:.Um-hum. Ok. Are there any other, um, I mean, you've listed

> basically 4 or 5 goals there.
> Teacher:.Um-hum.
> Interviewer:.Um, are there any that are, um, more priority or less of a priority?
> Teacher:.Well, I think the main thing again is that I want the kids...the *students to experience how they can solve the problem and to feel comfortable...trying an idea and then evaluating it and seeing what that did and...and to continue to explore*; and as they do that they'll gain some of the other concepts, but that's the main thing I'd really like them all to do (Interview 2, Paras 297 to 308).

There is an affective component to this goal in promoting the level of comfort that students feel when they are experimenting with ideas. But, there is also a mathematical component that relates to the students' habits of mind. Doug views experience with Boxer as a potential catalyst for change in students' behaviors as learners of mathematics.

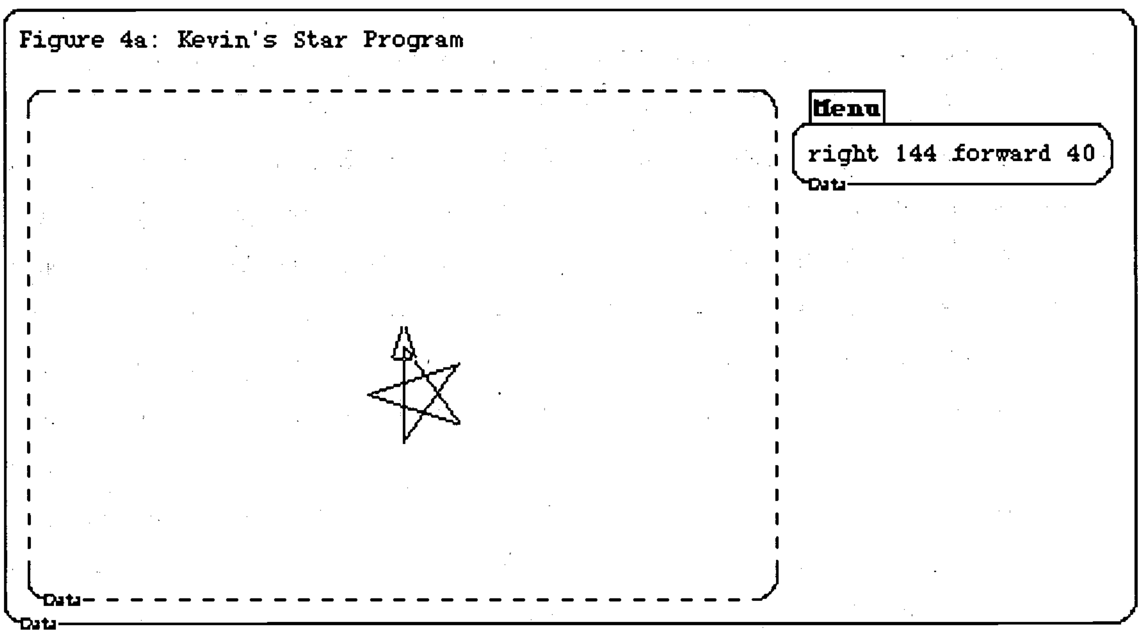

Figure 4a: Kevin's Star Program

Doug encouraged the students to think about their work as a process of design that involved reflection and revision. The dynamic feedback from Boxer during online activities provided Doug and his students with a new resource that promoted active exploration in the classroom. The following segment from the Connections class illustrates how Doug interacted with his students during class time when he has invited them to explore new ideas.

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Figure 4: Kevin's Star[3]

[Figure 4a displays Kevin's program]
Doug: Ah, yeah, ok. So you did that. [made a five-pointed star]
Kevin: The numbers can make 'em bigger.
Doug: Could you do that? Ok, why don't you try and see what that would look like. So you're seeing make it a double [changes the forward 40 to forward 80]. Ok, that looks cool, ok. Do you keep you're, um, those numbers the same?
Kevin: But the right has to be 144.
Doug: That has to be?
Kevin: Cause that's the angle of the star turns.
Doug: That's the angle that it turns...wow!
Kevin: [?]
Doug: How did you figure that out? This is something you did last year?
Kevin: It's on Logo Writer.
Doug: You did this in Logo Writer like last year...or?
Kevin: Well we have, we have a really old computer with floppy discs.
Doug: You have this at home?
Kevin: Yeah. And our really old computer with floppy discs, and, um, with the floppy ones that are like really old and it has Logo Writer on it.
Doug: Um-hum.
Kevin: And it showed how to do a star and a square and all kinds of stuff.
Doug: Cool. Oh, it showed it on there, how to do it.
Kevin: Yup, it showed the commands and stuff.
Doug: Ok, great. Can you, ah, explain to Robert how you kind of do that? (January 20, 1999, 27:00-28:10 minutes)

During this interaction Doug inquired about Kevin's work probing for the origins of his ideas and the depth of his understanding. This inquiry informed Doug about Kevin's knowledge of turtle geometry programming and of the mathematics of his design. This episode served as an informal assessment of Kevin's knowledge and as an opportunity to encourage communication between students. Doug encouraged Kevin to share his knowledge with his neighbor and later called on Kevin to share his design with the entire class. This brief clip portrays Doug's efforts towards achieving his goals during micro-interactions in the classroom. Further evidence of the unfolding of these goals in the classroom follows later in the paper.

In summary, Doug articulates goals related to student thinking and student habits of mind during interviews that focus on the use of Boxer and on the changes in his

[3] All student names are pseudonyms.

classroom instructional practices. A primary goal of increasing the overall presence of student thinking in his classroom arose from Doug's participation in the Collaborative reflecting one of the primary goals of the professional development program. A second goal, promoting new habits of mind, arose from Doug's reflections on the affordances of the technology, his knowledge of his students' competencies and ideas, and his knowledge of classroom instructional practices. The identification of Doug's goals provides a foundation for the remainder of the discussion in this paper because many of the adjustments that Doug makes to the curriculum plan respond to his assessment of the success of Boxer in promoting his goals. Doug's goals provide a structure that frames the process of learning and change that he undertakes during repeated implementations of the Connections class.

Learning about Instructional Practices: Exploration and Collaborative Problem Solving

In response to Doug's interest in pursuing the use of Boxer NCISLA researchers provided him with an initial curriculum that included a Boxer tutorial and a microworld focusing on the transformation of shapes in the plane.[4] After the first two rounds of the Connections class Doug began to revise this instructional plan. His revisions reflect his assessment of the extent that his goals for the implementation of Boxer were realized during his first two Connections classes. Employing his knowledge and with the support of both the researcher and the school's computer personnel Doug made changes in the classroom formats and the tasks for the Connections curriculum.

The first initiative that Doug pursued was to make use of a computer projection device provided by the school to demonstrate new features of Boxer to the class and to

[4] The transformations microworld was adapted from a logo microworld used in previous research by Laurie Edwards.

engage the students in more whole class discussions. Previously the students most often worked independently at the computer using the tutorial program after receiving verbal instructions from Doug at the start of the class. This initiative resulted from Doug's assessment that the students required more group interaction in order to help them acquire the knowledge to use the technology effectively.

Figure 5: Importance of Whole Class Activity

> Teacher: One of the things I think I have to figure out too is I got stuck sometimes I think in wanting to make sure they got to the computers and sometimes I think it's more valuable just to have the computers here, a big TV or whatever and spend the whole day perhaps, the whole class period looking together and talking and writing and experimenting and looking at what people are experimenting with, and listening to them instead of just always going off and trying it on your own or with your partner (Interview 1, Paras 280 to 287).

The following segment from the second day of the third round of the Boxer class exemplifies the format of instruction that Doug chose to implement during the introduction to the Boxer interface and programming language.

Figure 6: Introduction to Boxer

> Doug: Now, the "Read Me First " is really, really important. It's always critical you that read some of the instructions that's given here. It says look at the commands in the data box called "Menu ". Well, if you look at "Menu " it looks like this. How do we open that up?
> Tom: By clicking it?
> Doug: Clicking on it. Ok, let's click on the "Menu " box. So, it's open. Here's something that I noticed as I was going around. Some people got to this ahead of the rest of you. Execute a command.
> Kevin: Oh, I know how to do it.
> Doug: Arden, do you know how to do it? Can you refresh our memory? If we want to execute one of these commands, how do we execute it? Don't just tell me for right now please.
> Arden: We click on the..you see where it says forward 50
> Doug: If you want it to do "forward fifty " you do what?
> Arden: Double click.
> Doug: Double click. Could everybody double click on "forward fifty ". Ok, what's another command we could try? Kevin.
> Kevin: Left ninety.
> Doug: Double click on "left ninety ". What's something we might want to do now.
> Mary: Right ninety.
> Doug: What would "right ninety " do before you do it?
> Mary: Turns.

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Doug: Which way? Do you see which way the turtle is pointing right now? Or the triangle is pointing on this screen? It's pointing towards the clock. If we double click on "right ninety ", what's it going to do?
Kevin: It goes straight back up.
Doug: Kevin, it's going to go straight back up? Double click on "right ninety ". Make sure you double click, yeah. Ok, what do you suppose "clear screen " might do?
Ellen: It'll clear the screen.
Doug: It'll clear the screen? Double click on it and see what it does. It gets rid of what was there? You still have your triangle here, but *what I'd like you to do is take a minute, experiment with the "forward ", the "right ninety ", the "left ninety ", and then continue to read through this, and then there's some challenges here, at the bottom you can open up.* But make sure you get a pretty good sense of what "right ninety ", "left ninety ", "forward fifty ". Read all of the information in here though, ok. If you see something that you think is pretty interesting raise your hand and I'll come around and look at it. Ok. [Italics added] (January 20, 1999, 23:20-26:50).

The above segment is typical of the pattern of activity during the students' initial introduction to Boxer. Doug clarifies important details of the Boxer interface, assesses student knowledge of these details, and sets the stage for exploration by introducing the students to new aspects of the Boxer programming language. He concludes by encouraging the students to explore these new ideas and providing the students with important time for play that helps them to develop their comfort and their skill with Boxer. In general Doug allowed 10 to 15 minutes for exploration using this time to assess student progress during micro-interactions such as the segment portrayed above in Figure 4.

The second initiative that Doug pursued was to assign the students to work in pairs throughout the Connections class. This decision was driven by practical considerations (i.e., a shortage of computers that required some doubling) and by Doug's assessment that it is critical for the students to reflect on their work during online activity with the computer.

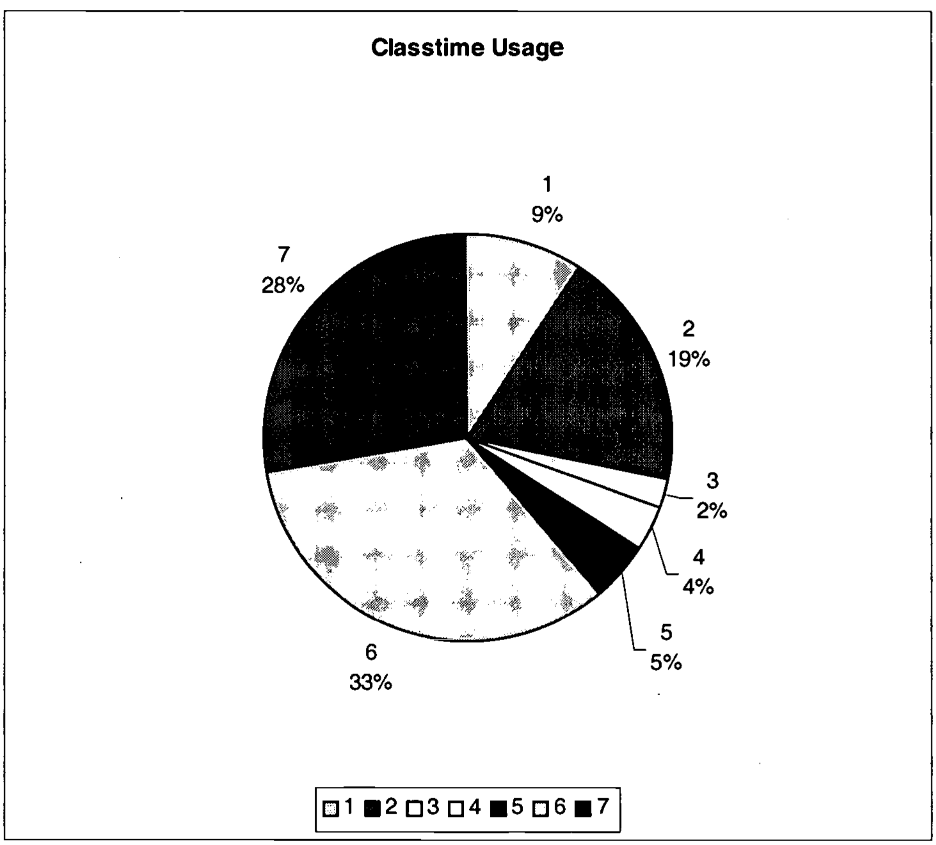
Figure 7: Working in Pairs

Teacher: There was a lot more exploration and discovery by the students where we would, I would often present an idea and show them an example and then I would say here is what I would like you to work towards and give them a few commands and have them experiment and then come back and share what they were doing. *And they had to*

> *work with a partner*, the way it was set up, there were only enough computers so they would have to have two to a computer. So there was a lot more exploration and discovery and sharing and then *looking at different ways a student could write a program that might make a specific shape and another student might do it in a different way. And it really was interesting to see the kids look at that, and able to discuss and share their thinking that went through,* [Segment Cut, italics added] (Interview 3, Para 52).

Doug decided to use dyads for all online activity because he believed that the students' ability to communicate their ideas needed support from structures that promote reflection during online activity. Based on his early experiences teaching with Boxer Doug determined that sharing with a partner during the design process promoted sharing with the group during whole class discussions.

Figure 8
Activity Structures in Doug's Mathematics Classroom 1998-1999



category 1 arrive and check homework
category 2 discussion of homework problems or classwork
category 3 discussion of new concepts motivated by student work
category 4 krypto challenge - game to encourage number sense

category 5 direct instruction and student practice using worksheets
category 6 mathematical work in pairs or groups using worksheets
category 7 problem of the day with discussion of solution strategies

In relation to the decision to use dyads for computer activity it is important to recognize that as a general practice Doug favored cooperative grouping structures in his mathematics classroom. Figure 8 displays for the percentage of time dedicated to different instructional formats in Doug's mathematics classroom. The data from classroom observation reports suggest that approximately 33 percent of class time was dedicated to group work in pairs. Oftentimes the discussion of homework problems and the problem of the day activities also involved dyadic interactions. It is reasonable to estimate that Doug's students spend at least 50 percent of their time in his mathematics class working in pairs.

The introduction of Boxer as a resource in the Connections class required Doug to think about how to orchestrate similar collaborative experiences for his students during online activity with Boxer.

Figure 9: Learning about Dyads

> Interviewer:.Ok. Um, what lead you to incorporate that, the sharing and...
> Teacher:.Oh, I, I, just from past experience in how I've run other classes I realized that, that is a...that's usually a technique that fosters, ah, understanding in, in a, students. Um, I just hadn't realized how I was going to incorporate it into my class. Partly the time limitation and not knowing how...quickly, or in some of the units, some of the ideas would be...we'd get to or how well the kids would understand them (Interview 2, Paras 337 to 344).

In figure 9 Doug identifies this dilemma as an obstacle that he faced as he began to teach with Boxer. Initially he was unaware of the tasks and concepts that would allow for productive sharing. Doug required knowledge not only of the technology, but also of the students' level of engagement with the geometric ideas. Acquiring this knowledge

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required Doug to create instructional spaces that would allow him to assess his students' thinking and their capabilities.

The process of assessment and recruitment of ideas first seen in Figure 4 helped Doug to identify fruitful directions to pursue in promoting exploration. However, it also required pedagogical skill forcing Doug to be flexible in his planning in order to capitalize on emergent ideas. The instructional segment captured in Figure 10 demonstrates how Doug's flexibility during micro-interactions with his students takes on an emergent quality. Nellie's design is included as Figure 11 and was projected on a large screen throughout Doug's interaction with her.

Figure 10: Nellie's Design

Doug: How did you get it to turn...like that...Did you add something?
Nellie: No, I just (?). I just kept clicking in it until I
Doug: But how did you get it to go in that direction, is what I'm wondering?
Nellie: Well how it is right now (?) I don't know
Doug: Um-hum, um-hum yeah. You sure you didn't change something on one of them?
Nellie: This I don't know if that was right fifty (?).
Doug: You must have had a right yeah, ok, thank you. [laugh] You had me very confused there for a second. You must have had at least one "right fifty" in there and then you changed it back to "right ninety"? Ok, that's cool. Very neat design.
Student: How did she get that diagonal?
Doug: How did she get this diagonal? Oh, ok. Good question. Let's look up at the screen here for a second. Nellie was experimenting and she has a really interesting design up here. Guys, could everybody please look over here for a second? And a lot of you have done some other really cool things. The problem here we have, is we only have the one computer hooked up to the screen. If somebody would like to come over and maybe type in something and demonstrate what they did that would be really cool. We're not going to have a lot of time to do that today because we're running out of time. But, notice, Nellie got this to go at a diagonal. Can you explain what you did Nellie?
Nellie: I think I... I changed the "right ninety" to "right fifty".
[brief segment cut]
Doug: Nellie went to this "right ninety" and she changed the ninety to a fifty. She did a "right fifty" and then, what do you think she did, to make it do this section, right here? Susan?
Susan: Forty five?
Doug: Well she did a "right fifty" but then to make it actually move what did she have to double click on?
Susan: "Forward Fifty"
Doug: "Forward fifty". Then she changed this back to the "right ninety". So Kevin, did you see, she actually changed this number to "right fifty" at one time, but then after that she changed it back to the ninety. That's how she got the diagonal. Once it was on

> that diagonal she could continue to do the "right to ninety" and got some interesting designs (January 20, 1999, 29:00-31:50).

This segment displays Doug's sensitivity to his students' interests and his flexibility in capitalizing upon emergent opportunities for sharing. He allowed a new design idea to be discussed while he promoted norms of sharing and exploration. He accomplished this goal by enabling the student, Nellie, to explain her idea to the class by providing support through questioning and re-voicing. Of course, access to appropriate technological support (e.g., the projection system) aided Doug's pedagogical intervention at this point in time.

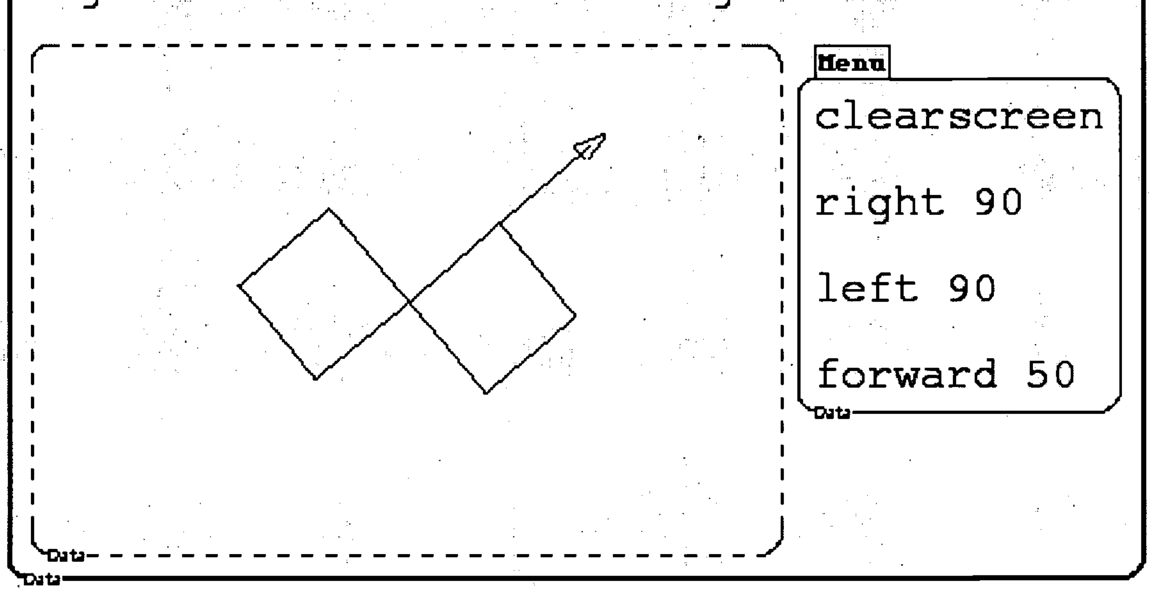
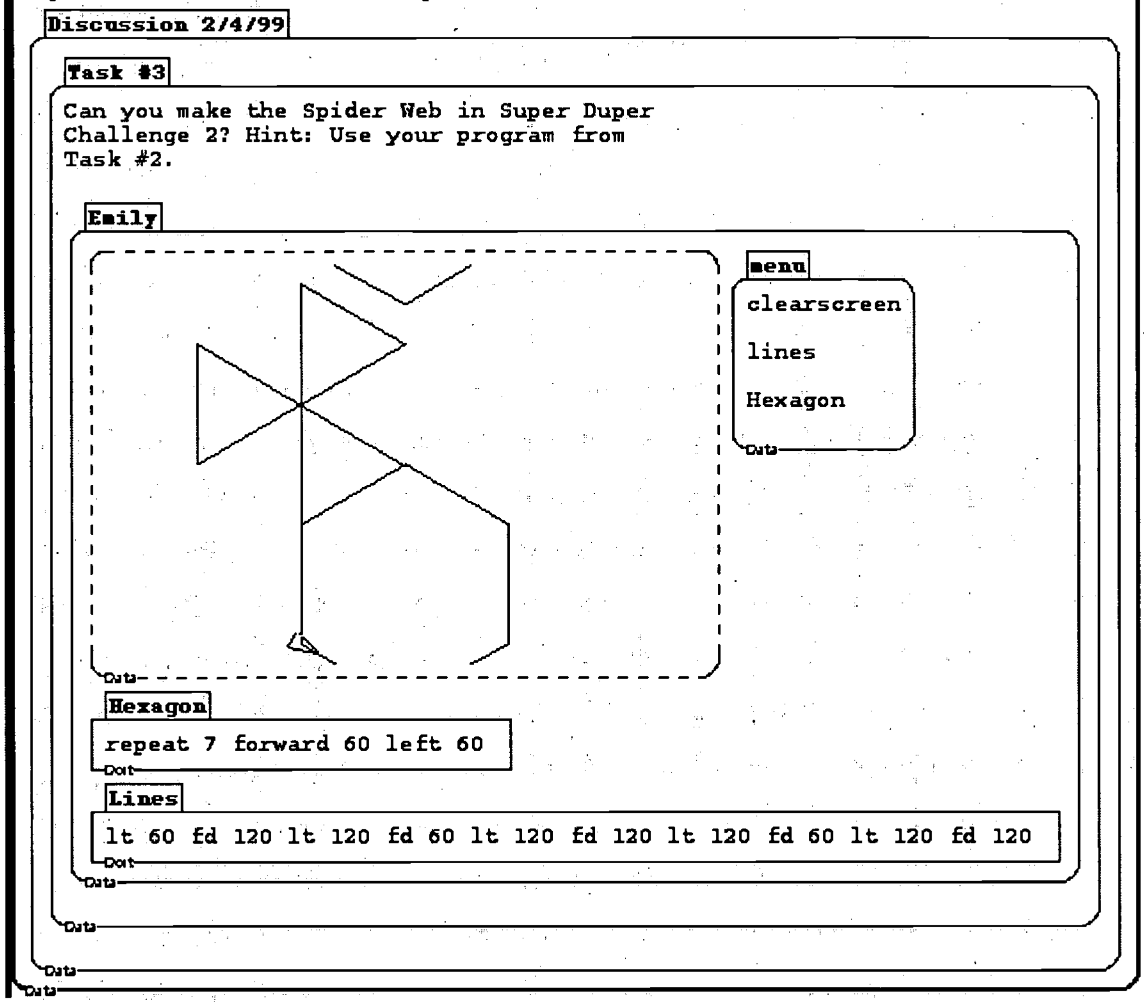


Figure 11 -- Nellie's Design

The discussion of Nellie's design demonstrates how the spontaneous sharing of ideas allowed Doug to provide students with avenues for exploration. An additional challenge that arose for Doug during the Boxer unit was how to accomplish planned interventions that also employ the sharing of students' designs and ideas. This task became easier as Doug acquired knowledge of the types of programs that the students were capable of designing and the geometric shapes that attracted their interest.

Figure 12a: Ellen and Susan's Program



The use of e-mail proved effective as a means of collecting student work and planning interventions that exposed the students to new programming constructs and mathematical ideas. On day ten of sixteen during the third round of the Connections class Doug led a discussion of student programs that were written in response to the following task: can you create a program that makes a “spider web” shape by tessellating equilateral triangles? This task required the students to demonstrate their understanding of angles in turtle geometry and to utilize some advanced programming structures (e.g.,

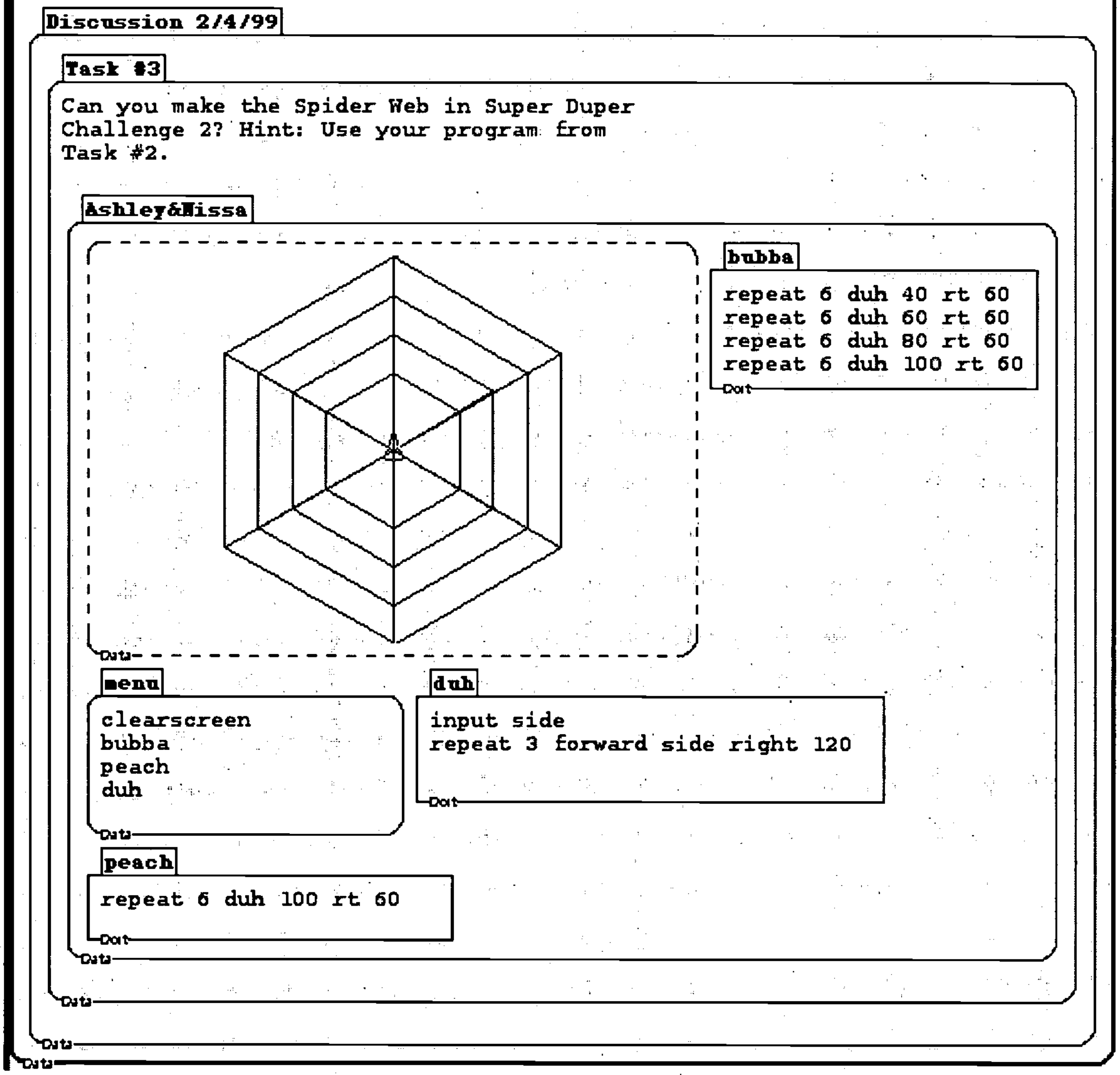


Figure 12b: Arden and Nellie's Program

looping and input statements). Figures 12a and 12b display the programs under discussion in Figure 13. The researcher prepared the microworld containing programs e-mailed by the students to both the teacher and the researcher. The discussion format involved the whole class and the programs and output were projected for the class to view.

Figure 13: Spider Web Programs

> Doug: [see figure 12a] well, first of all, Ellen, if we wanted see that spiderweb what do we need to click on... to create the spiderweb using your menu?
> Ellen: ... hexagon

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Doug: so you want us to double-click on hexagon first, so that makes a hexagon, now to complete this we should do what?
Ellen: lines
Doug: now double-click on lines... [in response to a student] and it's that cube again [laughs]... now did this get all of the lines in there?
Ellen: *I had a way to make all of lines but I couldn't figure it out....* I would make like one triangle part, and then I tried to turn it like left 60 degrees and then make another one, but it kept overlapping with it.
Doug: okay, *so we have the beginning of something here...* Susan, do you have a suggestion?
Susan: yeah, well I think if you click on lines first then it wouldn't do the same thing. It's like at a different point or different angle.
Doug: okay, let's see if we clear the screen and then run the programs in a different sequence.... [the lines program is run] here's the lines by itself and then if you run hexagon does it do the thing [hexagon program runs] [students laugh]... so you see where the triangle was pointing here at the bottom.
Amy: it looks like one of those hats
Doug: yeah. *It is an interesting design*, but this [points to output of lines program] got put inside the hexagon when you ran this [points to output of hexagon program] program first. *A real critical point here is always to remember where that triangle ends up and which direction is it pointing at the end of your program.* That's kind of an important idea. You have the beginning here [points to the output of the programs] and if you work with this we could continue to develop that. *What is missing here that doesn't allow Ellen to make these [hexagons] of different sizes?*
Barbara: *an input*
Doug: an input, yeah. If you tried an input do you think...
Ellen: *I tried that and it makes it so that... it's hard to explain.* It doesn't...It makes one, but then it doesn't go outside of it... it doesn't do what I wanted it to do.
Doug: *oh... okay. Well let's look at a couple others and see if how they work gives you any ideas about how you might be able to use what you started here Ellen.* We'll look at a couple of the other ones. If we could close up Ellen's, please. And, Arden and Nellie if you could look at yours... [a new program window opens, see figure 12b] I remember this command [points to one of the boxes in the window] okay, let's listen real carefully guys.
Arden: yeah, we did the whole program... we basically used duh [a program name] and then put that in with the numbers...it took us a while to get the numbers like that (40, 60, 80,...)
Doug: you're talking about up here [points to the portion of the window that the comment refers to]
Arden: yeah, that took us a while... the like, length, because at first they were too close. First we tried 40, 50, 60, 70,...
Doug: so if we wanted to see the spiderweb
Arden: just press Bubba [name of the program in the menu]
Doug: Bubba is what we want to click on... [program runs] so within Bubba we have the program called duh [laughter]. Now, if we did peach [program name] that was just the hexagon or the cube [hexagon tessellated from equilateral triangles] whatever you want to call it, two-dimensional or three-dimensional,... but you didn't use peach to do Bubba. You went back to... duh.... the triangle... yeah, [to Ellen and Susan] *so, do you see how she used these inputs [points to the input statements in the programs] within the program, so she had that over here [points] that might be something you could look at too and see what you can do with yours [her program].* Any questions for what Arden and Nellie did here? [Italics added] (February 4, 1999, 20:20 – 25:15 minutes)

Here Doug provided alternative ideas and corrective feedback for the students in order to help them successfully complete the assigned task. Ellen and Susan's description of the differences between their intentions in designing their program and the way that the program actually works helped Doug to understand the discrepancy between their performance on the task and the knowledge that they have available to complete the task. Doug recruits this information from Ellen and Susan for the class to reflect on and then he helps Nellie and Arden to explain their program, pointing out the programming structures that this pair employed to solve the problems that Ellen and Susan faced.

In summary, during the implementation of Boxer Doug faced two problems related to his goals for the Connections class. First, he needed to identify instructional formats that would allow students to engage with both the technology and the geometry in productive ways. A primary challenge that he faced was to identify the appropriate balance between online and off-line activities. Second, Doug needed to increase his understanding of his students' capabilities as programmers and as geometrical thinkers. Spontaneous moments of sharing provided some ideas for student exploration while helping Doug to assess student interests. However, structured interventions were also necessary. Doug needed to identify fruitful and interesting ideas for the students to explore in light of their capabilities and knowledge of geometry. This problem connects the technological and pedagogical problems associated with creating instructional interventions that promote particular goals. Two challenges arose for Doug, how to garner and how to deploy the resources necessary for these discussions. During this study the researcher provided feedback in response to Doug's ideas and offered technical support through the creation of microworlds that provided contexts for discussion.

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Learning To Teach with Boxer: Tool Competence and Curriculum Planning

Doug's pursuit of the goals that motivated his use of Boxer required him to learn about the forms of tool competence necessary to use Boxer effectively and to develop a curriculum plan to provide the students with rich opportunities for learning. Two levels of tool competency are required of the students. The first level entails understanding the interface and syntax that support the expression of ideas. The second level enables the students to take advantage of the dynamic nature of the computational medium during online exploration. The challenge of developing a curriculum plan was to allow for the simultaneous development of Boxer skills and geometric knowledge.

The first level of tool competence, using the Boxer interface and programming language, has relatively high costs in terms of instructional time. During the first two rounds of the Connections class Doug gained in his knowledge of the nature of the instructional investment required to promote tool competence with Boxer.

Figure 14: Interface

> Teacher: I guess I'm struggling with how to do this when they type in commands, um, *sometimes they don't even type them in the right place,* they get, they get very confused.
> Interviewer:.Um-hum. Ok.
> Doug:.Um, if they do have it in the right place, sometimes *they'll just start clicking on it over and over again and don't keep track of, really all the steps they took* (Interview 2, Paras 223 to 232).

At this stage in his learning process Doug identified problems that require instructional remedies. For example, he observed that students are struggling with the interface and that they fail to make a useful record of their work. Developing the students' general competence with Boxer required Doug to understand the problematic aspects of the technology before he could design interventions to help students acquire new competencies.

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Doug found that once students acquired comfort with the interface and the programming language they were able to make use of the dynamic feedback provided by Boxer. However, it is not just the dynamic capacity of Boxer that helps students to develop their ideas. Doug learned that it is important for students to produce a record of their thinking during their online activity with Boxer in order to be reflective on their work.

Figure 15: Making a Record of Thinking

> Teacher:.Um, *because I encourage the students to keep track of what they're doing,* but, you know, (?) do not. Um, but, once they...one of the things that, um, it's real...I think a...real powerful component is how they can, um, with the writing of the program, how *they can start to develop their idea, get a program and how they can incorporate that into a bigger one. That's been a real powerful experience for some of the students that have gotten to that point.* [Italics added] (Interview 2, Paras 246 to 252).

Doug also encouraged the use of successive approximation as a problem solving strategy because he believed that dynamic feedback through graphical output has a strong, positive influence upon his sixth-grade students' interest in exploring problems using Boxer. Doug tried to capitalize on the open toolset design of boxer by encouraging students to use their early programs as tools in later work. The spiderweb task shown in figures 12 and 13 exemplifies this effort.

The development of Doug's curriculum for the Connections class required several revisions in response to his assessment of his students' performance. Because of the limited presence of geometry in the sixth-grade curriculum Doug faced new terrain in identifying geometric topics to explore. Doug learned about the existing level of his students' geometry knowledge during his initial experiences with the transformations microworld.

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Figure 16: Sequencing Tasks

> Interviewer: Just to give, some sense of where we're at and what you're thinking, ah, and then, you know, we talked in general about things. From your perspective what have you learned from working with "Boxer" during the first group?
> Teacher: Well,...I, ah, guess I learned that *the students have a good sense of some parts of geometry. There's certain parts that they have a very strong understanding of, but that ah...those other sections that they really struggled with and I think it's really important that with my next group that I think more about the sequence of how I introduce the ideas to help them go from point A to point B* with hopefully less confusion along the way.
> Interviewer: One of the ideas, it sounds like you're breaking down the ideas into kind of ones that the students have an idea about already and ones that they need to develop.
> Doug: For instance, *they have a pretty good strong understanding of what a ninety degree angle is, that concept is pretty strong. But when you try to use, break that into the forty-five even, there are some students were unclear what would happen, they were much more random,* they wouldn't take half of it, ah, when we were at the original part they understood how to make the square. Once they experimented they learned the forward command pretty well and they got the right turn or the left turn, so they could do that but then they would be very confused about where the turtle ended up and what to do to make it do another square or another triangle sometimes in another location. Many of the students were really unclear of what to do with the triangle, how to make that. [italics added] (Interview 1, Paras 1-28).

As Doug identified particular concepts in geometry that required attention this directed his search towards tasks that were accessible to his students both mathematically and in Boxer.

The search for worthwhile tasks required significant knowledge and effort on Doug's part, aided by support from the researcher. Doug learned about his students understanding of geometric concepts through his assessment of their explorations of geometric shapes using Boxer. Below is a transcript of classroom activity portraying a discussion following an on-line test of three programs that students wrote to produce a triangle using turtle geometry (see figure 18 for the Boxer code).

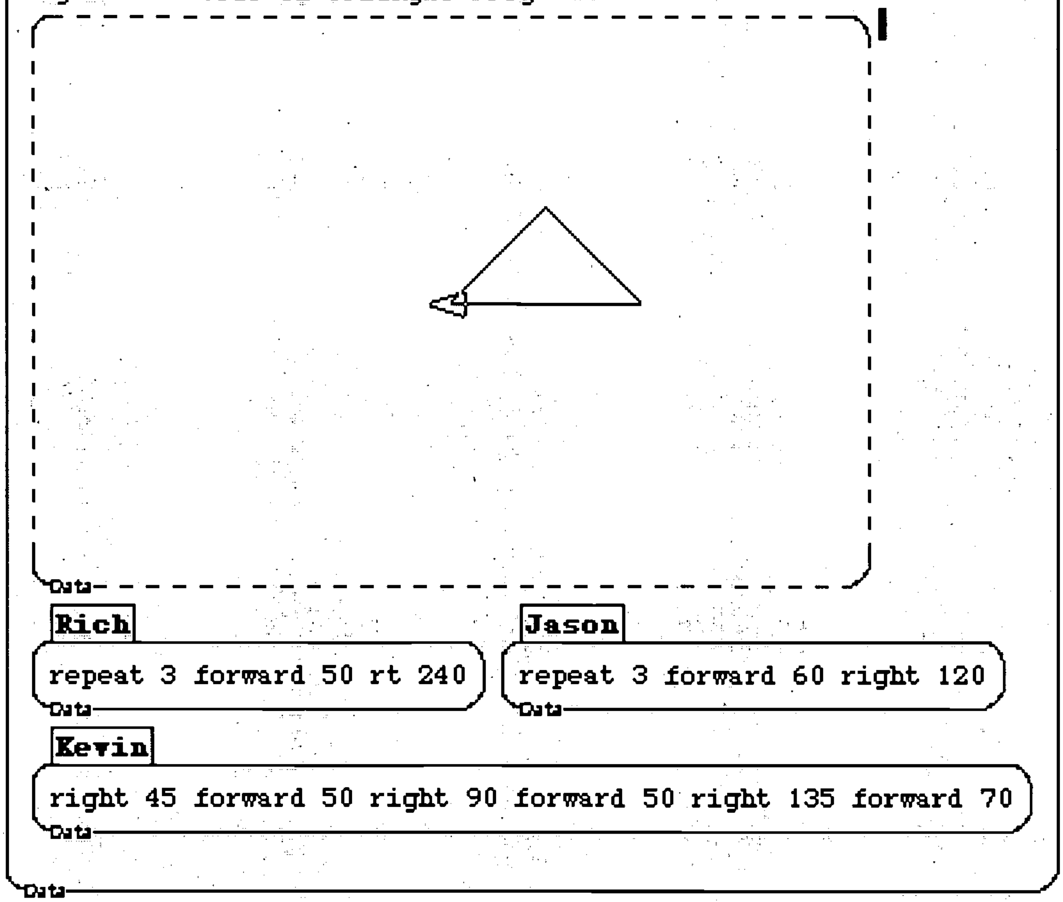
Figure 17: Triangle Programs

> Contextual Note: Three triangle programs written by students have just been tested on the computers in Doug's classroom. Prior to running the programs Doug led a discussion of the programs as they were written on the blackboard. Several of the students had predicted that the third program [Kevin's] would not work. In fact, Kevin's program produces an isosceles right triangle.
> Doug: okay... what do you think is happening on that one [Kevin's program]? They all are triangles... his made a triangle. What happened on that? Why does his work when it's not equal to 360? Come on and sit back down and let's think about this for a minute. I

wish I had this on my overhead, it would be a lot easier to see. But, let's kinda get a sense of what's going on here. Tom, you have an idea?
Tom: well, his angles at the top [gestures with his arms mimicking the two equal sides of the triangle] he's making a [?] Triangle like this... and on the bottom it's longer so it wouldn't be like an equilateral ...
Doug: his is not an equilateral is it?
Doug: Let's look at what our mouse, our turtle, our triangle ... if we do what he says [pointing to Kevin's program on the board] what's the first thing he told our turtle to do? What's the first thing he told the turtle to do? Marianne, do you see what his first command was?
Marianne: right 45
Doug: what would that do?
Marianne: it would turn the...
Doug: triangle, turtle...
Marianne:... right 45
Doug: okay, so we can turn it 45 kinda pointing like that [makes a mark on the board to simulate the turtle at a 45 degree angle to a vertical orientation]... okay, so we've done that [checks off right 45 in Kevin's program]. What would the second command tell it to do? Susan.
Susan: forward 50.
Doug: so, it's going to move 50 spaces... so it's going like this [draws a line at 45 degrees to vertical] and it's still pointing that way, right? What's going to happen next Ellen?
Ellen: it's going to turn right 90...
Doug: right 90, so that's like a right turn... [marks a 90 degree angle at the end of the line segment] so it's going to go like this... and how far is it going to go?
Ellen: 50
Doug: forward 50 [draws a line approximately equal to the first line]. So, it's going to come back down to about this location right? Now the turtle, whatever, is pointing this way right now [draws an arrow at the end of the line segment at an angle of 135 degrees from vertical]. What's his next turn going to do? What's the next turn going to do Barbara?
Barbara: well, it says right 135 so it's going to turn it in.
Doug: okay. If we were able to measure this 135 is going to be heading back this direction isn't it? It's going to point it in that direction. And then it's going to go how far?
Barbara: 70.
Doug: 70. And that's going to take it back over to here. [Draws a line to complete the triangle] questions, ideas, observations...
Contextual note: Doug concludes this discussion with a similar demonstration for one of the other programs (January 28, 1999, 13:55–17:35 minutes).

This segment provides an example of how Doug combined tasks and formats in a way that exposed the students to geometric ideas (e.g., properties of triangles) while increasing their Boxer tool competency (e.g., interpreting turtle geometry programs).

Figure 18: Code of Triangle Programs



The selection of appropriate tasks proved to be the most difficult learning process for Doug as the year progressed. One reason for this difficulty is the relatively small presence of geometry in the sixth-grade curriculum at his school. Through conversations with the researcher regarding the difficulties that his students demonstrated in understanding the use of angles in producing shapes Doug eventually settled upon the investigation of the relationship between the number of sides in a regular polygon and the measure of its angles as one of the capstone experiences of the Connections class. Appendix A contains Doug's lesson plan for this investigation. In this plan Doug makes use of both on-line and off-line learning formats to promote student understanding of the properties of regular polygons. The sequence of tasks in this lesson plan makes use of the features of Boxer that Doug found powerful for his students while providing off-line experiences that explore aspects of the angle relationships that are confusing or difficult to understand in turtle geometry.

Discussion

The corpus of data evidences the process of teacher learning that Doug underwent during the implementation a new technology in his classroom. In this case Doug acquired greater understanding of his students thinking and developed new notions of instructional sequencing and instructional support. The acquisition of the concepts, skills, and notions associated with the implementation of Boxer became a process of negotiation brokered by Doug's existing knowledge in consideration of his students' competencies and interests, his goals, and the affordances and constraints of the technology. Significantly, Doug's goals extend beyond the use of technology to include both a focus on student thinking and the development of habits of mind that support mathematical exploration.

Technology and Constructivist Approaches to Reform

An important agenda of the Collaborative, as well as current reform movements in mathematics and science education, is an increased emphasis on student thinking as a catalyst for teacher decision-making and student learning in the classroom. In this study Boxer served as a resource for Doug to use in his effort to understand the ideas and the knowledge that his students possessed. Doug observed that some students who have been reluctant to share their thinking in the past appeared more willing to do so in conjunction with their work on the computer. Doug's early experiences teaching with Boxer lead him to revise his instructional plan to include tasks and activity structures that helped to bring student thinking to the fore in his classroom during later rounds of the Connections class.

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The data demonstrates how Doug's instruction helped students to engage with new ideas and to share their thinking while working on-line and off-line. We show how providing a prominent place for student thinking is an explicit goal for Doug, and how he used Boxer towards reaching this goal. We believe that an important result from this study is the evidence that the use of technology in a classroom can support a teacher's efforts to increase the presence of student thinking during classroom instruction.

Assimilating Technology into Existing Class Routines

Like many other teachers, Doug demonstrated a strong commitment to both affective and content learning goals in his classroom. Like all good teachers, Doug's pedagogy included routines that he deliberately chose to help him accomplish these goals. The observational data from this study suggests that as Doug learned how to assimilate Boxer into his classroom he came to understand how the technology could be used to support and to enhance many of the existing patterns of activity in his classroom. For example, the discussion of students' triangle programs allowed for dynamic feedback in response to students' conjectures that one of the programs would not work thereby enabling further substantive discussion. In this case the use of Boxer enhanced a typical form of interaction in Doug's classroom, whole class discussions of students' solutions to a problem.

The classroom and interview data suggest that experimentation and sharing are important characteristics of Doug's preferred forms of classroom activity. The fact that Doug learned to employ Boxer in way that amplifies the presence of these features in his classroom is noteworthy because Doug was simultaneously learning about new tasks and new competencies that support student use of technology in the classroom. It appears that the repetition of the Connections class helped Doug learn to assimilate Boxer into existing classroom structures that support his role as an instructional leader. The implication of this finding for researchers, designers and professional developers is that the implementation of technology can be enhanced through a process that helps teachers to learn how to assimilate technological resources into familiar and productive class routines.

Affordances and Constraints of Open Toolsets

The need for educational tasks to serve dual purposes during the use of technology (i.e., promoting tool competency and content knowledge) increases the complexity of the curriculum planning process. Given teachers' work conditions it is too much to ask of a teacher to learn how to employ a technology as a resource in his classroom and to develop a curriculum that engages the students in the exploration of rich content. In this case, as Doug taught and developed an experimental class with the support of a university researcher and the school's computer personnel, we have the opportunity to learn from his experiences. The development of a hybrid curriculum involving both on-line Boxer tasks and off-line activities resulted from extensive redesign of an initial plan that entailed primarily on-line learning. Interestingly, despite the apparent decrease in the percentage of class time that Boxer was in use during his connections class Doug emerged from his experiences with great enthusiasm for the capabilities that Boxer added to his classroom.

One potential explanation for this enthusiasm is the way that Boxer functions as an open toolset. As Doug endeavored to accomplish his instructional goals (i.e., increasing the role of student thinking in his classroom and developing student habits of mind) Boxer provided capabilities that supported his efforts. The programmability of Boxer enabled Doug to redesign the on-line activities that he provided for students in response to his assessment of their knowledge of geometry and their competency as programmers. Moreover, this feature allowed the redesign process to become progressive. Success with individual tasks oftentimes resulted in the creation of programs that could be used to solve more complex problems. For example, the Spider Web task (see figures 12 & 13) built upon a prior task requiring students to produce a hexagon by tessellating an equilateral triangle. This feature of design activity with Boxer, where new ideas become conceptual objects to support further inquiry, served as a catalyst for Doug's thinking as he learned how to use Boxer as a resource in his classroom.

The affordances of an open toolset like Boxer do not come for free, however. While Doug's case provides evidence of a teacher reflecting upon and redesigning the presence of computer resources in his classroom, both his own knowledge of technology and the support of researchers and school computer personnel contributed to his success in this effort. We do not claim that this case provides a model for the implementation of technology into all classrooms. This case does suggest the need for further research into the potential benefits of applying technologies that are designed to function as open toolsets in the classroom. Based on the case of Doug's classroom, one hypothesis worthy of investigation is whether open toolsets can provide a powerful resource for classroom-based reform of instruction because they allow the flexibility necessary for progressive redesign towards a teacher's long-term or emergent goals.

Conclusions

This paper presents results of a study describing the introduction of Boxer, an educational software program designed as an open toolset, in a sixth-grade classroom. The focus of the analysis was the process of teacher learning that occurred during five consecutive implementations of an instructional unit based upon the exploration of geometric ideas using Boxer. Based on the lessons learned by the teacher over the course of six months of instruction using Boxer three conclusions can be drawn that have implications both for the design of educational technologies and professional development of teachers. First, based on the evidence presented in this paper it appears that the use of technology in a classroom can serve as a resource that helps a teacher to increase the focus on student thinking in his/her classroom. This finding suggests that technology can be used in classrooms in ways that support current constructivist-inspired reform movements in education. Second, Doug's apparent success implementing Boxer in ways that support and enhance the existing activity structures in his classroom suggests that the implementation of technology in classrooms can be productively accomplished through a process that helps teachers to learn how to assimilate technological resources into familiar and productive class routines. Third, based on the case of Doug's classroom it appears that open toolsets such as Boxer may provide a powerful resource for the classroom-based reform of instruction because they provide the flexibility necessary for revision in response to a teacher's long-term or emergent goals for instruction. While we believe that each of these conclusions is warranted based on the results of the study, we recognize that because of the nature of this study (i.e., an investigation of a single classroom teacher's experiences) further research will be necessary to support these conclusions. This paper contributes to the field by offering fruitful starting points for such a research endeavor.

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Appendix A

LESSON 6

Location:	Country View Elementary School: the first day in my classroom and the second day in all four classrooms.
Amount of time:	Two days.
Student Objectives:	Reinforce how to use the compass card and metric ruler to draw regular polygons. Students will determine the angle of change required to make a regular polygon in a *Boxer* program. Students will determine and measure interior angles of various regular polygons. Students will explore patterns and make conjectures about the relationships of interior and exterior angles of regular polygons.
Key Concepts:	How to draw and measure angles using a compass card. Regular polygons are ones in which all sides are congruent and all interior angles are congruent. That interior angles measure inside angles of polygons. The angle of change measures the amount of change in direction that the *boxer* turtle made.
Phase I: BOXER AND	Have students share their responses to the problems on the ANGLES worksheet, showing their solutions on the overhead. Hand out the worksheet on BOXER AND POLYGONS along with a compass card and metric ruler. Review the programs that the students wrote for the equilateral triangle and the square, encouraging the students to think of using the repeat command. Have the students draw out their programs on the back of the worksheet, being sure to clarify that all groups have successful

written a program for both polygons and can draw the shapes using the compass card and ruler.

Clarify that the *interior angles* are located on the inside part of the polygons.

Have the students measure the interior angles of the two polygons. Ask them to note any observations about what happened to the interior and the angle of change as they moved from the triangle to the square.

Be sure to circulate around to see that all students are correctly measuring the interior angles.

Make sure that all students understand that for the equilateral triangle the angle of change was 120 ° and its interior angle was 60 °. Also that the square has an angle of change and an interior angle of 90 °.

Phase II:

Have students, with their partners, make conjectures about what they think will be true about the angles of change and interior angles for the regular pentagon and hexagons. Have the students share their conjectures with the class and explain their reasoning behind them.

Have the students go to their computers and type in their programs. Go around to each group and have them share their thoughts on what happened. If their program did not work, ask them to think about what they could change in their program. If their programs did work, have them continue to look at the other polygons listed and attempt to write programs that will create them.

Have students come back to the large group and share their findings.

Ask the students if they noticed any patterns or relationships between the number of angles in a polygon and the angles of change. Also ask them to look for a relationship between the angles of change and the interior angles of the polygons they have created so far. Sometimes I find it helpful to direct the students' attention back to the compass card and ask them to think about how many degrees the turtle would change if it went around the compass card completely.

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So far I have had success in all my classes with students coming up with their own rules or relationships. The two relationships that students need to see are the following:

1) **Number of angles X the angle of change = 360 ° or that 360 ° ÷ the number of angles = the angle of change.**

2) **Angle of change + Interior angle = 180 ° or that 180 ° - angle of change = the interior angle.**

Have the students complete the rest of the worksheet and then go to their assigned computers to write in their programs to make sure that they work. Students should check the angle of change and interior angles on the polygons using the compass cards.

Assess the students' work by circulating among the various groups and have them explain how their programs work and their understanding of the angles of change and interior angles.

Have the students come back together as a large group. Have them write down a program that they think would work for a 20-sided polygon and identify what they predict its angle of change and interior angles would be.

Hand out challenge shapes worksheet for students to work on during free time or whenever they finish up with other assigned activities.

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BOXER AND POLYGONS

NAME ____________________

REGULAR POLYGONS	PROGRAM	NUMBER OF ANGLES	ANGLE OF CHANGE	INTERIOR ANGLES
EQUILATERAL TRIANGLE				
SQUARE				
PENTAGON				
HEXAGON				
HEPTAGON				
OCTAGON				
NONAGON				
DECAGON				

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