Design, Collaboration, and Computation: the design studio as a model for computer-supported collaboration in mathematics

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Abstract
The introduction of computational media to education has made the idea of learning in an open-ended, design-based environment appealing to educators. One important feature of such environments is the extent to which students are able to collaborate with teachers, experts and with their peers without losing control away their control of their own learning process. This paper looks at the architectural design studio as a model for dealing with this balance between control and collaboration in open-ended learning. In particular, this paper looks at using computers to create a "mathematics studio" where students learn mathematics using the pedagogy of the design studio. The paper presents two studies: one of how the design studio provides a model for collaborative work, the other exploring the use of computers to adapt the studio model to mathematics learning.

These two studies show that the design studio can provide an effective model for thinking about collaboration through design activities, and that the design studio model can be used successfully in mathematics learning with the help of computer technology. This research also suggests that whatever model we take for supporting collaborative activities, students' experiences of collaboration are strongly influenced by their sense of control over their learning process.

Keywords: architecture education, collaborative learning, computers and learning, design education, design studio, ethnographic case studies, interview studies, mathematics education, qualitative research, student autonomy, technology and education

Introduction

Since the writings of Francis Parker and John Dewey (Parker 1894/1969, Dewey 1915), educators have been excited by the possibilities of learning through design activities. The introduction of computational media to education has made this idea only more appealing, as educators saw how computers could make it possible to explore more areas of human understanding in an open-ended, design-based environment (Papert 1980, Kafai & Harel 1991, Resnick & Ocko 1991, Papert 1993, Wilensky 1995, Noss & Hoyles 1996). One important issue in the open-ended approach of learning-by-design is the need to provide students with skills to regulate their learning activities effectively (see Dewey 1938).

Two of the essential skills in learning are clearly the ability to direct one's own work and the ability to work with others. Dewey wrote in great detail about the role of freedom and social control in students' development, suggesting, in particular, that "freedom" is a necessary (though not sufficient) condition for the development of self-control. By "freedom" Dewey meant not only the physical freedom to move in space, but also the more important freedom to make decisions, to "frame purposes" and to exercise judgment (Dewey 1938). Other theorists similarly emphasize the extent to which learners must control their learning experiences (Sizer 1984, Papert 1991, Gardner 1993). In the same way, many learning theorists have argued that collaboration is a critical part of cognitive development. Vygotsky, for example, argued that the immediate potential for cognitive development (the "zone of proximal development") could only be fully realized in a collaborative context (Vygotsky 1978). But there is an even broader (and growing) consensus that an essential part of learning to think is learning to think with others (see, e.g., Pea 1993, Bruner 1996).

Finding a balance between self-directed activity and activity coordinated with others is thus an essential skill. For students to be successful in a relatively autonomous learning (or working) environment, they need to learn how to work independently, how to collaborate with their peers and with experts in their learning process, and how to balance these two modes of working and thinking.

This paper proposes one way of thinking about computers and learning that provides a structure for helping students develop these skills and find this balance. The paper looks at the architectural design studio as a model for learning in more traditional domains. In particular, it looks at the possibility of using computers to create a "mathematics studio" where students learn mathematics using the pedagogy of the design studio. The paper presents two studies. The first explores how the design studio provides a framework for collaborative work without taking control away from students. The second study examines the use of computers to adapt the studio model to mathematics learning.

Portrait of a Studio: Understanding Design Learning

The first study was of a design studio course taught at the Massachusetts Institute of Technology School of Architecture and Planning. The course was a mid-level architecture studio for undergraduate and graduate students, taught by a member of the school's junior faculty. For the study, an observer (this paper's author) was present for roughly one quarter of the studio's teaching hours. Observations focused on the work of five students in the studio, with an in-depth observation of one student's learning process. Direct observations of the studio were supplemented by detailed interviews with students and teaching staff.

The lay of the land

Walking into a design studio is quite unlike walking into a typical class room. In the MIT studios, 11 students have more space for their own individual drafting areas than most high schools provide for a class of 25-30 students. In addition to this space for individual drafting, the studio uses a meeting space the size of a typical seminar room, as well as a large open space for formal presentations of student work.

The pace of work in the studio is also quite unlike a traditional class. Studios at MIT meet from 2-6 pm three days a week. But these are more rough guidelines than a fixed schedule. Students and teaching staff routinely come to studio before or after 2 pm depending on the work they have to do on a particular day. Students and teachers often come in at night or on weekends as project deadlines approach. At any given time during "official" studio hours a class may be meeting around a seminar table discussing projects. Or students may be working at their desks. Or checking email. Or stepping out for a cup of coffee. Or meeting with faculty.

This informal approach to time in the studio makes it difficult, sometimes, to organize activities. Students may not all be present for a class discussion, and even major events in the semester, like final reviews, routinely start late and have participants drifting in and out. Problems of time management also come up for students; work is routinely left until the last minute and sometimes suffers as a result. But the large blocks of time allotted to the studio and the flexibility of the routine also make it possible for students to organize collaborative conversations with teaching faculty and with other students as the need for input in the design process demands. And the relative autonomy of students in the studio makes it possible for teaching staff to spend concentrated blocks of time with some students while others are working on their own.

The crit cycle

The focus of the architecture studio observed for this project was the design of a new business school for Oxford University in Britain. For purposes of this discussion, though, the specific details of the architectural explorations of the Oxford studio are less important than understanding that the semester of design learning was organized around a series of six assignments on a single project.

A typical assignment was a page or so of written description accompanied by some discussion and clarification from the professor. This would include a summary of the assignment's requirements, explanation of the reason for the particular assignment, description of the professor's expectations, and almost always discussion of examples of work for students to use as models. After this initial introduction, students began working on their response to the assignment. As questions came up, as students ran into problems in their emerging designs, or when students finished some coherent stage of their design process, they would sign up for individual conferences with the professor or with a teaching assistant.

These conferences are known as "desk crits," and are in a sense the heart of the studio process. Crits usually lasted somewhere between 20 and 40 minutes in the Oxford studio. During a crit, a student describes his or her work to the professor, including areas of particular interest or concern in the design. The professor probes the design, asking for clarification where needed, and then isolating potential problem areas. As students present possible solutions, the professor explores the implications of various design choices, suggesting alternative possibilities, or offering ways for the student to proceed in his or her exploration of the problem.

Based on this feedback, the student returns to his or her project, perhaps signing up for a desk crit again before the presentation of the assignment, perhaps asking for a desk crit with a teaching assistant. Or the student might work out some of the details of the problem in a desk crit with another student. The desk crit with the professor provides both an opportunity to develop a student's design understanding *and* a model for collaborative work with others.

Pedagogy of the crit

The pedagogical core of the desk crit is the idea of scaffolding. In each assignment—and often several times during an assignment—a student meets with members of the teaching staff or with other students for a detailed discussion of his or her work During these discussions, the "critic" works to understand what the student is trying to do with his or her design, and then help him or her develop that design idea. This help can take many forms, including offering suggestions, pointing out potential problems, or referring to examples of work by other architects that have addressed similar problems. Often critic and student will "design together," with the critic sketching quickly a series of design possibilities, exploring the consequences of possible design choices. In doing so, the critic both offers design ideas and models design thinking.

From a pedagogical perspective we can understand the desk crit in terms of Vygotsky's idea of a zone of proximal development (Vygotsky 1978). Vygotsky argued that development is a process whereby learners progressively internalize processes they can first do only with the help of others. The zone of proximal development is the set of things we can do with the help of others, but not quite do on our own. In the desk crit, the professor—or another student—provides design skills and knowledge that the student lacks. The student is designing, as it were, beyond his or her reach with the help of another. As the student becomes more sophisticated, the feedback moves to a higher level, helping the student take the next steps on the path to good design.

A model for collaboration

The design studio thus provides a provocative model for thinking about collaborative learning. Donald Schon has written at length and with substantial insight about the nature of the desk crit and its importance to learning in the design studio (Schon 1985). In Schon's analysis, the crit provides a framework for interaction between the professor and student that allows the professor to develop the student's design skills and knowledge through collaborative work on the student's design. Perhaps more important from the perspective of collaborative learning, though, the crit also provides a model for design conversations more generally: when students meet to discuss their work, they talk about "giving" or "getting" a crit from one another. Last, but certainly not least, the organization of the design studio makes it possible for these collaborative conversations to take place during a student's design process. Students have the time and the freedom to ask for a design crit—a structured collaborative conversation—when and where they need it.

A Digital Math Studio

The second project described here was an attempt to take the basic structure of the design studio and apply it in a traditional domain. The Escher's World research project at the Massachusetts Institute of Technology Media Laboratory brought twelve high-school students from public schools in Boston, Massachusetts to the Media Laboratory for twelve hours during the spring and summer of 1995. In these workshops students used computers to learn about mathematics and art simultaneously. The emphasis throughout the workshop was on creating an open, studio-like atmosphere for learning. Students were encouraged to sit and work where they liked, to use media of their own choosing, to collaborate or work alone as they wished, to eat, take breaks, go to the bathroom, and change projects at their own discretion.

About the workshops

Workshops were divided into two sections; the first section was organized around the concept of mirror symmetry, the second around the concept of rotational symmetry. The majority of the day was spent on investigations and explorations of these concepts. Investigations lasted approximately one hour, with students working on short problems on their own or in small groups and discussing their observations. Based on their investigations, students spent two to three hours working on extended projects in design on their own or with a partner. Students worked on one shorter project (approximately one hour), presented their work to the group for discussion, and then began a more ambitious project (approximately two hours), integrating ideas about symmetry, principles of design, and feedback from their presentation. For example, in one project, students made graphic designs that used mirror symmetry but moved the focus of the picture away from the center of the image (see **Error! Reference source not found.**). In another project, students tried to create designs that used rotational symmetry but created an unbalanced composition (a very difficult design challenge, as it turned out).

Workshops took place in a conference room at the Media Lab that had been modified to resemble an art studio. Macintosh computers were provided, with one computer available for every two or three students. The computers were networked to flatbed scanners, color printers, and a large format color plotter. Computers were equipped with commercial drawing and image-manipulation programs and with commercially-available dynamic geometry software (the Geometer's Sketchpad). During the investigation portion of the workshops, students were introduced to some of the basic functionality of these programs. Students were able to work on the computers or with traditional materials during their explorations; all of the students chose to use a computer for some portion of their work.

Student Work in Escher's World

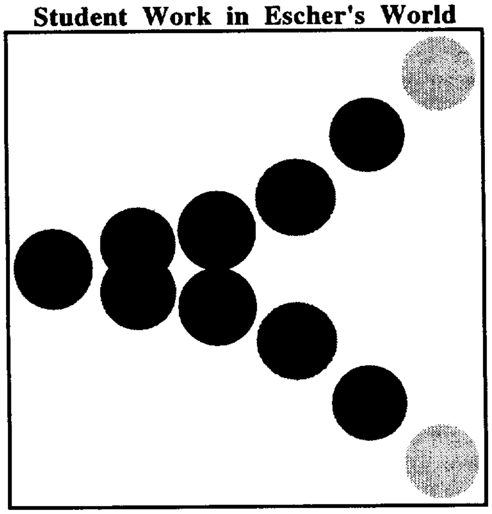

Figure 1: Student Work in Escher's World: One student's exploration of mirror symmetry and its effect on the focus of a viewer's attention to a design. The original was in color.

Data Collection

The main source of data for the Escher's World workshops was structured interviews with each student immediately before and after the workshop, and then two to five months after the completion of the workshop. Interviews contained (1) a series of questions about mathematics and art, focusing particularly on attitudes towards these disciplines, (2) a detailed discussion of four works of art from a set of seven images, and (3) two to four mathematics problems from a set of 16 problems.

Results

Mathematics Learning

The results of the Escher's World project are presented in more detail in several previous papers (Shaffer 1997, Shaffer in press). Briefly put, during the Escher's World workshops, students developed their understanding of the mathematical concept of symmetry. During the workshops all of the students (12/12) were able to make designs using mirror symmetry, and 83% of the students (10/12) were able to make designs using rotational symmetry. Only 1 of 12 students was able to use and explain ideas about symmetry before the workshop, whereas 11 of 12 students were able to do so after completing the workshop. After the workshop students were able to find new examples of symmetry in the world around them: 75% of the students (9/12) reported thinking about symmetry beyond the context of the workshop in post interviews or follow-up interviews. Students reported seeing symmetry in drawings, chairs, wallpaper, rugs, video games, flowers, and clothing.

Students also began to use visual thinking, and began to like mathematics more as a result of the workshop. Before the workshop, only 33% of the students (4/12) used visual representations such as a drawing or diagram to solve word problems in interviews. After the workshop 75% of the students (9/12) did so. In post-interviews and follow-up interviews, 67% of students (8/12) reported feeling more positive about mathematics as a result of the workshop. This reported change was supported by survey data (collected for 6/12 participants), where the overall rating for questions about feelings towards mathematics went up for 67% of students surveyed (4/6).

Understanding the success of Escher's World

Students learned about the mathematical idea of symmetry in the Escher's World workshops, and learned to apply visual thinking skills to mathematical problem solving. At the same time they discovered they liked mathematics and liked this new kind of learning environment. One student said simply: "If school was like this, attendance would be perfect!" Previous work has looked in some detail at how this kind of "mathematics studio" learning environment "worked" for students (Shaffer 1997). This earlier work shows the importance of students' sense of control over their learning in the studio setting.

Here the key question is whether and how the collaborative interactions of the "studio model" helped generate positive results in this computer-supported application of design pedagogy in learning mathematics. The data from the Escher's World project shows that collaboration played an important role in students' learning. Moreover, the fact that the studio setting gave students control over their collaborative interactions was a key part of the success of the studio.

There were several ways in which students talked about feeling as if they were in control of their collaborations during the workshops, but the most prevalent comments were about students' control of the timing and extent of their collaborative activity. Students talked about their ability to decide for themselves when to work alone, when to work with a peer, and when to consult with an adult. One student said simply: "[In the workshop] if I don't know something, I just ask you or other friends to sit by me. In class [at school] you can't talk." Similar sentiments were echoed in two-thirds of the comments where students talked about both control and collaboration. In almost all of the comments about working with peers (16/19) and about getting help from adults (16/18), students talked about the fact that in the workshop they were in control of how and when these interactions took place.

Student Interview Responses (Proportional by Area)

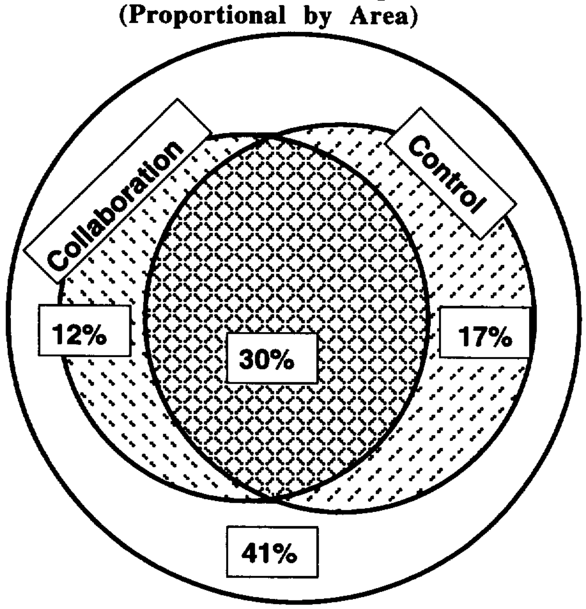

Figure 1: Student Interview Responses: Student's references to collaboration and control in Escher's World show substantial overlap. The area of the regions on the diagram are proportional to the percentage of total student references in each category (Collaboration but not Control = 12%, Collaboration and Control = 30%, Control but not Collaboration = 17%, neither Control not Collaboration = 41%).

A look at the relative frequency of student comments overall about Control and Collaboration make it clear that these were critical issues in students' experiences of the Escher's World mathematics studio (see Figure 1). Referring to the theoretical work described above in the introduction, excerpts from interviews in the Escher's World project were coded for Control when students referred to freedom of physical as well as intellectual movement, when they talked about making their own choices, judgments, or decisions—in short, when they described in a positive or negative way the effects of their own control (or lack of it) in their learning experience. Similarly, excerpts were coded for Collaboration when students referred to ways in which their learning experience was affected by the active participation of others (or lack thereof). This included descriptions of help given to or received from adults or peers, joint work with others, public presentations and feedback on ideas or work, and conversations or other "purely social" interactions—in short, Collaboration refers to the range of students' relations to other people as it connects to their learning experiences.

By these criteria, more than half of the excerpts from interviews about the studio as a learning environment (73/123 or 59%) were about either students' feelings of control over their learning experience or students' collaborative interactions with others. Perhaps more interesting, students' comments in these areas show significant overlaps. Students referred to both control and collaboration in 36 excerpts—that is, in almost 75% of the comments about collaboration students referred to the importance of feeling in control of their learning experience. Overall, student comments about collaboration were correlated with comments about control with $r=0.79$.

Conclusion

These two projects thus show that the design studio, with its combination of loose schedule and structured desk crits, provides a useful model for thinking about collaborative activity in an open learning environment. The design studio provides a framework for collaborative activity that preserves student autonomy in the learning process and provides a model for collaborative interactions. This work also shows that the design studio model can be used successfully in other disciplines with the help of computer technology. Other papers have described in some detail the role that computers played in making the Escher's World project work (Shaffer 1997). Here what is most important is recognizing the design studio as a potential model for computer supported collaborative learning environments.

Perhaps most important, this research suggests that whatever model we take for supporting collaborative activities, students' experiences of collaboration are strongly influenced by their sense of control—or lack of control—over their learning process. Learning to work with others is an essential skill, particularly for the modern workplace. This work suggests that some care is needed in thinking about how create an environment where both collaboration and personal control of the learning process are given adequate support to help students master a domain like mathematics or design. The design studio may offer a model for one solution to this delicate balancing act.

References

Bruner, J. S. (1996). *The Culture of Education.* Cambridge, MA: Harvard Univ. Press.

Dewey, J. (1915). *The School and Society.* Chicago: Univ. of Chicago Press.

Dewey, J. (1938). *Experience and Education.* New York: Collier Books.

Gardner, H. (1993). *Multiple Intelligences: The Theory in Practice.* New York: Basic Books.

Kafai, Y., & Harel, I. (1991). "Learning through design and teaching: exploring social and collaborative aspects of constructionism." In I. Harel & S. Papert (Eds.), *Constructionism* Norwood, NJ: Ablex Publishing.

Noss, R., & Hoyles, C. (1996). *Windows on mathematical meanings: learning cultures and computers.* Dordrecht, The Netherlands: Kluwer Academic Publishers.

Papert, S. (1980). *Mindstorms: children, computers, and powerful ideas.* New York: Basic Books.

Papert, S. (1991). "Situating constructionism." In I. Harel & S. Papert (Eds.), *Constructionism* Norwood, NJ: Ablex Publishing.

Papert, S. (1993). *The children's machine: rethinking school in the age of the computer.* New York: Basic Books.

Parker, F. W. (1894/1969). *Talks on Pedagogics.* New York: Arno Press.

Pea, R. (1993). "Practices of distributed intelligence and designs for education." In G. Salomon (Eds.), *Distributed Cognitions: Psychological and Educational Considerations* Cambridge: Cambridge Univ.

Resnick, M., & Ocko, S. (1991). "LEGO/Logo: Learning through and about design." In I. Harel & S. Papert (Eds.), *Constructionism* Norwood, NJ: Ablex Publishing.

Schon, D. A. (1985). *The Design Studio: An exploration of its traditions and potentials.* London: RIBA Publications.

Shaffer, D. W. (1997). "Learning mathematics through design: the anatomy of Escher's world." Journal of Mathematical Behavior, 16(2).

Shaffer, D. W. (in press). "Escher's world: learning symmetry through mathematics and art." Symmetry: Culture and Science.

Sizer, T. R. (1984). *Horace's Compromise: The Dilemma of the American High School.* Boston: Houghton Mifflin.

Vygotsky, L. S. (1978). *Mind in Society.* Cambridge, MA: Harvard University Press.

Wilensky, U. (1995). "Paradox, programming, and learning probability: a case study in a connected mathematics framework." Journal of Mathematical Behavior, 14, 253-280.