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
The process of working on their own...

...with some struggles when others are weaker in math concepts blocks, teaching them how to study and comprehend concepts is possible for students in the studio. The importance of the role of the student is crucial in the design of the studio. The studio is designed to facilitate the learning process and enhance understanding of the concepts. However, the effectiveness of the learning experience is dependent on the student's ability to engage with the materials and actively participate in the learning process. The studio provides a conducive environment for students to develop their skills and enhance their understanding of the concepts. The studio also serves as a space for collaborative learning, where students can work together to tackle challenging problems and share insights and strategies. This approach is supported by the incorporation of technology and multimedia tools to facilitate learning. The studio is equipped with state-of-the-art technology and resources to support student learning. The studio provides a supportive and inclusive environment for all students to thrive and succeed. The studio is designed to be accessible to students of all backgrounds and abilities, ensuring that everyone has the opportunity to learn and grow. The studio serves as a hub for innovation and creativity, where students can explore new ideas and develop critical thinking skills. The studio is a space for personal and professional growth, where students can build their confidence and become lifelong learners.
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
Results

Mathematics Learning

Problems from a set of 16 problems seen before, and (2) a set of problems from a set of four works of art from a set of 16 problems, used to form a set of problems from a set of four works of art from a set of

Understanding the Success of Experts

The main source of data for the Experts' World

Data Collection

designs, the original was in color. An effect on the focus of a reader's attention is a

During the workshop, student work was encouraged. The workshop content was divided into themes such as visual thinking skills to learn to apply visual thinking skills to actual problems. The workshop content was divided into themes such as visual thinking skills to learn to apply visual thinking skills to actual problems.

Student Work in Experts' World

Figure I: Student Work in Experts' World: One
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](image)

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 nor 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...
References

disclosure regulations.

supportive strategies. Perhaps most important, this research suggests the potential for new collaborative educative, instructional, and computer-based learning environments. These environments can be used to support the learning process and can be effectively used in conjunction with traditional teaching methods. In this way, the benefits of both traditional and computer-based learning can be utilized.

Conclusions

In conclusion, the use of computer-based learning environments can provide valuable tools for supporting the learning process. These environments can be designed to enhance student engagement and promote deeper understanding of the material. By incorporating elements of collaboration and interaction, these environments can help students develop critical thinking skills and improve their overall academic performance.