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Abstract

The ill-structured nature of design problems makes them particularly challenging for problem-based learning. Studio-based learning (SBL), however, has much in common with problem-based learning and indeed has a long history of use in teaching students to solve design problems. The purpose of this ethnographic study of an industrial design class, an architecture class, and three human-computer-interaction classes was to develop a cross-disciplinary understanding of the goals and expectations for students in a SBL environment and the ways in which experienced facilitators assist students in solving complex design problems. The expectations that students are to iteratively generate and refine design solutions, communicate effectively, and collaborate with others establishes the studio as a dynamic place where students learn to experiment on their own, to teach and to use all studio members as resources in that search. Instructors support students as they grapple with complexity of design problem-solving through pedagogical practices that include assignments, associated meta-discussions, explicit prompts, reminders, modeling, and coaching. Using sample illustrations from our cross-case analysis, we present the studio method as a legitimate constituent of problem-based learning methods.

Introduction

Jonassen and Hung (2008) have pointed out the challenges to the use of design problems within problem-based learning (PBL). While they note that diagnosis-solution problems, decision-making problems, situated case/policy problems, and design problems are all appropriate for PBL, they concluded "the extremely high level of ill-structuredness [of design problems] may present challenges or even negative effects on students' learning in PBL environments" (2008, p. 21). Whereas diagnosis-solution, decision-making, and

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situated case/policy problems involve narrowing the solution options, design problems involve multiple possible solution paths, "dealing in the process with many variables and constraints, some initially known and some discovered through designing" (Schön, 1987, p. 42). Indeed, Jonassen has noted that design problems "are usually among the most complex and ill-structured kinds of problems that are encountered in practice" (2000, p. 80). Yet Jonassen and Hung (2008) also acknowledge that the need to solve design problems is at the center of certain professional practices. The education of engineers, instructional designers, architects, landscape designers, and the like must, by necessity, prepare students to solve the very complex and ill-structured design problems with which they must grapple as professionals.

Jonassen and Hung (2008) further noted that design problems might be more suitable to studio-based learning (SBL) than PBL. In this paper, we argue that SBL can be considered a type of PBL where students learn to solve problems to which there are multiple solution possibilities. Just as Hmelo-Silver and Barrows (2006) have identified the goals and facilitation strategies used to support students as they learn to solve medical diagnostic problems, the purpose of this study is to identify the a) expectations for students within SBL and b) facilitation strategies used by experienced teachers to guide students through the design problem-solving process.

Towards these ends, we have conducted an ethnographic study of the studio method as implemented in one industrial design class, one architecture class, and three human-computer-interaction (HCI) classes that used a modified version of the studio method. In this paper, we present the intellectual foundation of our work followed by the results of our study that examined the ways in which experienced studio teachers support students as they learn to solve problems in which there are a variety of solution options.

Studio-based Learning, Problem-based Learning, and the Nature of Design Problems

SBL originated in the Bauhaus School of Design during the early 1900s in Germany (Bayer, 1975) and later was adopted as a key component of a variety of college and university design programs (Schön, 1985, 1987). The studio, as commonly used in design-related curricula such as architecture, landscape architecture, interior design, and industrial design, consists of a space where students are assigned individual desks that are, in most cases, available to them at all times. Studio classes typically meet multiple times a week for three- to four-hour sessions, with students encouraged to work in the studio rather than at home during off-hours.

In their studio classes, students are presented with a design problem, work individually or in groups to solve it, and subject their work to reviews during formal and informal critiques. The course instructor typically does not conduct traditional "lectures" but instead

orchestrates experiences that lead students to new insights in their work. For example, industrial design students asked to design an innovative teapot may be assigned to study trends in teapot design throughout history in order to develop an understanding of the form and function of the teapot. When designing a hand-dispenser for medicine, they may work with an artist to prepare sketches of the hand in order to develop an understanding of the hand's anatomy.

The primary means through which students' design knowledge is refined is through the project critique, or crit. Encompassing desk-crits, pin-ups, juries, and project reviews (Dannels, 2005), critiques provide opportunities for students to present their design solutions, articulate their reasoning, and receive feedback from faculty, peers, and occasionally guests. Critiques occur formatively throughout a project's development, as when faculty circulate throughout student work groups offering input on the design process or call for spontaneous pin-up sessions, as well as at the completion of a project.

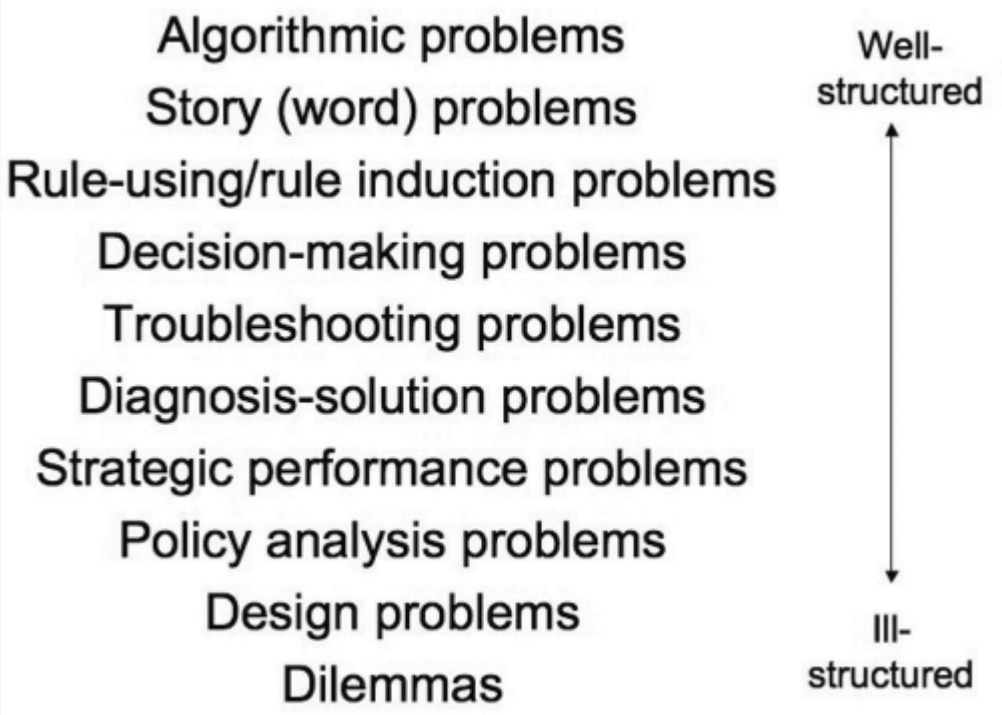
Although on first glance, SBL seems different from PBL, Monson and his colleagues (2008) came to see SBL as a type of PBL through the course of their 5-year project to teach both methods to pre-service teachers, education faculty, and public school teachers. SBL, as with PBL, represents a comprehensive student-centered approach to learning to "conduct research, integrate theory and practice, and apply knowledge and skills to develop a viable solution to a defined problem" (Savery, 2006, p. 12). Like PBL, SBL is organized around a realistic problem. Students work in groups or individually to solve the design problems and periodically present their emerging solutions for critique. As in PBL, students must seek, integrate, and apply knowledge from a wide variety of disciplines or subject matter relevant to the problem solution. They initially engage with the problem at their current level and are responsible for seeking additional knowledge when needed to solve the design problem. Peers are regarded as valuable resources and collaboration with other class members is essential to the success of both PBL and SBL experiences.

Monson and his colleagues initially treated PBL and SBL as separate teaching methods; however, they came to see them as similar, differing primarily in the breadth of the initial problem and the breadth of the resulting solutions. Whereas Jonassen (2000) classified ten problem-types on a continuum from structured to ill-structured (see Figure 1), Monson (2008) classified problems into four primary types based on the breadth of the initial problem and the breadth of the resulting problem solutions (see Figure 2).

As indicated in Figure 2,

- Linear problems involve a limited number of parameters and there is a correct solution. The most structured type of learning problem, linear problems would include algorithmic and story (word) problems in Jonassen's (2000) classification scheme.

Figure 1. Typology of problem types (Jonassen & Hung, 2008, p. 12).



- Diagnostic problems involve many complex aspects; however, the trajectory from problem to solution is "always a function of narrowing possibilities" (Monson, 2008, p. 9-10). This category includes Jonassen's (2000) decision-making, troubleshooting, diagnostic, and policy analysis problems.
- Inductive problems may have a wide variety of possible solutions, however, the parameters of the problem itself are limited. For example, Monson (2008) uses the example of "playing Bridge" to illustrate the fact that many possible solution paths may be present, but the rules of bridge are limited. Jonassen's (2000) rule using/rule induction problems and strategic performance problems would be included in this category.
- Ambiguous problems are complex with a variety of solution possibilities. Monson (2008) contrasts "playing Bridge" with "playing dolls" to illustrate the differences between the rule-bound problems of Bridge and the ambiguous nature of "playing dolls." This category includes Jonassen's (2000) design problems and dilemmas.

Monson (2008) considered both inductive and ambiguous problems to be "design problems" because "the path of problem to solution maintained or increased possibilities rather than diminished them" (p. 10). When considering ways to facilitate students'

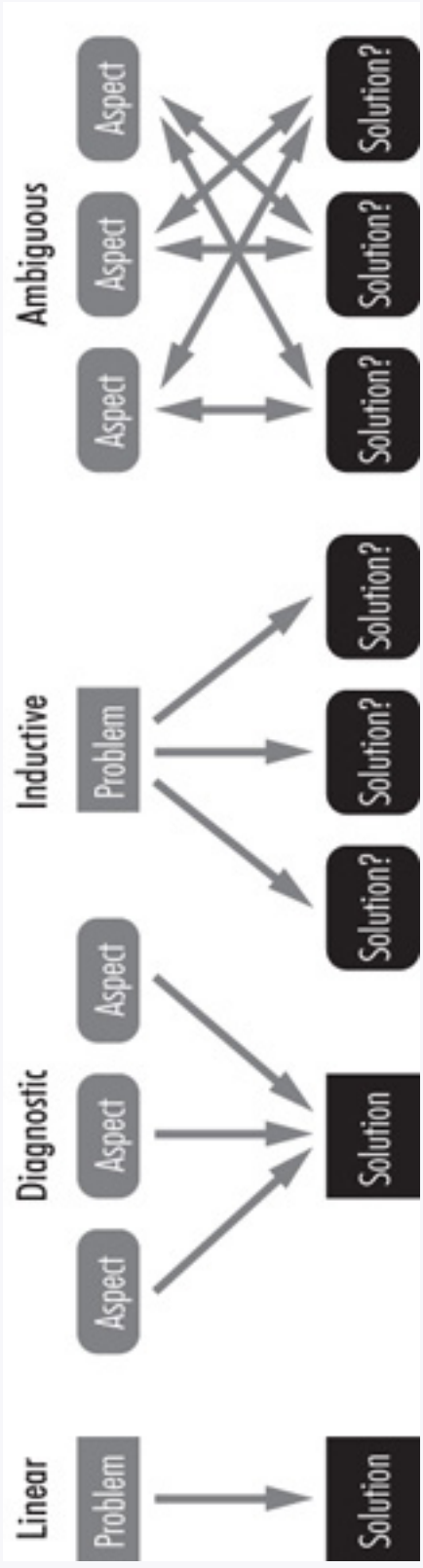


Figure 2. Problem types (Monson, 2008, P. 8).

design problem-solving processes, we have found the distinction between divergent and convergent problem-solving processes to be useful; it seems intuitive that the teacher's strategies would be different when the goal is to narrow the solution possibilities than when the goal is to expand them. It is this issue of teaching strategies to which we turn our attention next.

Goals and Facilitation Strategies for PBL

Hmelo-Silver and Barrows (2006) have provided insight on the strategies that experienced teachers use to support students as they learn to narrow solution options while solving medical diagnostic problems. Hmelo-Silver videotaped five students as they participated in two PBL sessions of approximately two and one-half hours each. These sessions focused on the medical diagnosis of a patient and were facilitated by Barrows, the second author. Focused interviews and collaborative viewing of the PBL videotapes with the PBL facilitator supplemented the classroom data.

Based on interviews with the facilitator, Hmelo-Silver found that Barrows had specific educational goals for the students relative to the content of the lesson. Students were expected to:

1. Explain disease processes responsible for a patient's symptoms and describe what interventions can be taken,
2. Employ an effective reasoning process,
3. Be aware of knowledge limitations,
4. Meet knowledge needs through self-directed leaning and social knowledge construction, and
5. Evaluate their learning and performances.

(Hmelo-Silver & Barrows, 2006, p. 27)

Although the first educational goal was specific to the discipline (medicine) and problem type (diagnostic), the other four goals are most likely applicable to a wide variety of PBL contexts. The expectation that students will a) employ an effective reasoning process, b) be aware of knowledge limitations, c) meet knowledge needs through self-directed leaning and social knowledge construction, and d) evaluate their learning and performances could be considered to reflect the "rights and duties" of students within any PBL curriculum.

Cobb and his colleagues (i.e., Cobb, Wood, et al., 1992; Cobb, Yackel & Wood, 1992, Yackel & Cobb, 1996) adopted the term "norms" to refer to the rights and duties that guide students and teachers as they co-construct knowledge within the classroom. In their investigations of how teachers foster an understanding of the nature of "knowing" within the mathematics classroom, Cobb and his colleagues recognized that the classrooms had a unique set of shared beliefs and expectations about what constitutes "knowing" and how

that knowledge is constructed in the classroom. They further observed that classroom norms reflect the beliefs and expectations of a discipline, as well as those specific to the classroom learning-community. For example, within the PBL learning community examined by Hemlo-Silver and Barrows (2006), the expectation that students should explain their reasoning strategy would be a PBL classroom norm, while beliefs about what would constitute an acceptable explanation of the disease processes responsible for a patient's symptoms would be a disciplinary-specific norm.

Yackel, Cobb, and Wood (1991), found that classroom norms develop in two ways. On some occasions, the teacher provides explicit instruction. More frequently, norms are co-constructed through student–teacher interactions in which the teacher selects a particular classroom incident through which both domain-specific norms and norms of the classroom can be negotiated. Although some authors (Lopez & Allal, 2007) have questioned whether classroom norms can be separated from the norms of a domain itself, they generally agreed that teachers seek to develop classroom and domain-specific habits that are consistent with the expectations and behaviors of the profession.

In their examination of the PBL classroom behaviors of five students and their facilitator, Hmelo-Silver and Barrows (2006) found that the facilitator used several specific strategies to help students co-construct the norms of the PBL classroom in order to achieve the desired educational goals. The primary way that the facilitator established the rights and duties of the PBL classroom was through modeling the use of open-ended and metacognitive questioning. He pushed students for an explanation, neither evaluating nor offering additional information, simply placing the students' knowledge in public view to help them see the limits of their understanding. Revoicing was used to restate an idea for the group, giving it legitimacy and keeping an important idea alive, subtly influencing the direction of the discussion. When the process stalled, the facilitator would ask a student to summarize what was known thus far to provide students with practice in case presentation and to allow students to check their shared understanding. Furthermore, students were encouraged to generate hypotheses to promote effective reasoning and self-directed learning, as well as to focus their learning and data collection processes. The facilitator guided students to evaluate hypotheses during structured white-board discussions. Through these pedagogical practices, the PBL facilitator modeled the problem-solving process, coached students to consider possible solutions and narrow the possibilities, all the while giving students the primary responsibility for identifying the correct solution.

But when the goal is to generate a variety of solution paths rather than narrow the possibilities, the problem remains: what are the "rights and duties," or classroom norms, of the SBL environment, and how do facilitators guide students in solving ill-structured design problems in which the initial variables are ambiguous and a variety of solutions are possible? Through an examination of studio classrooms in architecture, industrial

design, and HCI, our intent was to tease out the norms and pedagogical practices that were common to all of these studio classrooms in order to build a cross-disciplinary understanding of how SBL facilitators support students as they learn to successfully solve complex design problems.

Methods

The present study did not involve a purposefully designed intervention, but rather focused on the everyday practices of the studio-classroom community. Ethnographic data have been collected and analyzed from one semester-long course in architecture, one semester-long course in industrial design, two semester-long courses in HCI, and one quarter-long class in HCI.

Context of Investigation

The architecture and industrial design studio classes met for four-hour blocks of time, three days per week. In addition, each student had a dedicated workspace in the studio accessible 24 hours a day, seven days a week, 365 days a year, and students were encouraged to work in the studio space outside of scheduled class time. Course activities revolved around project-based assignments designed to reveal principles important to the discipline. Students were presented with a series of assignments that they were expected to submit individually; however, they were encouraged to use additional resources, including their peers, as needed to complete the assignments. Project-based assignments were supplemented by frequent public critiques where students presented their design ideas to faculty, peers, and occasional guests.

Students in both courses were in the first semester of their second year of professional study and had participated in a two-semester studio sequence in their respective disciplines the prior year. In general, students in these courses reflected the demographics of the university: mostly white with roughly equal representation of men and women.

The HCI courses that were the subject of our investigation were selected because of the prior experience of the course professors in implementing the studio method into HCI instruction. These instructors have used a "modified studio approach" based on their observations of an architecture studio (Reimer & Douglas, 2003) for at least ten years. A modified studio approach was necessary because the typical course structure of computer science departments makes it difficult for all of the features present in architecture or industrial design studios to be implemented easily. As is typical in studio classes, the HCI courses incorporated a series of project-based assignments followed by design critiques where students publicly presented their concepts to their peers and professors. Approximately half of the class time was devoted to lectures (seven crits, seven lectures, and one exam in the semester-long class; six crits, four lectures, and one exam in the

quarter-long class), with the course assignments and associated critiques providing an opportunity for the students to apply the principles that were introduced in the lectures. Class projects were completed in teams. These courses did not provide dedicated studio space for students, nor was the studio scheduled for the extended hours that are common in architecture and industrial design studio courses. Instead, students met in a typical classroom for approximately three hours per week, as they would for a standard lecture-based course. Thus, one aspect of our work was to identify techniques that instructors can use to successfully implement SBL within the constraints of conventional classroom facilities and academic scheduling.

Both HCI classes were senior seminars that included a mixture of senior level undergraduates and graduate students. Although the classes did include women and international students, the majority of the students were white males.

The exercises and the projects for all five courses mirrored the kinds of complex design problems that a designer within that domain would encounter in the professional world. Students were asked to design interfaces in HCI, buildings in architecture, and products in industrial design. For example, the task of designing a teapot in the industrial design studio appeared to be deceptively simple, yet was actually a very complicated project that required an understanding of form, function, and materials. The assignments in HCI required students to simultaneously grasp the complexity of the problem, the hierarchical organization of features in the user interface, and the means for managing the complexity through programming.

For a brief comparison of each class, see Table 1.

Role of Researchers

The authors of this paper represent the two educational researchers, the research assistant, and the instructors of each of the courses. The educational researchers and their assistant conducted the data analysis and interpretation. The course instructors, as key informants, reviewed the findings to provide domain-specific insight on the educational researchers' interpretations of the data.

Data Collection and Analysis

In all the classes, key classroom interactions, as identified by the instructor of each course, were videotaped for analysis. In addition, we collected all student and instructor-generated artifacts produced for each class, as well as instructor reflections on the course activities. (See Table 2.)

Our analysis primarily focused on the video recordings of the classroom critiques as key locations where faculty guide students to reflectively examine their work and refine their designs (Schön, 1983, 1987; Shaffer, 2003, 2007). Across the three disciplines exam-

Table 1. Context of investigation, summary table.

Discipline	HCI	HCI	HCI	Industrial Design	Architecture
Instructors	1	1	1	2	1
Number of Students	9	10	12	32	21
Level of Course	Senior/first year graduate level elective	Senior/first year graduate level elective	Senior/first year graduate level elective	Required, second year undergraduate	Required, second year undergraduate
Meeting Space	Typical classroom	Typical classroom	Seminar room	Dedicated studio space	Dedicated studio space
Classes per Week	2, 1 hour 20 minutes each	2, 1 hour 20 minutes each	2, 1 hour 20 minutes each	3, 3 hours 50 minutes each	3, 3 hours 50 minutes each
Weeks	15	15	11	16	16
Total In-class/studio Hours (per syllabi)	37	37	24	154	150
Number of Projects	5 undergrads; 7 for graduates	4	5	4	3
Number of Formal Project Critiques Observed	5	5	4	14	6

ined, the studio critique provided a shared context around which we observed both the norms guiding student/teacher knowledge construction and the pedagogical practices through which these norms were developed and maintained. Furthermore, Dannels (2005) argues that the oral genre of the design crit is the site where students learn the traditions and rituals of a design discipline.

Each video was viewed in full at least twice, with sections of the video watched multiple times for a more thorough analysis of dialogues and action. While watching the

Table 2. Data collected from each course.

	HCI Semester 1	HCI Semester 2	HCI Quarter	ID	ARCH
Video					
☒ Project briefings		X	X		
☒ Project critiques	X	X	X	X	X
☒ Group work out-of-class	X	X			
☒ Desk or table critiques	X	X		X	X
Course documents					
☒ Syllabus	X	X	X	X	X
☒ Project brief guidelines	X	X	X	X	X
☒ Grading rubric	X	X	X		
☒ Miscellaneous handouts	X	X	X	X	X
Electronic discussions	X				
Student Quickwrites			X	X	X
End-of course open-ended student survey	X	X	X		
Student design journals	X	X			
Student projects & other assessments	X	X	X	X	
Instructor journal	X	X		X	X
Sketch of classroom	X	X	X	X	X

video, the analyst composed a written narrative marked frequently with time stamps. This written narrative provided a detailed description of the action in the video by topics, speakers, and contexts.

The artifacts collected in each course were examined to gain insight on the design process as it unfolded among the students and faculty. Syllabi and written assignments were used to determine the overall structure of the course activities. Instructor journals documented the decisions that guided their class activities as well as their "reflections-on-actions" (Schon, 1983). Responses to student "quick writes" were transcribed from handwriting, coded, and then categorized into themes. In the "quick writes" students were provided a prompt (e.g., "When have you rejected a design concept? What made you stick with an idea?" or "What exercises/events/activities have we had in class that have helped you become a stronger designer?") and given ten minutes to write an anonymous response. From the HCI courses, we also collected copies of the exams, project reports and design journals generated by the students to look at the kinds of written feedback that the instructors' provided to the students. The instructor comments were compiled and coded as we searched for patterns in the ways that instructors provided guidance, prompts, and critique to students as they refined their designs in the HCI studio.

Each of the five courses served as one case study (Merriam, 1998; Stake, 1995; Yin, 1994). The construction of the cases began by first organizing the video narratives and other diverse types of data for each course into a case. In order to create a common

framework for our cases, we constructed a description of the surface structure, pedagogy, and epistemology of each class based on coding categories that were derived from Shaffer's (2003, 2007) analysis an architecture studio at the Massachusetts Institute of Technology (MIT). After several readings of the data and several drafts of each case, we developed a tentative version of each case for instructor review.

Once the cases were finalized, the individual cases were analyzed across cases to identify the norms and pedagogical practices common to all studio classrooms, as well as differences among them. We relied upon qualitative data analysis techniques in which the researcher undertakes a continual process of looking for patterns in themes and categories within the data. LeCompte (2000) describes this method of qualitative analysis as a series of step-wise activities. This technique also is partially derived from the tradition of constant comparative analysis as described by Glaser and Strauss (1967). Like Hmelo-Silver and Barrows (2006), we first clustered the data by themes that reflected the classroom norms and then looked for recurring patterns in the instructors' pedagogical practices that supported the development of these norms. The norms and pedagogical practices we report were informed by multiple data sources and were observed, in one form or another, on multiple occasions and in multiple classrooms.

Results

In the following sections, we first outline the broad categories of studio-classroom norms and pedagogical practices that we identified through our analysis. We then illustrate the interrelationship of studio-classroom norms and pedagogical practices through examples from our data. The norms and pedagogical practices are necessarily linked and mutually interdependent: the classroom norms are necessary for the production of pedagogical practices, and the pedagogical practices are reinforced and solidified through the studio–classroom norms.

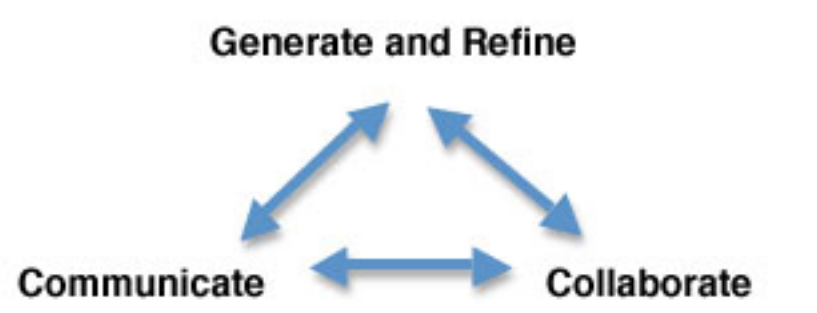
"Habits of the Studio:" The Norms of the Studio-classroom

As in the PBL classroom described by Hmelo-Silver and Barrows (2006), the expectations that students were to a) employ an effective reasoning process, b) be aware of knowledge limitations, c) meet knowledge needs through self-directed leaning and social knowledge construction, and d) evaluate their learning and performances were embedded in the dialogue we observed during the project crits. Our analysis, however, focused on the specific rights and duties of participants in the SBL environment.

Although the norms co-constructed within the five studio classrooms reflected disciplinary as well as studio-classroom norms, through our cross-case analysis we have identified general "habits of the studio" that represent expectations and responsibilities for student and teacher participation in SBL across the multiple disciplines we observed.

Students were expected to: a) generate and refine design solutions iteratively by reflecting on the feedback of others; b) communicate their design ideas visually and verbally using the conventions of the profession; and c) collaborate with their peers to both give and receive assistance in obtaining their learning goals.

Figure 3. Complementary rights and duties of students in studio-based learning classrooms.



As indicated in Figure 3, these norms represent more than discrete educational goals; rather they reflect the complementary rights and duties of participants in SBL classrooms. Students were expected to work both individually and collaboratively to generate and refine their design ideas. They were expected to communicate their emerging ideas to teachers, peers, and in some cases guests for input during project critiques. Through these discussions, students were expected to communicate their design ideas using the conventions of the profession. They were provided with the opportunity to receive feedback and expected to incorporate this feedback in subsequent design decisions, coming to understand that design is an iterative process where tentative design decisions are made and then revised when additional information becomes available. Furthermore, students learned that design decisions were not inherently right or wrong, but that decisions must be reasoned and defendable, and are subject to change with additional knowledge. In addition, students were expected to rely on their peers as crucial resources. Through their experiences, students learned that the studio is an environment where all input is valued, with the primary responsibility being on the student to present his or her ideas in a logical, rational, and persuasive manner.

Pedagogical Practices

One key finding from our analysis was that even when students have prior experience with SBL, as in the architecture and industrial design courses we observed, instructors and students must actively work to establish the rights and duties of the studio environment. Consistent with Yackel, Cobb, and Wood (1991), we found that the norms of the studio develop in two ways. On some occasions, the teacher purposefully takes up the

"expert coach" position, providing explicit direction as to students' expected behaviors. More frequently, rights and responsibilities are co-constructed through student–teacher (student designer–master designer) interactions in which the teacher selects a particular incident through which classroom and professional expectations can be negotiated for the studio experience. This constructive framework further positions teachers and students in social interactions in which the design process is a shared experience: the instructor defers to the design process of the students, and the students learn from each other as they witness, support, and critique their own and their peers' design processes and outcomes.

The pedagogical practices we observed can be clustered into three main categories: a) assignments and associated meta-discussions; b) direct modeling and coaching by instructors and professionals in the field; and c) explicit prompts and instructions.

The Interrelationship of Studio-classroom Norms and Pedagogical Practices

In the following examples, we illustrate how these pedagogical practices are used to establish and maintain the norms of the studio classrooms. Likewise, the norms of the studio support and enable the pedagogical practices used by the instructors. (See Table 3.)

Assignments and meta-discussions: Norms of collaboration.

In the architecture classroom, an early assignment established the tone of the studio and emphasized the benefits of collaboratively relying on one another for puzzling out design problems. The first weeklong project required students to work in teams to present a conceptual model of Ronchamp (the chapel of Notre Dame du Haut) completely from memory. The project caught students by surprise, and for a moment they expressed some panic at individually not remembering the details of Ronchamp. But the exercise was focused on collective knowing, that is – how students could pool their collective knowledge, much to their relief. One group could not remember any details of Ronchamp, but they did have an understanding of the designer, Le Corbusier, and put together a model based on what they knew of his designs, which in itself was acknowledged as a contribution to the studio. This tone of collaborative input into one another's designs was sustained through the semester and significantly impacted students' growth and the refinement of their designs.

Field trips were used to both stimulate design ideas and develop the sense of trust necessary for collaborative learning. The architecture studio course required a three-day field trip to Washington DC to examine various buildings and attend lectures by prominent architects, while the studio included an all-day field trip to a glass factory and museum, as well as a visit to the local studio of a porcelain artist later in the semester. The industrial design instructor noted in her journal: "We unzip our overcoats when we are

Table 3. Summary of categories of classroom norms and pedagogical practices observed across the five studios.

Studio classroom norms		Pedagogical Strategies		
		Assignments and meta-discussions	*Modeling and coaching*	*Prompts and reminders*
Generate & refine design solutions	Students are encouraged to take up design ideas from others to and similarly hand off their designs to others as they generate and refine idea in an iterative fashion. They learn that solutions are not right or wrong but must be reasoned and defendable.	Short assignments that are intended to force students to make quick design decisions; Requiring several "out of the ordinary" designs among iterations; Low-fidelity prototypes.	Using pin-ups and crits to facilitate creative problem-solving; Role-playing how designs will be used; Developing hypothetical narratives by the end user.	Facilitators reinforce keeping designs fluid; Encouragement to use sketching at this stage.
Communicate	Students learn to articulate design ideas through conventions surrounding the kinds of, and uses of, visuals and verbal discourse characteristic of the discipline.	"What happened here" discussions to examine design and learning process; Develop language of design through explicit naming and walking through the conventions of the discipline.	Observations of other critiques to learn about design communication expectations and protocol; Questioning by guests to instill a sense of the professional standards and expectations.	Table crit discussions of common design problems; Pin-ups left up for extended periods to remind students of key design concepts.
Collaborate	Students were asked to find ways to incorporate the input of instructors and peers in their design work. Students begin to view their peers as experts and seek out their advice.	Community building activities that set the stage for subsequent collaboration; Fieldtrips to design studios and workshops; Using post-it notes and tracing paper overlays on pin-ups to layer comments from peers.	Cross-reference students to one another; Explicit invitations to comment on each other's work.	Explicit mention of rules and responsibilities in the studio space periodically; Engaging peer discussion in design crits and pin-up sessions.

in another environment…We suddenly know more about each other because of that experience."

Assignments and meta-discussions: Norms of generating and refining design ideas. The course instructors also used assignments and the associated discussions as a way to help students generate and refine their design ideas. For example, in the industrial design studio, the instructor recognized that the students were having trouble committing to a final design. The instructor noted in her journal:

> *I soon noticed the calendar and began to feel a panic about the final design due date for this project. I was deliberating about how to jump start them into form commitments and quick evaluation. SECTIONS. This was the answer I thought. There is nothing like a full-scale drawing that forces us to make all of the decisions that we like to avoid. And a full section drawing requires that you know almost everything about your project. So we gave the students a deadline for 5 days later to have a full-scale section to pin up. We then asked for volunteers to have an overlay of trace paper pinned up for a sketching critique. The method has worked like a charm. Truly fine forms have evolved since last Friday. We left the sections on the wall for a couple of days and joined the students periodically in sketching discussions – overlays after overlays of refinements to their concepts.*

In this example, the course instructor developed a particular assignment in response to the needs she observed in her students' work. Through a pin-up session in which both instructors and students drew on top of each other's designs using overlays, students had the opportunity to not only present and discuss their emerging design idea, but to give and receive feedback in order to progressively refine their work.

Assignments and meta-discussions: Norms of communication. Within the project critiques, instructors often shifted the discussion to a meta-level where they could identify concepts, behaviors, or skills that were essential to professional practice. For example, at one point in a project crit in architecture, the instructor asks: "What did I ask every single group?" The students answered: "orientation." The instructor explains that the typical orientation of design on a page is where "north is up." In this way she signals to students how architects communicate their designs on paper. By waiting for every group to NOT mention orientation and by not making it an issue during presentations, she doesn't single out groups or indirectly find fault with any one person. The instructor makes an instructional point in a meaningful and nonthreatening way, while also emphasizing the norms of studio practice and the norms of architectural practice as well.

When guest professionals were asked to participate in project critiques, they also used student projects to elevate the discussion to a meta-level in order to point out key practices in the discipline. In one case, the architecture instructor invited guest architects to a daylong pin-up to review the students' designs. In almost every crit, the comments by the guest architects focused on the context of their designs, that is, how their design sat on the landscape in relation to the existing structures. These conversations forced students to literally "ground" their design in a way they had not considered before. The guests and the students talk about the "experience" of the building. For example:

> Guest 1: *Looking at this one, for example (goes up to second student's propos-*

als), so much of the experience is about the procession to it, and it seems like this scheme is very much a mental scheme, it's not an experiential scheme. It doesn't show what the experience would be like. It's a mental connection in a drawing. When you're there you may not experience that. Connecting it a little bit more with the nature that exists there...

Guest 2: *What you end up with: does it respond to the site well? Does it respond to the function? Does it work?*

When the instructor or guest had to ask too many questions, it was obvious to both the instructor and students that either the student's preparation was inadequate or they had not formulated in their mind how to articulate their ideas and coordinate their narrative with the images they chose for presentation. In the example presented above, Guest 2 goes on to say: "I think all three of you can generate your own ideas, but for me I think all three of you need to work on how you communicate your ideas because we had to ask a lot of questions at first: What is this site? What is this building?"

In this extended exchange, the guest architects identified a key variable—the experience of the building—that architectural designers should consider. This critique also replicated the ways that students typically present their work in professional practice and reinforced the fact that they needed to be prepared to communicate their design ideas both visually and verbally.

Modeling and coaching: Norms of communication. As the example above also illustrates, one powerful and common way in which students were introduced to the expectations and practices of the studio was through modeling and coaching by more experienced students, faculty, and guest professionals. In the example presented above, the guest architects introduced students to professional discourse through modeling the language of design as well as coaching them to better articulate their design decisions through questioning. In another example from our data, the industrial design professor arranged for her students to observe a "mini-critique" of the work of senior-level students by a guest artist early in the semester. This crit modeled for students the expectations held for communicating during a design critique, but also helped them to focus on the criteria of evaluating good design. Although the students in this second-year industrial design course were familiar with the studio culture from their prior experiences, the more experienced student modeled behavior and reinforced crucial values and responsibilities.

Some of this modeling of thought patterns, language, and behavior is done tacitly when working alongside students in the design process, while other modeling is done explicitly, through direct comments and conversation with students in the design crits. We were able to distinguish different kinds of modeling behavior, described in detail below:

by thinking aloud; through questioning; and narratives and role-plays.

Modeling and coaching by thinking aloud: Norms of generating and refining design ideas. Instructors also modeled the way that designers generate and refine design ideas as illustrated in the way one HCI instructor described the final project to her students. In this excerpt from a class discussion, the professor talks through the variables that she would consider in approaching the design project.

> *And so the early part of the design which we already went through in the bus kiosk, had to do with trying to decide, you know, what is it we're going to design? What kind of a problem are we going to take on? What kind of, sort of, broad functionality is it going to have? And then, who are the users for this? And then, you know, moving through that a little it more, looking at some artifacts, doing some user studies, just like at the bus kiosk, ah, and then trying to decide: ok, here's our functional requirements; these are what the system should do. Not how, but what. And then with that, tie that onto some usability issues, and just general, you know, knowing about the users is just, you know, what are they able to do? What kind of world do they live in? What's their ages? What's their interests? What's their language capacities? What's their physical abilities?*

Modeling and coaching ideas through questioning: Norms of generating and refining design. In other cases, the instructors modeled the process of generating and refining design solutions through coaching students to respond to a series of prompts and questions. In the following excerpt, the industrial design instructor was encouraging her students to explore multiple design solutions. The instructor tried to situate her students within the design problem and attempted to model for them the questioning strategies of design-based thinking that underlie the norms of the discipline. Notice how the teacher coached the student to consider different ways of solving the problem.

> Instructor: *Think about the ritual of the day, what do people do throughout the day?*
>
> Student: *So like something I attach to a toothbrush holder or something?*
>
> Instructor: *Maybe it is as simple as that? But you're not going to come up with it this afternoon. But yes, you're trying to find something that blends into your life.*
>
> Instructor: *You're taking what we're saying a little bit too literally, I think. I think we're trying to get your head into a place of, all of you, get into the place . . . if you're*

> *focusing on, this is something I need to do everyday, then let's think about all the other things I do every day.*
>
> Instructor: *I want you to understand the difference between what I just said, and attaching a pill dispenser to a cell phone, OK? Don't leap to the obvious.*

Modeling and coaching ideas through narratives and role-plays: Norms of generating and refining design. Another way that the studio instructors encouraged students to see a design problem from multiple perspectives was through the use of narratives and spontaneous role-plays. In the following example from one HCI studio class, the instructor used role-playing during the project crits to shift the students' frame of reference as they worked on refining their designs for a computer interface. The instructor asked for a volunteer from the class to take on the role of being of the user of the interface technology which required the students presenting their project to take on the task of responding with the correct screen shots.

> Instructor: *So I have a challenge for [Student 1]. What I would like you to do is—[Student 2], I would like you to set the interface to the main, the main screen—and I'm going to have [Student 1] to do something very specific. [Student 1], I would like you to go to the board and see if you can actually do what he's asking you to do with his interface. [Students 3 and 4], you guys are going to have to adjust the interface as she hits buttons if you can, if it's feasible. So, one idea of a task you might ask her to do, for example, is tell me what the, what was it, barometric pressure? Tell me what the barometric pressure is, you know, where this device is currently sitting.*

The extended interchange that followed focused on the question: "Who are our users?" This pedagogical approach provided new insight for the presenters, shifting their perspective from the small details on which the students typically focused to the larger design context. Having a student volunteer to "work" the project interface while the presenters pulled up the appropriate screenshots became a central exercise that emphasized a key factor that HCI designers must consider—usability, from the perspective of the user. This movement back and forth in scale was a vital part of the critique as modeled through the instructor's comments.

Modeling and coaching: Norms of collaboration. The instructors also modeled the use of other students as resources for collaborative problem-solving by issuing clear invitations for the students to comment on others' work during the critiques. Furthermore, the instructors explicitly encouraged students to use each other as resources in specific ways. For example, the industrial design instructor demonstrated throughout the semester

that she knew all of her students' work, and was able to refer students to one another as someone who could help with a specific problem. Faculty modeled how students should pool their own knowledge and resources for projects in HCI as well. For example, as she reviewed their fourth project, one HCI instructor asks: "Who's the creative one?" A student replies: "She's good at making this stuff look not horrible . . . after I throw it all together." The instructor replies: "That's why it's nice to have a team—you leverage each other's strengths, right?" This places students in roles of peer educators as well as helping students to see the studio as a place of equal opportunity, where at any time they can emerge as "someone with a good idea or good understanding of a problem/question."

Explicit prompts and reminders: Norms of collaboration. The primary ways in which the norms of the studio classroom were developed and maintained were through assignments with associated meta-discussions and modeling or coaching. However, at times the instructors were very explicit about the general "habits of the studio." Explicit prompts and reminders most often focused on establishing collaborative studio-classroom communities while also emphasizing the individual responsibilities of each studio participant.

For example, on the third day in the second-year architecture studio class, the instructor verbally provides the students with a "big-picture" overview of what they will try to accomplish: a collaborative working environment in which students and instructors will all learn from each other; individual development as architectural professionals; the studio as reflection of design process in that designs and projects can often get "stuck," and therefore the need for community and flexibility is essential; individual and collective paths "into the unknown" of architectural design; and an understanding of architecture as practice, not mastery.

In this introduction, the instructor uses several techniques to level the power structure of the studio away from the typical student–instructor model to a communal model of learning. First, and perhaps most importantly, she uses the collective first-person pronoun "we" at all points, signaling to the students their positioning as a community and emphasizing that the individual design processes will form a collectively shared group experience in the studio. Throughout, she also refers to her students as "architects," not as students. The instructor reminds the students that she is there to learn alongside them, stressing that architecture can never be mastered, but simply continually practiced. In this exchange, the instructor established key ideas that are foundational "habits of the studio."

The instructors reinforced these essential norms in word and deed. The following excerpt from a critique in the same architecture classroom illustrates how, despite the student's temptation to look to the instructor as the authority figure, the instructor explicitly returned the responsibility to solve the design problem back to the student.

Student: *Upon your suggestion, that's actually kind of a good idea.*

> Instructor: *It's not a suggestion, it's just a question, . . . I'm just trying to understand how you're seeing the space.*

Although this might be an appropriate response in many classes, the norms and expectations of the studio differ from those of conventional classrooms. In the studio, as in PBL classrooms, students are expected to take responsibility for their own learning (Hmelo-Silver & Barrows, 2006). Students, however, sometimes struggle with this responsibility (Root, Rosso-Llopart, & Taran, 2008). In this example, the instructor was strategically evasive to push students to develop their own design solutions rather than look to her for continual validation. In this class, as well as others, the instructors pointed out behavior that was inconsistent with the expectations of the studio-classroom community in a way that was not punitive, but instead reinforced students' entry into the profession.

Discussion

The intent of this ethnographic study was to illuminate the "educational goals" (following Hmelo-Silver & Barrows, 2006) or norms (following Cobb and his colleagues, i.e., Cobb, Wood, et al., 1992; Cobb, Yackel & Wood, 1992, Yackel & Cobb, 1996) that guide student/faculty interactions as they learn to solve ill-structured design problems in the studio classroom, and to explicate the pedagogical practices through which experienced faculty guide students as they come to understand the design-problem-solving process. Through looking at the SBL activities of participants in architecture, industrial design, and HCI studio classes, our intent was to tease out norms that were common to all of the SBL classrooms observed, and to examine the pedagogical practices through which those norms were developed and maintained across the duration of the studio classes.

Intricately tied to professional norms, the studio-classroom norms established a set of explicit and tacit expectations for each member of the learning community. Through our analysis, we found that students need to learn to iteratively **generate and refine** possible solutions to a design problem. They need to learn how to both broaden and evaluate solution possibilities. Within a given discipline, they need to learn how and when to consider disciplinary-specific variables that impact the design solution. **Collaboration** with others is essential to seeing the design problem in new and different ways, serving to both broaden solution possibilities and assist in idea refinement. And finally, students need to learn to **communicate** clearly, using the conventions of their discipline, in order to convey their design ideas and gain meaningful input from others.

These expectations can be challenging for students and faculty more familiar with traditional university classrooms. In most cases, the norms that guide student

and teacher behavior are tacit knowledge of which participants are unaware. This may be particularly true in schools of architecture and design in which faculty have "grown up" immersed in the studio culture. This tacit nature of norms may be especially problematic when other disciplines seek to adapt the studio practice. With only a marginal awareness of the norms guiding their behaviors, faculty from design schools may fail to mention them to faculty from other disciplines; if they were fish, the norms of studio practice would be their water. Without extensive observations of studio interactions, such as the one described here, faculty from other disciplines may be unaware of these subtle codes among faculty and students. Through identifying the pedagogical strategies that experienced SBL teachers use to guide students as they grapple with the highly complex and ill-structured nature of design problems, we have illustrated how design problems can be used as a form of problem based learning.

Like PBL, SBL represents a comprehensive student-centered approach to learning (Savery, 2006). But whereas the diagnostic and decision-making problems typical of law (i.e., Kurtz, Wylie, & Gold, 1990), medicine (i.e., Barrows & Tamblyn, 1980), business (i.e., Merchand, 1995), and related disciplines require that students learn how to identify key problem variables in order to narrow the solution possibilities, design problems are by their very nature ambiguous, where the initial variables are unknown and many possible solution paths exist. As Jonassen and Hung (2008) point out "the degrees of intransparency, dynamicity, heterogeneity of interpretations, and legitimacy of competing alternatives of design problems tend to be at an extremely high level, which makes them highly ill-structured" (p. 20).

In our analysis of five studio-classroom communities, we identified the processes through which students learn to solve ill-structured design problems while being simultaneously inducted into practices that reflect the professional world of their discipline. Instructors used a combination of structured and spontaneous activities to point out the values, roles, and expectations of the studio classroom, as they developed the "rights and duties" of the studio classroom simultaneously with professional norms. Regardless of previous studio experience, these rights and duties of students in the studio classroom must be established at the onset and redistributed throughout its duration because the unique social positions of instructors and students within a studio are constructed through the specific interactions studio participants have with one another.

We found that classroom interactions were enhanced by conscious efforts by the instructors to develop shared expectations regarding the roles and responsibilities of each participant. They carefully crafted assignments intended to reveal particular design principles and used public critiques of student work to elevate the discussion from the specifics of a project to principles applicable in multiple situations. Through assignments, meta-discussions, explicit prompts, reminders, modeling, and coaching

by instructors and professionals in the field, students came to understand the ways of thinking and knowing within their discipline as well as their roles and expectations in the studio classroom. Thus, experienced studio instructors increased the transparency of the design problems as they modeled their design-thinking; guided students through the heterogeneous, dynamic nature of the design problem through their assignments, sub-assignments, and associated meta-discussions; and helped students learn to evaluate the legitimacy of competing alternatives as through questioning and prompts.

Teaching, too, in many ways, is a design problem. There are many variables that come into play and many possible solutions paths. Through our discussion, we hope to, in some small way, reduce the ill-structured nature of teaching using SBL through illuminating strategies that experienced instructors use to facilitate the design problem-solving process. Through our data excerpts and associated discussions, it was our intent to make the goals and pedagogy of SBL more transparent, illustrate the way that experienced SBL faculty manage the dynamic nature of design problem-solving discussions, provide guidance as to the legitimacy of competing pedagogical alternatives and thus reduce the "heterogeneity of interpretations" of the studio method for faculty who did not learn the process within their own professional preparation.

Notes

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For more information, see: http://www.studiocollaborative.soe.vt.edu

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