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Mentoring Models in an A/E/C Global Teamwork e-Learning Environment

Renate Fruchter, Sarah Lewis Stanford University

Abstract

Understanding the goals and constraints of other disciplines are key to working well in cross-disciplinary *Problem-, Project-, Product-, Process-, People*-Based *Learning*™ (P^5BL) teams. Education programs rarely offer learners opportunities to participate in authentic cross-disciplinary P^5BL experiences in a global teamwork e-Learning environment. This paper reports on models of mentoring in cross-disciplinary learning in Stanford University's P^5BL program. It addresses Architecture/Engineering/Construction (A/E/C) industry's needs to broaden the competence of engineering students to exercise the acquired theoretical knowledge and understand the role of the discipline-specific knowledge in a multi-disciplinary P^5BL environment. In P^5BL undergraduate and graduate students play the roles of apprentice and journeyman, and faculty and industry practitioners play the role of "master builders" and mentors. An analysis of mentoring opportunities is presented within a situated perspective on learning, exploring theoretical constructs and practical implications of the development of communities of practice that reach beyond the university walls. The study presents an analysis of mentoring techniques in scaffolding students' cross disciplinary design process, as well as a description of students' rolls in scaffolding mentors understanding of cutting edge collaboration technologies in A/E/C. The paper discusses implications for the design of P^5BL environments, processes and implications for university and industry relationships.

Introduction

Isolation of Architecture/ Engineering/Construction (A/E/C) students within discipline-specific education has impacted graduates ability to function within interdisciplinary design teams when they enter industry. Not only are new graduates commonly hampered by poor cross-disciplinary communication, coordination and negotiation skills, they emerge from educational institutions with narrow perceptions of what it means to participate in the design process as a member of their specific discipline.

P^5BL - the People- Problem- Process -Product - Project-based Learning approach in the Stanford School of Engineering addresses this problem by offering graduate students the unique opportunity to exercise their specialized skills as engineers, architects, construction managers in an cross-disciplinary, collaborative, geographically distributed teamwork experience. They have to solve a problem: to produce a design for the construction of an environmentally conscious, architecturally exciting, structurally sound building within tight ecological, time and budget constraints[1]. The added challenge: team members are distributed over broad geographic areas, spanning six time zones. An engineer may be on the West Coast at Stanford University, while the architect may be in Slovenia and the construction manager on the East Coast at Georgia Tech.

The P^5BL program offered at Stanford is a two Quarter class that engages architecture, structural engineering, and construction management students from universities in the US, Europe and Japan, i.e., Stanford University, UC Berkeley, Cal Poly San Luis Obispo, Georgia Tech, Kansas University in the US, Aoyama Gakuin University inTokyo Japan, University of Ljubljana in Slovenia, Bauhaus University in Weimar Germany, ETH and FHA in Switzerland, Strathclyde University in Glasgow UK, and TU Delft in Netherlands. Teams of A/E/C students are involved in a multi-disciplinary building project in which they model, refine and document the design product, the process, and its implementation. The project is based on a real-world building project that has been scoped down to address the academic time frame of two Quarters. The project progresses from conceptual design to a computer model of the building and a final report. As in the real world, the teams have tight deadlines, engage in design reviews, and negotiate modifications.

P^5BL employs innovative technologies to bridge these distances in time and space. The P^5BL challenges and thrusts students into an unfamiliar technologically rich environment to work through open-ended problems of a building project with ill-defined goals and emergent constraints. A variety of support tools scaffold students learning as they work through the problem:

- a web-based team work space hosts assignments, shared documents, and prompted discussions to shape the teams design process;
- weekly class meetings provide students access to a "master builder" who addresses issues as they arise and keeps the process moving forward;
- presentations of iterations to the class provide teams with feedback from multiple perspectives;
- Mentors bring outside resources and alternative perspectives to the design process; and ongoing surveys about the course experience encourage students to reflect on their own learning.

Learning within this environment can be viewed from multiple perspectives. Students gain concrete performance-based skills, an aspect of learning commonly described by the behaviorist tradition. Students gain conceptual understanding identified when discussing education from a cognitive perspective, such as: conceptualizing a problem from multiple perspectives, understanding the goals and constraints of other disciplines, and gaining awareness of the impact of various constraints and potential workarounds.

While the acquisition of performance based skills within the context of increasingly complex cognitive models is part of students' learning experience in **P^5BL**, it is also is part of their experience in other courses. Most unique is the learning illuminated by looking at P^5BL from the situative perspective.

The situative perspective on learning focuses on "the nexus of cognition, social interaction, disciplinary practices, and culture" [2,3]. From this perspective, "knowing" is fundamentally a social, rather than an individual, activity. Learning is rooted in one's participation in communities of practice, in which an individual forges identity as a member by participating in activity, discourse, and reflection surrounding the communities shared experience of work [4]. By shifting the focus of learning from concrete skills and cognitive understanding to participation and thinking strategies we are able to observe the effects of social aspects of learning on students' participation and expression of identity development as members of a profession. Within the A/E/C industry, being an "A" "E" or "C' requires knowing not only one's discipline, but knowing how to communicate, collaborate and negotiate with people of related professions, recognizing their goals and constraints in the realization of the design task. For instance, from the situative perspective, being an architect, structural engineer, or construction manager involves much more than knowing the academic domain of architecture, structural engineering, or construction management, respectively.

Cross-disciplinary learning and assessment

Cross-disciplinary learning is the key to developing these interdisciplinary design skills necessary for participation of architects, engineers and construction managers in the A/E/C industry. Recognizing this, students come to **P^{5}BL** to seek out a cross-disciplinary experience. They do not, however, begin with a clear understanding of what it means to function well in a cross-disciplinary environment. From their perspective, they arrive to the class as experts in their fields, having completed at least an undergraduate major, and in the process of a graduate degree. Academic training often lends them towards a linear, sequential, rigid design process in which the architect designs the building, the engineer then determines its structural features, and the construction manager estimates and negotiates costs. Students with such assumptions quickly find themselves frustrated by working with those who do not share or seem to have an understanding of the goals and constraints of the other disciplines. It is common for a novice team to

- spend a great deal of time asserting individual roles and traveling far down a path only to discover a hidden constraint not fully worked out, or
- sacrifice essential elements of the design in order to reconcile conflicts, leaving all members unsatisfied with a less-exciting product.

To address this, throughout the course students are asked to reflect on their design process, maintaining an awareness of their own level of cross-disciplinary learning and participation. By focusing on team interaction, students become aware that the process - the social relations and context under which the problem solution is designed-- is an emergent and changing aspect of the problem itself. Students record their understanding of the related disciplines throughout the two-quarter time frame, using a framework for thinking and assessing their state of cross-disciplinary learning (CDL) based on metrics developed in a prior study [5]. This study developed the CDL framework to describe and assess process-oriented learning not captured by traditional assessment tools. In terms of CDL, students were observed to move along a continuum described by the following four categories:

Islands of knowledge: the student masters his/her discipline, but does not have experience in other disciplines
Awareness: the student is aware of the other discipline's goals and constraints.
Appreciation: the student begins to build a conceptual framework of the other discipline, is interested to understand and support the other discipline's goals and concepts, and knows what questions to ask
Understanding: the student develops a conceptual understanding of the other disciplines, can negotiate, is proactive in discussions with participants from the other disciplines, provides input before input is requested, and begins to use the language of the other disciplines.

The CDL is used as a metric and assessment method to observe students' evolution over the two Quarter time frame. CDL is an excellent indicator how well the course works to achieve its cross-disciplinary teamwork learning goals at three levels of granularity – (1) overall class population, (2) professional community level, and (3) individual level. In addition to the CDL assessment, students are evaluated along the following dimensions: (1) the product quality in terms of discipline solutions, (2) product quality in terms of alternatives indicating system integration thinking, (3) team work process, (4) team presentation of product and process, and (5) project documentation.

Mentoring cross-disciplinary Learning

Students learn cross-disciplinary design skills through interacting in their design teams and through carefully constructed mentoring relationships. Through coaching and role modeling, mentors engage students in developing a personal understanding of what it means "to be " an "A" "E" or "C" within a cross-disciplinary design team. Mentoring in P^5BL is both structured and flexible; students are required to engage periodically with mentors, but are also encouraged to connect regularly beyond the course requirements. Mentors are afforded dedicated class time to provide feedback on projects, and each student is required to meet with at least two mentors from their discipline to get a variety of perspectives. In addition, **P^5BL** hosts informal social hours, in which mentors and students exchange ideas and stories. Student-initiated meetings with mentors take place either in person at Stanford or in the mentors work environment, or via Internet, asynchronous communication via e-mail or a web-based consulting forum.

Because students come to P^5BL with extensive domain knowledge but lacking experience implementing that knowledge. The mentoring relationship is designed to provide spaces in which the student is at times the center of the activity, scaffolded by support from mentors, and other times peripheral to the activity, learning through contributing, observing and discussing from the sidelines of the design space. The later strategy harnesses the power of "legitimate peripheral participation" [6], a term describing the induction of an apprentice into a community of practice. In this case the apprentice receives little direct instruction; instead novices participate in peripheral tasks as they learn the language, skills and actions of the activity.

P^5BL's bi-directional mentoring strategy, in which students are at the same time peripheral and central, provides students with the self-directed learning experience afforded by a complex building project for which they are centrally responsible, as well as a forum to observe experts at work solving a similar problem (Figure 1).

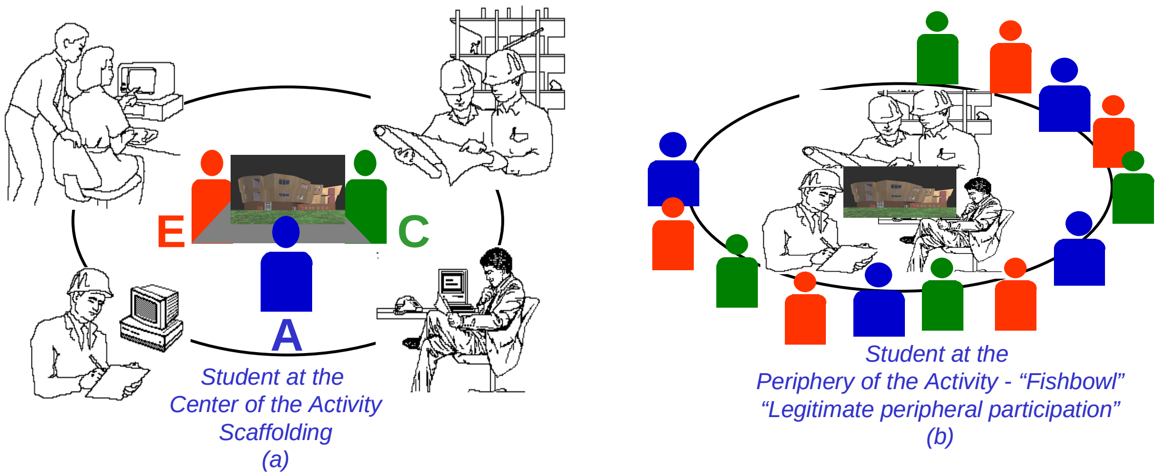

Figure 1: Bi-directional Mentoring Strategy

During most mentoring meetings, students participate in design tasks while mentors coach and question (Figure 1a). Mid-quarter, however, mentors lead a two-hour "Fishbowl" design session, in which they tackle the challenges faced by a particular team while students watch, ask questions and provide input from the sidelines (Figure 1b). By participating at the periphery of a cross-disciplinary design task, students are given the opportunity to see the effect of the design process on the creation of the product itself. They are able to see how "A" "E" and "C" practicing professionals use cross-disciplinary knowledge to facilitate design

Mentoring in action

Mentoring begins at **P^{5}BL** during the formal kick-off meeting, which plays an important role in situating the design task within a professional environment. Organized in formal conference format, the kick-off gathers professors, students, owners, and industry professionals at a board table for a presentation introducing the course and its challenges, and viewing projects from previous years. Volunteer mentors from the A/E/C industry meet each other and the students, and are introduced to the technology involved in the P^{5}BL experience. The first week students from Stanford and Berkeley and as far away as Georgia, Japan, UK, Switzerland, Netherlands, and Slovenia meet in person for the first and only time as an entire class until the closing ceremony six months later in which they present their final designs before industry professionals. Although students complete the course for a grade, most report that the pressure of presenting before professionals provided a greater incentive to produce an exciting design.

During the first quarter, students begin designing four alternatives, one of which they select to take through detailed development for their final design. Teams are given constraints including an environmentally sensitive site, a footprint, a restrictive budget, and an opinionated owner with which to work. From the beginning of the course, instructors assess CDL through students' self-evaluation on survey forms, coding of responses to questions, and general team interaction in the team's discussion forum.

Mentors play a key role in helping students from different disciplines learn to work together. In the following we will discuss a sample team as an example of successful recovery from a breakdown in cross-disciplinary communication. *Team A* had the "A" (architect) member from UC Berkeley and three others, the "E", "C" and apprentice from Stanford University. In the CDL assessment, the engineer ("E") consistently showed evidence of an *Appreciation* of the other disciplines goals and constraints, asking relevant questions to uncover the goals of the other disciplines. The construction manager ("C") and the Architect ("A") showed strong evidence of an *Islands* frame of reference, experienced in their own disciplines, but not in the others, not knowing which questions to ask or how to participate as the project progressed. The fourth member was an undergraduate "apprentice" who demonstrated some *Awareness* of all the disciplines, but had not yet specialized.

Team A begins sketching the first of four required alternatives to present to the class for discussion. The *Islands* framework of thinking and interactions is reflected in asynchronous conversations and synchronous meetings, e.g., "A" requests that "C" and E" wait for the architectural sketches before providing input, explaining that it is "A's" job to provide the initial design, and that this takes time for her to work out on her own. When "A" eventually posted her design in the team web space, the engineer was disappointed that it wasn't structurally more challenging, and began suggesting changes. "A" expressed resistance, insisting that design was the architect's role. Eventually, "E" became frustrated with both the design and the process, and proposed a detailed structurally exciting alternative design that eventually was selected by vote among team members. "C" participated little in the early designs and debate, explaining that until the design was proposed, a construction manager had nothing to work with to determine costs. The architect was upset at the shifting roles in the team and considered quitting. The team was at an impasse.

The team's cross-disciplinary participation patterns had a profound effect on the design process. Teams whose members demonstrate an understanding of each other's goals and constraints tend to have clearer, more proactive and more frequent communications, and are more likely to participate in "brainstorming" across disciplines. Teams whose members demonstrate an *Islands* pattern of participation tend to spend more time negotiating logistics, reasserting each others roles, presenting design decisions rigidly without rationale and waiting to raise discipline-specific concerns until far into the design process. Although there was much discussion over roles and responsibilities among *Team A*'s members during design meetings and in the on line discussion forum, this team showed little evidence of progressing either towards an acceptable solution or towards greater functioning as a cross disciplinary team.

Mentoring a recovery: Mentors helped this team's cross-disciplinary learning in several phases of the design. At the first mentoring session, each team presented an initial design for mentor questions and comments, helping students establish fundamental constraints and identify possible points needing further consideration. *Team A* received input from a structural, cost and architectural perspectives on the initial design presented by "A."

When the team reached its impasse, mentors played a key role in helping individuals to reconstruct their understanding of their roles in light of the requirements of the new, structurally focused design developed by the engineer. Mentors actively supporting the development of the team's process through coaching. Individuals consulted with mentors privately, expressing feelings and concerns about roles and responsibilities in the design process and brainstorming alternatives. Mentors expressed empathy as members of the profession, but also encouraged a more fluid design process by modelling cross-disciplinary interaction. For example, an engineer mentor, while exclaiming *"Architects are like that! "* at a complaint that "A" was not taking into account structural issues, followed up with the question, *"Well, what is "A" really getting at? She must have an underlying vision for a space "like this."* By meeting with the architecture mentor, "A" was able to work through her evolving role in the project, viewing the structural features as a design challenge rather than a threat to her architectural contribution.

Subsequent meetings involved the entire group meeting with one or more mentors of a given discipline. In these meetings, mentors were also able to prompt teams into uncovering constraints early in the process, often from a perspective outside their domain. For example, an engineer models cross-disciplinary thinking by probing around construction constraints, *"How are you going to get your equipment in there? That's a tight space."* Insight from these meetings not only informed students of the given discipline thinking strategies, but also modeled these strategies for the entire team.

In these mentoring activities described above, mentors participate at the periphery, serving as resources for students own questions, but also occasionally probing and questioning to influence the thinking and direction of the team. The primary participants are the students, who may understand qualities of a well designed product from their previous training, but have not yet participated in a well-designed process. In order to scaffold students' process-oriented learning, mentors also participated in an activity in which they were the primary participants, moving students to the periphery.

The "FISHBOWL"

The "Fishbowl" is an extended mentoring session in which students turn their problem completely over to a professional interdisciplinary design team of mentors, and then watch the problem-solving process, asking questions, providing suggestions and requesting clarifications from the sidelines (Figure 1b). Because mentors are working on a specific problem with which students have been grappling, the discussion is engaging. Because students are not central participants, they have sufficient distance to focus on the process the experts are modelling. In comparing design sessions of experts skilled in interdisciplinary interaction with those of novice interdisciplinary teams, some marked differences come to light. Students begin to notice patterns of participation that make the design process fluid, dynamic and exciting.

Team A's "Fishbowl" exercise began with the team presenting their current alternative developed by the "E", and some of the unresolved issues with which they were grappling. They pulled up their AutoCAD model on a SmartBoard, a four-foot high touch screen monitor that facilitates group interaction in sketching and negotiating designs. The Architect described the project and presented her dissatisfaction with the structural design, describing conflicts with internal spaces. The structural engineer presented some issues surrounding materials. The construction manager indicated that since the design was in the initial stages, there was not much she could do at this time.

The design was then turned over to an A/E/C team of mentors to discuss and explore possible directions, with the entire class surrounding the discussion. For two hours, mentors examined sketches, re-sketched, debated, negotiated, consolidated and moved forward in an animated design process that involved all members of the team and occasionally student observers, who jumped in with ideas and disagreements. Some noticeable practices of expert cross-disciplinary designers became visible, revealing a continual iterative, flexible process of: (1) seeking conceptual agreement, (2) probing the boundaries of the problem from multiple perspectives, (3) seeking agreement on process.

Seeking conceptual agreement: Unlike most student teams, mentors spent significant time up front gaining agreement on the conceptual goal of the project overall, as well as conceptual understanding of constraints. For example, in the case of *Team A*, the mentor engineer spent significant time uncovering the architects conceptual model and identifying key features that were intended to reflect that model. The team discussed this underlying concept in light of cost early on, negotiating which features to emphasize and which to sacrifice given the restrictive budget. The team continually revisited and honed in on this underlying concept as they progressed in the design, allowing the concept to drive the design process. This strengthened the team and served as quality control: for example, when the team encountered situations in which they were making significant aesthetic sacrifices for structural or cost concerns, these were quickly examined with regards to the underlying concepts. If they violated these conceptual goals, that path was quickly abandoned and another route sought.

Mentors use a variety of thinking and participation practices to collectively reach conceptual agreement that is not frequently observed in novice design teams. Transparent thinking strategies, in which individuals wonder out loud, experiment with "what if" statements, and lay out incomplete thoughts bring the rest of the team along in the formulation of the idea itself, so that the idea appeared more likely to include specific concerns of the other disciplines. Mentors relinquish control of the line of discourse to seek understanding of concepts put forward by other disciplines, and use conceptual models and analogies relevant to other disciplines to convey their ideas.

Probing boundaries from multiple perspectives: Experts visit the problem constraints frequently and from all perspectives, despite their specific area of expertise. For example, the mentor architect frequently checked in during each new iteration the cost constraints and structural elements, preventing the pursuit of impossible paths. Experts anticipate each other's concerns, offering necessary details to rule out dead-ends early on. Frequently during a brainstorm surrounding an alternative, the mentor engineer requested material cost estimates to calculate the feasibility of structural decisions before they were made, avoiding a break in the design process and preventing wasted time.

Mentors continually revisit or challenge original constraints in light of the elaboration of the problem, occasionally opening doors in directions that previously appeared closed. At one point far into the design process, mentors revisited and re-negotiated their understanding of the footprint constraint in light of an emerging structural issue, changing their trajectory fundamentally. Mentors also sought detail at every step, rapidly shifting from exploration of materials and costs of specific elements to the big picture of how these elements worked with the overall concept and goals. Their experience in the field allowed them to do this immediately; they frequently drew knowledge of specific costs, availability and effective trade-offs from previous projects. Additionally, mentors were clear not to confuse features that they liked with underlying concepts that were essential to maintain; they frequently made quick, clear concessions on detail in order to preserve the overall concept.

Seeking process agreements: Throughout the design process, the expert mentors maintained an explicit awareness of their process. Mentors continually restated past decisions and future directions with statements such as, *"So my understanding is that we've decided ___ and now we're ready to move on to ___ ."* Early in the process, mentors proposed areas of focus to narrow the problem space, with statements such as "*lets agree to sacrifice [this area] in order to maintain the expression and focus on [another area]."* As a result, all participants in the team maintain a mental map of where they've been and where they think they are headed. This enables them to provide quick agreement or disagreement on proposed decisions, pointing out trade-offs and negotiating solutions with flexibility, and reverting to a modified position or readily considering a change in trajectory when challenged.

The "Fishbowl" exercise provided students an opportunity to reflect on their own practices in light of their observations of experts in cross-disciplinary teams. By observing mentors interacting with each other, students had the opportunity to learn participation patterns commonly employed by professionals but rarely discussed in academic training and difficult to discover without having had extensive experience.

Reverse Mentoring

While Mentors influenced students design practices by connecting them to larger communities of practice in industry, students clearly influenced mentors' practices within these communities as well. By making explicit the commonly practiced but little understood skills of interdisciplinary design, P^5BL encouraged mentors to rethink the importance of these interactions in their own design practices. Additionally, industry mentors worked in the field for many years using traditional tools. As a result, most had little experience employing high-tech communications technologies. Not only were they unfamiliar with how to operate these technologies, they were unfamiliar in harnessing the types of communications these technologies afford and changing the business process to leverage the communication technologies. Exposure to these technologies enabled mentors to bring a vision of distributed design to their organizations.

Like the "Fishbowl" session, mentors participated at the periphery, observing student interaction in a high tech medium, participating in high-tech practices in increasingly sophisticated ways as they learned. During the initial presentations of student designs, mentors were able to see students in Europe participating via video conferencing, and were able to watch students use touch screen technology to rapidly sketch ideas and share iterations via the web-based whiteboard. Later during team design sessions, mentors themselves used the touch screen SmartBoard to explore and communicate concepts. During their own interaction with the technology, they encountered some of the social and technical problems associated with distributed design, such as the ineffectiveness of unseen gestures in remote communications and bandwidth issues that cause audio-visual problems; they looked to student practices to uncover workarounds for these problems. While mentors expressed enthusiasm for the potential of videoconferencing technology for facilitating communications in their industry, they were most moved by the potential of collaborative technologies to speed up the design process. Using large touch screen technology, mentors were able to rapidly generate sketches and recover previous iterations quickly; because of its size, the SmartBoard is able to include large groups in the conceptual design. By offering multi-user input via pens, team members could trade leading roles quickly during brainstorming sessions, clarifying problems specifically and documenting decisions by saving documents as they were designing.

In P^5BL, students use touch-screen collaborative technologies at all phases of the design process. Given light-weight touch-screen laptops at the beginning of the quarter, students are able to bring their work anywhere; during a social hour at a local coffee house, mentors were surprised to find students able to quickly pull up diagrams, clarify points and sketch concepts they were casually discussing. Mentors were even more surprised to find that these casual discussions can be fully and easily communicated to distributed team members via a powerful collaborative technology developed by P^5BL -- one that embeds features of the design process in the sketch-product itself. RECALL a client-server-based technology that saves sketches and the conversation surrounding them, was developed by P^5BL Lab researchers to facilitate distributed [7]. By capturing the thinking and communications into the sketched design and making this design rationale fully and non-linearly recoverable, RECALL affords rapid iteration of a problem over remote distances, avoiding the need for time-consuming misunderstandings and clarification of points. Mentors expressed fascination with this technology, quickly realizing its potential to enhance their own practices.

A P^5BL Lab developed AEC Discussion Forum tool was used by the team members to interact asynchronously and capture the free flow of ideas, solutions, feedback, requests for information, exploration, and interaction with mentors. Industry mentors learned the affordances of the AEC Discussion Forum through hands-on interaction with the teams. This helped them understand the value of the technology in reducing communication cycles, consequently time-to-market. One of the mentors took his experience to the next level and started a pilot project within his company using the AEC Discussion Forum to foster collaboration, sharing, capturing, re-using design knowledge and best practices.

Conclusion

Mentoring at P^5BL provides a rich multi-dimensional experience that goes beyond the usual design of "authentic" project based learning by embedding the context within a cross-disciplinary support community of mentors who serve as critics, coaches, and friends. This differs from many problem-based learning experiences that locate the problem within the classroom, limiting the student's understanding of the problem space to the tasks at hand and domain specific skills required accomplishing these. Thus while they may be learning architecture through the design of a building, they may not be afforded the opportunity to learn the work habits, thinking practices and participation patterns of architects within the actual context of the colleagues and professional concerns, affordances and constraints in which they work. The P^5BL mentoring experience provides students with connections to communities of practice that foster their growth within their field in a cross-disciplinary context. Students benefit from mentors' extensive experience in cross-disciplinary teamwork, gradually breaking with the *Islands* frame of thinking that has developed from isolated study of their discipline within academic context. Students begin to develop an identity related to professional practices as they explore solutions to an authentic problem with the support of people experienced in their field, building confidence and ongoing relationships that will support their professional endeavors in the future. Through mentoring, students gain not only an understanding of the goals and constraints of related disciplines, but develop patterns of participation that enable them to use this understanding to facilitate interdisciplinary design. The developing of mentoring relationships has implications for industry and the university as well. Mentors are exposed to the latest academic R&D, and are able to bring these ideas into the work place. Universities gain access to internship and employment opportunities for their students and the multidimensional skills developed in P^5BL are sought by industry. Mentoring facilitates students' appreciation of cross-disciplinary learning, enabling them to structure their programs to take advantage of learning opportunities outside their academic departments. After taking a P^5BL course, most students changed their course plans to incorporate classes in the related disciplines [5]. A carefully designed mentoring experience can greatly enhance students' experience in problem based learning.

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RENATE FRUCHTER

Renate Fruchter is the director of the Project Based Learning Laboratory (**P^{5}BL** Lab) in the Department of Civil and Environmental Engineering, and a senior research associate at CIFE, at Stanford. She leads a research effort to develop collaboration technologies for multidisciplinary, geographically distributed teamwork, and e-Learning. She is the leader and developer of the innovative “Computer Integrated A/E/C” course launched in 1993 and currently offered in a global setting including universities in US, Japan and Europe.

SARAH LEWIS

Sarah Lewis is a Graduate Student in the *Learning, Design, and Technology* M.Sc. Program in the School of Education, at Stanford University.