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Mentoring Models in Support of P^{5}BL in Architecture/Engineering/Construction Global Teamwork*

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Understanding the goals and constraints of other disciplines is key to working well in cross-disciplinary projects. Education programs rarely offer learners the opportunity to participate in authentic project-based cross-disciplinary collaborations in a global teamwork e-Learning environment. Problem-, Project-, Product-, Process-, People-Based Learning^{TM} (P^{5}BL) is an approach that has been developed to address this issue. This paper presents mentoring models in cross-disciplinary teamwork learning experiences developed in Stanford University's P^{5}BL program. It addresses the Architecture/Engineering/Construction (A/E/C) industry's need to broaden the competence of engineering students to utilize the acquired theoretical knowledge and understand the role of discipline-specific knowledge in a multi-disciplinary A/E/C P^{5}BL learning environment. Mentoring opportunities are presented within a situated and constructivist perspective on learning, to explore the theoretical constructs and practical implications of developing communities of practice that reach beyond the university walls.

INTRODUCTION

ISOLATION OF Architecture/Engineering/Construction (A/E/C) students within discipline-specific education programs, departments, and schools has impacted on 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 a narrow perception of what it means to participate in the design process as a member of their specific discipline.

The *Problem-, Project-, Product-, Process-, People*-Based Learning (P^{5}BL) laboratory and education program in the Department of Civil and Environmental Engineering at Stanford was established in 1993. It was created to provide a learning environment that addresses this problem by offering graduate students the unique opportunity to exercise their specialized skills as architects (A), engineers (E), and construction (C) managers in a cross-disciplinary, collaborative, geographically distributed teamwork experience [1]. The A/E/C global teamwork program is based on a P^{5}BL pedagogical approach, where P^{5}BL stands for *Problem-, Project-, Product-, Process-, People-*Based Learning. P^{5}BL is about teaching and learning teamwork in the information age. P^{5}BL is a methodology of teaching and learning that focuses on problem-based, project-organized activities that produce a product for a client. It is based on re-engineered processes that bring together people from multiple disciplines. The design of the P^{5}BL lab and program are grounded in cognitive and situative learning theory. The cognitive perspective characterizes learning in terms of growth of conceptual understanding and general strategies of thinking and understanding [2]. The A/E/C P^{5}BL experience was designed to facilitate team interaction with professors, industry mentors, and owners that provides a structure for modeling and coaching which scaffolds the learning process, both in the design and construction phases, as well as in techniques such as articulating and reflecting on the cognitive processes.

The situative perspective shifts the focus of analysis from individual behavior and cognition to larger systems that include individual agents interacting with each other and with other subsystems in the environment [3]. Situative principles characterize learning in terms of more effective participation in practices of inquiry and discourse that include constructing meanings of concepts and uses of skills. Greeno argues that the situative perspective can subsume the cognitive and behaviorist perspectives by including both conceptual understanding and skill acquisition as valuable aspects of students' participation and their identities as learners and knowers. Teamwork, specifically cross-disciplinary learning, is key to the design of the A/E/C P^{5}BL. Students are expected to engage with other team members to

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determine the role of discipline-specific knowledge in a multi-disciplinary project-centered environment, as well as to exercise newly acquired theoretical knowledge. It is through cross-disciplinary interaction that the team becomes a community of practitioners—the mastery of knowledge and skill requires individuals to move towards full participation in the socio-cultural practices of a larger community. Negotiating language and culture is equally important to the learning process: through participating in a community of practitioners (A/E/C), the students learn how to create discourse that requires constructing meanings of concepts and uses of skills.

This study presents an analysis of mentoring models in scaffolding the students' cross-disciplinary teamwork design process, as well as a description of students' roles in scaffolding the mentors' understanding of cutting-edge collaboration technologies.

THE P^{5}BL A/E/C GLOBAL TEAMWORK PROGRAM

The P^{5}BL A/E/C 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 and Kansas University in the US; Stanford Japan Center in Kyoto, Japan, and Aoyama Gakuin University in Tokyo, Japan; the University of Ljubljana in Slovenia; Bauhaus University in Weimar, Germany; ETH Zurich and FHA in Switzerland; Strathclyde University in Glasgow, UK; KTH in Stockholm, Sweden; and TU Delft in the Netherlands).

The A/E/C student teams represent the core atoms in this learning environment. The students come from various programs, departments, and universities and bring to the program their discipline and national culture (i.e. egos, goals, constraints, languages, representations, and tools). Team formation in the A/E/C education program is a function of team size, members' roles, and participants' locations. One of the innovative features of this course is the role each of the participants plays:

- undergraduate and graduate students have the roles of apprentice and journeyman respectively;
- faculty members and researchers play the role of 'master builders'; and
- industry representatives play the role of mentor, owner, and sponsor.

The size of the teams is determined by two factors: (1) the three disciplines, and (2) the roles (i.e. journeyman and apprentice). Consequently, each team has one architect, one structural engineer, one construction management student as journeymen from the M.Sc. programs, and one or two apprentice students from the B. Sc. program. The pedagogical reason behind the decision not to have more students from any of the A/E/C disciplines in a team is to ensure that all students maintain a constant, high engagement with the project and recognize that they have a well-defined responsibility to represent their profession within their team. A/E/C students are challenged to cross three chasms during their learning experience: discipline, space, and culture. The geographical location of the team members provides the students with an opportunity to be exposed to a virtual teamwork in a cross-cultural environment, as well as justifying the use of information technologies to accomplish the goals of the project. Interaction between the disciplines is key to the functioning of the team and to the development of the cross-disciplinary learning experience for each individual.

The core activity in this learning environment is a building project with a program, a budget, a site, a time for delivery, and a demanding owner. The project is based on a real-world building project that has been scoped down to address the academic time-frame of two academic quarters: the first quarter focuses on concept development and the second focuses on project development. A/E/C teams model, refine and document the design product, the process, and its implementation. The students learn to (1) regroup as the different discipline issues become central problems and impact on other disciplines, (2) use computer tools that support discipline tasks and collaborative work, and (3) use video-conferencing and desktop-sharing technology to have face-to-face meetings and interact with the teaching team and industry mentors. The project progresses from the 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. A team's cross-disciplinary understanding evolves over the life of the project. The international structure of A/E/C teams adds a real-world collaboration complexity to the learning environment, which includes space, time, coordination, and cooperation issues. A key focus is the effective use of IT resources to support instruction and learning outcomes. Typical project examples can be viewed in the project gallery of P^{5}BL (http://pbl.stanford.edu).

P^{5}BL employs innovative technologies to bridge these distances over time and space. P^{5}BL challenges and thrusts students into an unfamiliar, technologically rich environment in which they have to work through open-ended problems on a building project with ill-defined goals and emergent constraints. A variety of collaboration technologies scaffold students' learning as they work through the project, such as discussion forums, web group spaces, video-conferencing, instant messaging, 3D modeling, etc. [1].

The A/E/C global teamwork experience starts in

January and ends in May each year. The learning and teamwork activities are both structured and unstructured. There are three types of structured weekly activities: *IT lecture, Lab session*, and *A/E/C professional practice session*. The *IT lecture* series introduces the concepts, system architecture, advantages and limitations of information and collaboration technologies from a user's point of view. Emphasis is placed on the potential of each of the collaboration technologies, its impact on the behavior of the individual and on team dynamics, as well as on the build environment. The *Lab sessions* introduce the students to these collaboration technologies through hands-on exercises. Each collaboration technology has a pedagogical objective and is justifiable in the context of the A/E/C students' teamwork activities. Students actively use the information technology infrastructure to communicate, collaborate, and coordinate among the geographically distributed team members.

The *A/E/C professional practice session* can take one of the following forms, depending on the stage of the course:

- *Round table discussions* are organized at the beginning of the course. A/E/C industry practitioners and faculty are invited to discuss the role of each discipline, the value it adds to the project and product, building systems integration, and the teamwork process (cross-disciplinary interactions and impacts in the decision-making process).
- *Role modeling* through case studies. Signature project case studies are introduced to the students, such as Frank Gehry's Guggenheim Museum and the Music Experience, KL&A's Aspen Music Hall. All the case studies are dissected and analyzed from a cross-disciplinary perspective, emphasizing (1) the exploration of alternatives in the concept development phase, and (2) the project development and construction as a function of the cross-disciplinary impact among architecture, structural systems, mechanical systems, and constructibility.
- *Informal A/E/C project reviews*. These are sessions in which each A/E/C student team meets with a full A/E/C mentor team (including faculty and industry practitioners) to discuss their concepts and preliminary solutions and receive constructive and critical feedback, as well as guidance and real industry data.
- *Fishbowl sessions*. These are sessions in which A/E/C student teams briefly describe their current project challenges and hand over their project to a full team or A/E/C industry mentor who works on the project for an hour (see the 'Mentoring in action' section).

Learning in 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, as identified when discussing education from a cognitive/constructivist perspective, such as problem-solving and reasoning [4–6], as well as metacognitive processes, the capacity to reflect upon one's own thinking and thereby to monitor and manage it and construct explanations [7]. Consequently, A/E/C students conceptualize the problems from multiple perspectives, understand the goals and constraints of other disciplines, and gain 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 the students' learning experience in P^5BL, it is also part of their experience in other courses. Most unique is the learning that is revealed 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' [3, 8]. 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 his/her identity as a member by participating in activities, discourse, and reflection surrounding the communities' shared experience of work [9]. 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 on the development of identity 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 how to communicate, collaborate and negotiate with people in 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 the interdisciplinary design skills necessary for the participation of architects, engineers and construction managers in the A/E/C industry. Recognizing this, students come to P^5BL 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 in the class as experts in their field, having at least completed an undergraduate major, and being in the process of gaining a graduate degree. Academic training often leads 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 do one of the following:

- spend a great deal of time allocating individual roles and traveling a long way down a path only to discover a hidden constraint that has not been fully worked out; or
- sacrifice essential elements of the design in order to reconcile conflicts, leaving all members dissatisfied with a less-than-exciting product.

To address this, throughout the course students are asked to reflect on their design process, in order to maintain 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 in 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 [10]. This study developed the CDL framework to describe and assess process-oriented learning that is 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 learner masters his/her discipline, but does not have experience in other disciplines.
- *Awareness*: The learner is aware of the other discipline's goals and constraints.
- *Appreciation*: The learner begins to build a conceptual framework of the other discipline, is interested in understanding and supporting the other discipline's goals and concepts, and knows what questions to ask team members representing the other disciplines to elicit key information that will impact on their discipline solution.
- *Understanding*: The learner 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 as to how well the course is working to achieve its cross-disciplinary teamwork learning goals at three levels: (1) overall class population, (2) professional community level, and (3) individual level. In addition to the CDL assessment, students are also evaluated on the following: (1) the product quality in terms of discipline solutions, (2) product quality in terms of exploration of alternatives and system integration thinking, (3) the teamwork process, (4) team presentation of the 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, as well as becoming part of their respective professional communities. 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 allocated dedicated class time to provide feedback on projects, and each student is required to meet with at least two mentors from their discipline in order to obtain 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 the Internet, asynchronous communication via e-mail, or a web-based consulting forum.

Students come to P^5BL with extensive domain knowledge but lacking experience in 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 at other times peripheral to the activity, learning through contributing, observing and discussing on the sidelines of the design space. The latter strategy harnesses the power of 'legitimate peripheral participation' [11], 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 (Fig. 1).

During most mentoring meetings, students participate in design tasks while mentors coach and question them (Fig. 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,

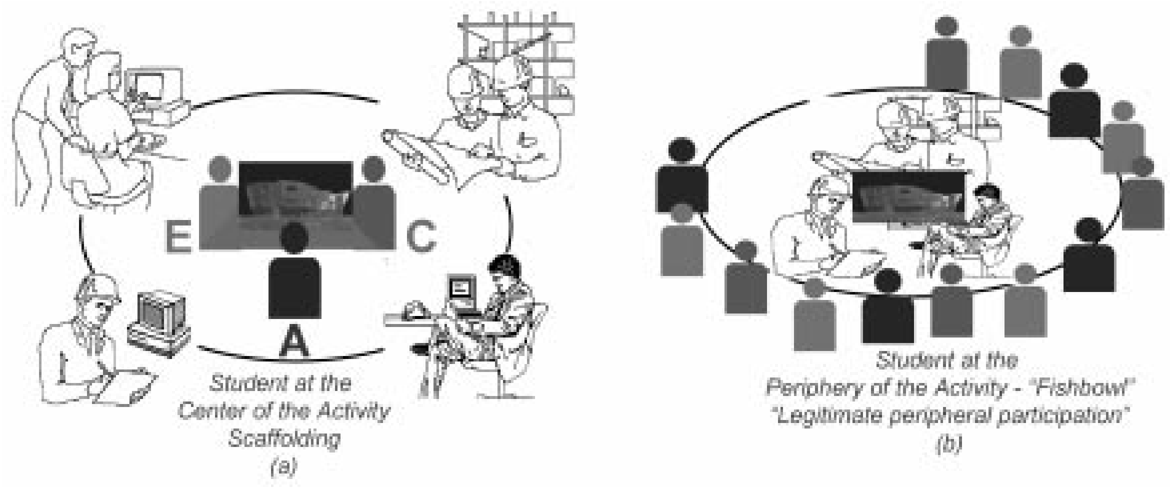

Fig. 1. Bi-directional mentoring strategy.

ask questions and provide input from the sidelines (Fig. 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 practicing professionals in 'A', 'E' and 'C' use cross-disciplinary knowledge to facilitate design.

MENTORING IN ACTION

Mentoring begins at P^5BL 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 that introduces the course and its challenges and shows 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^5BL experience. In the first week, all the students from the partner universities in Europe, the US and Japan meet in person for the first time at Stanford. The second time they meet at Stanford for the closing ceremony six months later, in which they present their final designs before industry professionals. The rest of the time the team members and the learner community meet in cyberspace on the Internet using synchronous and asynchronous collaboration technologies. Although they complete the course for a grade, most students report that the pressure of making a presentation before professionals provides 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 to work with. From the beginning of the course, instructors assess CDL through student 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. Below, we will discuss a sample team as an example of successful recovery from a breakdown in cross-disciplinary communication through mentoring. *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, by 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, as 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 began by sketching the first of four required alternatives to present to the class for discussion. The *Islands* framework of thinking and interactions was reflected in asynchronous conversations and synchronous meetings ('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 would take 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 was not 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 was eventually voted for by 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 communication, 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 about 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. This helped students establish fundamental constraints and identify possible points that needed further consideration. Team A received input from a structural, cost and architectural perspective 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 supported the development of the team's work processes through coaching. Individuals consulted with mentors privately, expressing their 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 modeling cross-disciplinary interaction. For example, an engineer mentor, while exclaiming 'Architects are like that!' at a complaint that 'A' was not taking structural issues into account, 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 of 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 the mentoring activities described above, mentors participate at the periphery, serving as resources for the students' own questions, and probing and questioning their ideas and solutions to influence the thinking and direction of the team. The primary participants are the students, who have learned to understand what constitutes 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 participated in an activity in which they were the primary participants, moving students to the periphery. We called this learning and mentoring experience the 'fishbowl'.

THE 'FISHBOWL'

The 'fishbowl' is an extended mentoring session in which students completely turn their project and current issues over to a professional interdisciplinary A/E/C 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 the specific problems with which students have been grappling, the discussion is engaging and concrete, since students have a sense of ownership of their project. Because students are not central participants, they have sufficient distance to focus on the process the experts are modeling. In comparing the 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 '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, sketching, and negotiating design solutions. The architect described the project and presented her dissatisfaction with the structural design, describing conflicts regarding the 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 industry mentors to discuss and explore possible directions, with the entire class looking on. 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 process of: (1) seeking conceptual agreement, (2) probing the boundaries of the problem from multiple perspectives, and (3) seeking agreement on process.

Seeking conceptual agreement

Unlike most student teams, mentors spent significant time 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 considerable time uncovering the architect's 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 a quality control: for example, when the team encountered situations in which they were making significant aesthetic sacrifices for structural or cost concerns, these were immediately examined with regard to the underlying concepts. If they violated these conceptual goals, that path was abandoned and another route was sought.

Mentors use a variety of thinking and participation practices to collectively reach conceptual agreement, but this is not usually observed in novice design teams. Transparent thinking strategies, in which individuals wonder aloud, experiment with 'what if' statements and describe incomplete thoughts, bring the rest of the team along in the formulation of the idea itself, so that the idea becomes more likely to include the specific concerns of the other disciplines. The mentors relinquish control of the line of discourse in order to understand the 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

The experts visit the problem constraints frequently and from all perspectives, despite their specific area of expertise. For example, the mentor architect repeatedly checked the cost constraints and structural elements, thereby preventing the pursuit of impossible paths. Experts anticipate each other's concerns, offering the necessary data to rule out dead-ends early on. During a brainstorm surrounding an alternative, the mentor engineer frequently requested estimates of material costs to calculate the feasibility of structural decisions before they were made, thus avoiding a break in the design process and preventing wasting time.

Mentors continually revisit or challenge the 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 renegotiated their understanding of the footprint constraint in light of an emerging structural issue, thereby 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, and they frequently drew on knowledge gained on previous projects of specific costs, availability and effective trade-offs. Additionally, mentors were clear about not confusing features that they liked with underlying concepts that were essential to maintain, and 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 the 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 space for problems, with statements such as: 'let's agree to sacrifice [this area] in order to maintain the expression and focus on [another area].' As a result, all participants in the team maintained a mental map of where they had been and where they thought they were headed. This enabled 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' experience provided students with an opportunity to reflect on their own practices in light of their observations of experts in cross-disciplinary teams. By observing mentors interacting with one another, 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. Subsequently, students reported that they started to emulate during their team meetings the same processes of (1) seeking conceptual agreement, (2) probing the boundaries of the problem from multiple perspectives, and (3) seeking agreement on processes they observed during the 'fishbowl' sessions. Consequently, the 'fishbowl' mentoring experience was effective in providing role modeling and scaffolding the students' skills in teamwork and professional performance.

REVERSE MENTORING

While mentors influenced students' design practices by connecting them with 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. In addition, industry mentors who had worked in the field for many years using traditional tools had little experience of employing high-tech collaboration and information technologies. Not only were they unfamiliar with how to operate these technologies, they were unfamiliar with harnessing the types of communications these technologies afford and changing the business process to encompass the communication technologies. Exposure to these technologies enabled mentors to bring a vision of distributed design to their organizations.

As in 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, the US and Japan participating via video-conferencing in activities originating from Stanford, and were able to watch students use SmartBoard touch-screen technology to rapidly sketch and share ideas via the web-based whiteboard. Later on in the 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, and they observed student practices for identifying workarounds for these problems.

While mentors expressed enthusiasm for the potential of video-conferencing technology to facilitate communication in their industry, they were most interested in the potential of collaborative technologies to speed up the design process. Using large touch-screen technology, mentors were able to generate sketches and recover previous items rapidly (because of its size, 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 in all phases of the design process. As students are given lightweight wireless touch-screen laptops at the beginning of the program, they are able to take their work anywhere. During a social hour at a local coffee house, mentors were surprised to find students pulling up diagrams to clarify points and sketching concepts they were casually discussing. Mentors were even more surprised to find that these casual discussions could be fully and easily communicated to remote team members via a powerful collaborative technology, RECALL, developed by P^5BL Lab (which 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 real-time indexing and distribution of rich content such as sketching, audio and video [12]. By capturing the original thinking and communication in 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, immediately realizing its potential to enhance their own practices.

A P^5BL Lab developed an A/E/C discussion forum tool called ThinkTank, which 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 potential of ThinkTank through hands-on interaction with the teams. This helped them understand the value of the technology in reducing communication cycles and, 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 ThinkTank technology to foster collaboration, sharing, capturing, re-using design knowledge and best practices.

CONCLUSION

Mentoring models utilized in the P^5BL A/E/C global teamwork program provide 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 the domain-specific skills required to accomplish 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, provisions 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 and gradually break with the *Islands* frame of thinking that has developed from isolated study of their discipline within the 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, thus 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 of their academic departments. After taking a P^5BL course, most students changed their course plans to include classes in the related disciplines [10]. A carefully designed mentoring experience can greatly enhance students' experience in problem-based learning.

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