Teamwork: Assessing Cross-Disciplinary Learning

Renate Fruchter

Stanford University, Project Based Learning Laboratory

Katherine Emery

Stanford University, School of Education, "Learning, Design and Technology" Program

Abstract: Multidisciplinary teamwork in an information age learning environment poses new assessment challenges. This paper presents a study that focuses on the assessment of a learning environment in which students collaborate in multidisciplinary, geographically distributed teams. The study presents a new metric, *cross-disciplinary learning*, as a journey from the state *of island of knowledge* (discipline-centric) to a state of *understanding* of the goals, language, and representations of the other disciplines. The metric proposes a four-tiered classification, designed to measure the students' evolution of cross-disciplinary learning, that is based on the perspectives of cognitive and situative learning theories. The four tiers are *islands of knowledge*, *awareness*, *appreciation*, and *understanding*. An additional metric is based on a longitudinal assessment that tracks the programmatic changes such a cross-disciplinary education program can lead to. The paper describes the multidisciplinary, collaborative, geographically distributed teamwork learning environment, the assessment methodology, data collection and analysis, and discusses the preliminary results.

Keywords: teamwork, cross-disciplinary learning, assessment

Introduction

Fragmentation among Architecture/Engineering/Construction (A/E/C) professionals, which is emphasized by divergent education, is today's status quo. One of the reasons for the current poor coordination and communication among professionals in the fragmented A/E/C industry and among project phases is rooted in the way education is structured today, by discipline.

PBL, the People-, Problem-, Process-, Product-, Project-Based Learning Lab, was created to provide a learning environment where A/E/C students would collaborate in multi-disciplinary, geographically-distributed teams on project-centered activities that produce a product for an industry client (Fruchter, 1999). The design of the PBL lab is 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 (Dewey, 1958). The design of the A/E/C PBL--to provide team interaction with professor, industry mentors and team owners--provides a structure for modeling and coaching which scaffolds the learning process, both in the design and construction phases, as well as for techniques such as articulating and reflecting on 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 (Greeno, 1998). 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 PBL. Students are expected to engage with other team members to 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 sociocultural practices of a larger community. The negotiation of 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 to construct meanings of concepts and use of skills.

Motivation

The study comes in response to three distinct problems. First, there is a pedagogically perceived need to enhance traditional assessment methods in order to monitor and evaluate the evolution of the cross-disciplinary learning experience students have in multidisciplinary project-based courses, such as A/E/C PBL. Traditional assessment dimensions included in course evaluation questionnaires, such as Tau Beta Pi developed at Stanford, offer basic performance measures—however, they focus on the teaching aspect rather than on the learner and learning perspective. This assessment approach can be effective in the case of conventional classes where there is one discipline-centric focus, one instructor, a reader or text book(s), homework assignments, a midterm, and a final exam.

In addition, current studies of university courses in which technology is a key component tend to focus on the technology—specifically, on media selection and media effects. Neither of these issues address the individual learner (Walther, 1997). Technology is central to the design of PBL—without it, the students would not be able to collaborate across geographic distances. However, the technology is constantly changing. Even within a two-quarter period, certain technologies are updated or even replaced by newer technologies. This study, rather, focuses on the importance of the learner's experience in A/E/C PBL, which includes the interaction with and through various technologies.

And finally, we are interested in determining how to design and conduct an assessment within the perspective of cognitive and situative learning theory. If traditional assessment methods have limited value in evaluating a collaborative, multidisciplinary, geographically distributed team of students, they are equally ineffective in measuring:

- Effective participation in practices of inquiry and discourse
- Increase in skill acquisition and conceptual understanding through multidisciplinary collaboration.

With the emerging interest in multidisciplinary, project-based learning and teamwork, new assessment dimensions need to be considered to evaluate cross-disciplinary learning. The study formalized two key questions:

1. What is the impact of cross-disciplinary learning on the student population in the class overall, as well as on the students within each discipline?
2. What is a key metric for recording the student's longitudinal curricular/programmatic changes as a consequence of a multidisciplinary, project-based teamwork experience?

A/E/C PBL Teamwork Learning Environment

The "Computer Integrated Architecture/Engineering/Construction" (A/E/C) is the main education program housed by the PBL Lab, in the Civil and Environmental Engineering Department, at Stanford. It is aimed at developing a new A/E/C learning culture, an exciting education paradigm, and an engaging computational infrastructure for collaborative multi-disciplinary work that takes the *distance* out of distance learning. The A/E/C education program, launched in 1993, is based on the PBL methodology of teaching and learning that focuses on ***problem*** based, ***project*** organized activities that produce a ***product*** for a client. PBL is based on re-engineered ***processes*** that bring ***people*** from multiple disciplines together. The A/E/C course brings together faculty, practitioners, and students from different disciplines, who are geographically distributed. One of the innovative features of this course is represented by the role each of the participants plays, i.e.:

- undergraduate and graduate students play the roles of apprentice and journeyman, respectively,
- faculty members and researchers play the role of "master builders,"
- industry representatives play the role of mentors.

The core atom in this learning environment is the A/E/C student team, which consists of an architect, a structural engineer, a construction manager from the M.Sc. level, and one or two undergraduate apprentices.

In 1998-1999, PBL organized the 6^{th} generation A/E/C program in an international pilot, engaging students from Stanford, UC Berkeley, Georgia Tech, UK, Slovenia, and Japan. A/E/C teams are typically situated in three time zones, e.g., architect at Georgia Tech, structural engineer at Stanford, construction manager in Glasgow, UK, and apprentice at Stanford.

In this teaching environment emphasis is placed upon teamwork in a hands-on building project. The international structure of A/E/C student teams adds the "real-world" collaboration complexity to the learning environment, which includes space and time coordination and cooperation issues. A key focus is the effective use of information technology (IT) resources as tools to support instruction and learning outcomes.

The Building Project. 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 academic Quarters. The students learn to (1) regroup as the different discipline issues become central problems and impact 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, interact with the teaching team and industry mentors. 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. A team's cross-disciplinary understanding evolves over the life of the project. (Project examples http://pbl.stanford.edu)

Team formation in the A/E/C education program has been a function of team size, member roles, and participant location. 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 will have one architect, one structural engineer, one construction management student as journeymen from the MS programs, and one or two apprentice students from the BS 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 in the project and have a well defined responsibility to represent their profession within their team. 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 justify 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.

Mentoring and coaching. The role of the instructor is changing in a PBL learning environment, from the traditional teacher who delivers the course material in class to the *coach*. Industry practitioners play the role of mentors. They become active participants in the teaching process. This change in role from teacher to coach, industry practitioner to mentor, provides a structure for modeling and coaching which scaffolds the learning process, both in the design and construction phases, as well as for modeling techniques such as articulating and reflecting on cognitive processes.

The roles of information technology (IT) as facilitator for improved communication and cooperation within multidisciplinary teams are determined to support the diverse:

♦ Modes of interaction over time and space.

Time. Throughout the teaching, learning, and building project process, participants transition between synchronous and asynchronous types of interaction.

Space. Faculty, practitioners and students meet for lectures, round table discussions, or project team meetings to review design proposals. Such face-to-face meetings can take place in a co-located setting, or in a distributed setting, and use network applications (e.g., groupware) to share and exchange information and discuss their design decisions.

♦ Needs of content capture, sharing, exchange, and reuse, i.e., knowledge management.

♦ Types of interaction. A wide spectrum of Internet-mediated, Web-based, and videoconference tools are provided to support the different modes of interaction among learners, instructors and mentors, such as:

- *The World Wide Web* is used for team building and as a medium to disseminate and share conceptual design solutions of the design teams asynchronously among students, instructor, mentors.
- *Shared WWW Project Workspace* was created for each A/E/C project team to archive, share, access, and retrieve project information that ranged from sketches, Word documents, Excel spreadsheets, AutoCAD drawings, email notes, and CAD related change notifications (Fruchter et al, 1998).
- *Team Discussion Forums* are set up for each team to facilitate asynchronous capture, sharing, tracking, and re-use of ideas, issues raised by students, instructors, or practitioners.
- *Recall,* a Web based application that supports capture, access and retrieval of knowledge, information, and sketches in informal media (Yen et al, 1999).
- *Digital Lecture Archive* enables interactive learning, as well as supports the diverse learning styles and preferences goals of the students anywhere, anytime. Windows Media facilitates

live broadcast, capture, and on-demand access to digital lectures, A/E/C panels, and team meetings.
- *Videoconferencing and application* sharing are available to the students for *Face-to-Face Meetings in Cyberspace, Distant Learning Lectures, Office hours in Cyberspace,* and *Final Project Presentations.*

Assessment Methodology

Cross-disciplinary learning is a journey from the state of ***island of knowledge*** *(discipline-centric) to a state of* ***understanding*** *of the goals, language, and representations of the other disciplines.* The proposed *cross-disciplinary learning* metric consists of four key dimensions to measure the students' learning evolution. These dimensions are defined as follows (Figure 1):

- ***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 disciplines, is interested to understand and support the other disciplines' 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 the input is requested, and begins to use the language of other disciplines.

This classification is grounded in the situative perspective—that effective participation in practices of inquiry and discourse leads to conceptual understanding and skill acquisition. At each level of classification the students are demonstrating changes in participation through practices of inquiry as well as changes in conceptual understanding of other disciplines. This paper proposes an assessment method based on a four tiered classification to monitor the evolution of the learner and presents preliminary results in exercising this methodology in a multidisciplinary A/E/C course.

This process is not linear—it is expected that students, as they become more engaged and involved in the design negotiation, will move through several of the classifications within a single meeting. The objective of any multidisciplinary education program is for all or the majority of the students to reach the state of ***understanding*** by the end of the course.

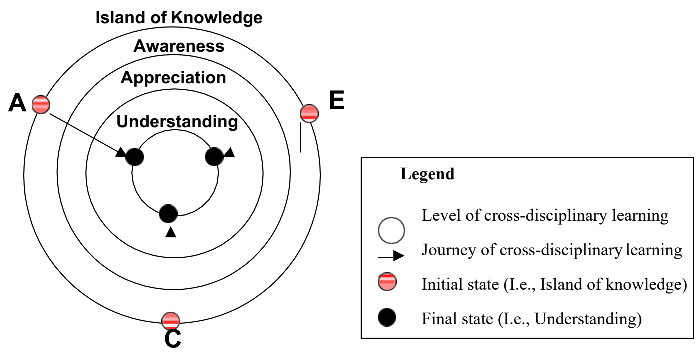

Figure 1: Four Tiered Classification for Cross-Disciplinary Learning Assessment

Data Collection

This assessment study was performed in the context of the 6th A/E/C generation. During this A/E/C PBL program there were five A/E/C student teams. The student population was composed of 16 students, i.e., five architecture students, five structural engineering students, five construction management students, and one undergraduate apprentice. The time and space distribution of the teams was as follows:

- One team was located in the Bay Area, i.e., Stanford and UC Berkeley students, two locations and one time zone.
- One team was located in the US, i.e., Stanford and Georgia Tech, two locations and time zones.
- Three teams were distributed over three universities, i.e., Stanford, Georgia Tech, Strathclyde, and Slovenia – three locations and time zones.

Methodology. The data collection methods covered a spectrum of subjective and objective observation of team interactions, such as, (1) surveys and rationale provided by learners, (2) exit interviews, (3) video analysis of team meetings and final project presentations, and (4) Web team discussion forums and (5) team shared project Web workspaces. The surveys were created in HTML and distributed online in an interactive format for self-administration by the students. Students responded to a questionnaire in which they were asked to reflect on the interaction between team members. The students were asked to situate themselves within the four classifications of cross-disciplinary learning *(Islands of Knowledge, Awareness, Appreciation and Understanding*). This request was posed at three distinct moments during the two Quarters -- at the start of the program, at the end of the first Quarter of the program, and at the end of the second Quarter of the program. Students were also required to provide rationales for their assessment. The results of the survey were collected online to better facilitate the manipulation of the data.

Ethnographic observation included videotaping, transcribing, and analysis of synchronous team meetings to determine key moments where individuals or teams demonstrated awareness, appreciation, or understanding of another discipline. In addition, observations were conducted of asynchronous team interaction, via email and online communication programs such as discussion forums, shared workspace (Fruchter et al, 1998), and Recall (Yen et al, 1999).

Data Analysis

The paper presents preliminary analysis results of the survey at the start of the program and at the end of the first Quarter. Final results that include the statistics and assessment at the end of the class, i.e., at the end of the second Quarter will be presented at the conference.

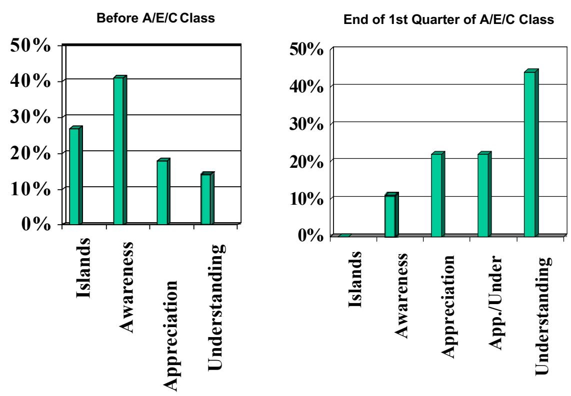

Figure 2: Assessment of Cross-Disciplinary Learning Evolution per Class

The data collected was organized and analyzed from three perspectives: the class as a whole (Figure 2), the disciplines (*Architects, Structural Engineers, Construction Managers* – Figure 3), and the individual (*Apprentice* - Figure 3). This decision was made to allow for multiple interpretations of the data and demonstrate the use of the cross-disciplinary learning metric at the macro and micro level. For example, Figure 2 presents the Evolution of cross-disciplinary learning per class, recorded before the class began and at the end of the first Quarter. At the beginning of the quarter, 27% of the students identified their interaction with other disciplines as *Islands of knowledge*. These students recognized that they were masters of a particular discipline, but did not have experience in other disciplines. 41% of the students claimed *Awareness* of other disciplines' goals and constraints. 18% of the students responded that they demonstrated *Appreciation*, an active interest to understand and support the other disciplines' goals and concepts. Students who had 1-3 years of working experience claimed full *Understanding* of the other disciplines (14%). The data shows that 68% of the students had yet to achieve appreciation or understanding of the other disciplines—this confirms that A/E/C students, at the entry graduate level, have little experience with the disciplines they will collaborate with in the industry.

At the end of the first Quarter, the class as a whole showed progression towards understanding. In Figure 2, no students remained in *Islands of knowledge*. 11% of students claimed *Awareness* of other disciplines, 22% claimed an *Appreciation*. 22% of the students defined a new classification, *Appreciation/Understanding*, to represent movement beyond Appreciation, but not full *Understanding* (44%). At the end of the first quarter, 88% of students classified themselves as having achieved an *Appreciation* or *Understanding* of other disciplines. Our observations were corroborated by data captured in other media, such as email, discussion forums, video.

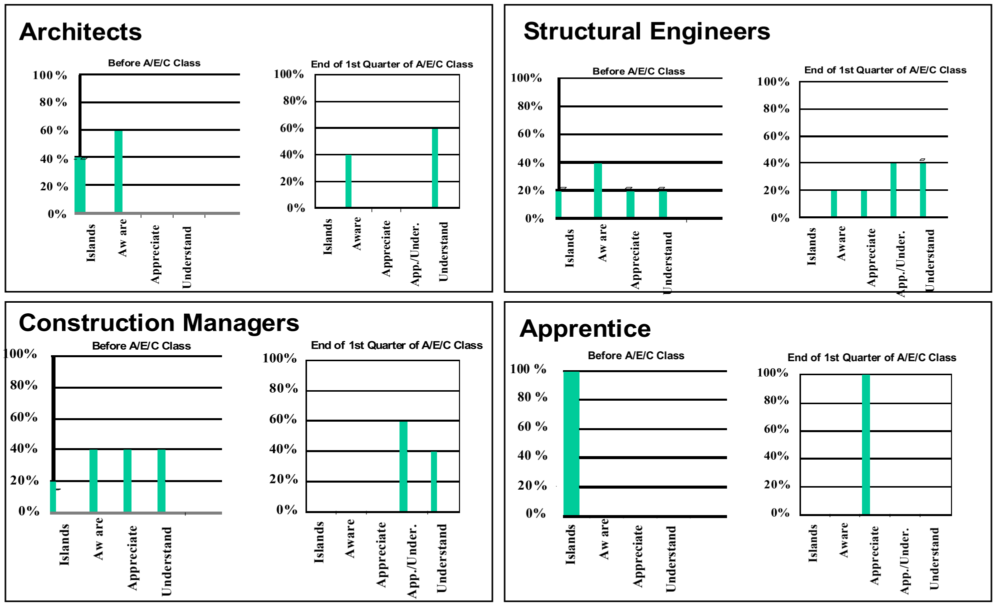

Figure 3: Assessment of Cross-Disciplinary Learning Evolution per Discipline

Figure 3 represents the evolution of cross-disciplinary learning per individual discipline. As presented, the architects began the quarter with 40% *Islands of knowledge* and 60% *Awareness*. At the end of the first quarter, 40% had moved to *Awareness* and 60% to *Understanding*. Individual rationales provided in the survey confirmed the students' awareness of learning progress. Specific examples include rationales, such as:

- **Before the course:** "Awareness. I have worked in the architectural profession for a couple of years so I have a bit of real world knowledge as to how collaboration/coordination works. I never really had much sympathy for the other disciplines and, as most professionals do, I tended to blame consultants rather than attempt to understand the reasoning or rationale behind their motives. I always saw the other professions as distinctly different and as opposition." *Architect*

- **After the first quarter:** "Understanding. The A/E/C has taught me a lot about the problems the other design professionals face—by working very closely with them I can now forsee issues that may become problems as well as understand why some things work better than others. It has also helped me become friends with my teammates. It's much easier to be understanding and sympathetic to your friends than it is to your opposition." *Architect*

The structural engineers began the quarter with 22% demonstrating *Islands of knowledge*, 33% *Awareness*, 22% *Appreciation* and 22% *Understanding*. At the end of the quarter, they also demonstrated progression towards *Understanding*—14% *Awareness*, 14% *Appreciation*, 29% *Appreciation/Understanding*, 43% *Understanding*. Rationales for the engineers showed that the higher levels of *Appreciation/Understanding* were a result of previous experience with other disciplines, through classes and personal contacts.

- **Before the course:** "Before Jan. 99 I had an APPRECIATION of architecture. I was always interested in architecture, and took some classes in "architectural engineering." I had an AWARENESS of the construction discipline, because it was not something I had been exposed to very much (it wasn't taught at my undergraduate school)." *Engineer*

- **After the first quarter:** "I would say I have an APPRECIATION/UNDERSTANDING of both the architect and the construction manager. I've learned a lot more about construction because the CM on our team is very outspoken." *Engineer*

Construction managers demonstrated the highest progression during the first quarter. Beginning data showed 14% *Islands of knowledge*, 29% *Awareness*, 29% *Appreciation* and 29% *Understanding*. The end of the first quarter, however, showed 60% *Appreciation/Understanding* and 40% *Understanding*. Rationales explained previous relationship with the structural engineer, but not with the architect:

- **Before the course:** "Understanding (Engineer).I am also an engineer and have a strong background in structural design, so I understand very well the requirements and constraints of the structural engineer and could pro-actively provide input and guidance. Appreciation (Architect). I appreciated the profession of the architect and had worked with some in the past, but not in the same conceptual capacity. I did not speak the same language although I was able to support the goals and concepts." *Construction Manager*

- **After the first quarter:** "No change in my relationship with the structural engineer. Beginning to "understand" the role of the architect. This is, in part, because our architect is just beginning to understand her own role with regard to construction and engineering, so it is a process of mutual discovery. We may have come further in our mutual understanding if she had a stronger concept of her own role, but that will come with time. So, I expect to get a much greater level of understanding with regard to the role of the architect as the quarter progresses." *Construction Manager*

The undergraduate apprentice classified herself in *Islands of knowledge* at the beginning of the quarter, with movement towards *Appreciation* by the end of the first quarter. Her rationale explains that while she was not an expert in a specific discipline, this experience has allowed her to learn about all of the disciplines:

- **Before the course:** "Islands of knowledge—I cannot say that I have mastered by discipline, but I had awareness and interest in architecture as an academic discipline before January 1999. I had very little knowledge of engineering but I viewed it as something that would be necessary for an architect. I had no idea what construction management was all about."

- **After the first quarter:** "Appreciation—after the first quarter, I gained a big picture of A/E/C collaboration: goals, focus and work habits. I have decided to work more closely with the architect this quarter, and I have looked at the design process that the architect had gone through last quarter. I modified her floorplans in order to accommodate the architectural requirements for the purpose of my own practice. During the practice, I realized that my concern was not only architectural, but also structural (feasibility of position of columns and shear walls) and cost and building efficiency (location of computer lab, elevator/restroom core, etc.). Although I still know very little about structural systems and construction methods, I can ask E/C whether an architectural modification with affect them, and how." *Apprentice*

In examining the data from the perspective of individual disciplines, we were able to see patterns in the movement from *Islands of knowledge* to *Understanding*. For example, at the beginning of the course, the architects did not have much experience in other disciplines, whereas the structural engineers and construction managers showed more experience with other disciplines. The rationales explained that levels of *Appreciation* and *Understanding* were a result of courses taken in other disciplines, or personal contact with another disciplines. It is also interesting to note that both engineers and construction managers created a new category of *Appreciation/Understanding*. They made clear distinction when identifying their state towards the other two disciplines. However, the architects grouped the structural engineer and construction manager into one discipline and assessed their state with respect to the one discipline.

Results from observations of synchronous/asynchronous team interaction further supported the findings. Interactions were compared with student response to evolution of cross-disciplinary learning. The following excerpts exemplify the four dimensions of cross-disciplinary learning.

Islands: *fragmentation of the design process, sequential. No experience in other discipline.*	**Islands of knowledge:** "There is little I can think of to do while the architect is designing. " –Engineer
Engineer is ***aware*** *of the constraints, progressiong towards appreciation.*	**Awareness:** "The architect's interaction with the engineer in the beginning of the project is crucial. He/she must be in constant communication with the engineer. If not, frustrating things may happen. In our case, the architect's initial proposal had severe structural problems. However, by getting it to the engineer in the very initial stage of the project development, a preliminary structural solution was adapted (with some architectural changes)…also, the C's initial participation is crucial as well. Primarily because of 'constructability' issues. The C's preliminary feedback is essential for having a sound and cost effective project." --Engineer
Appreciation: *this interaction shows an active engagement and inquiry between disciplines, leading to understanding.*	**Appreciation:** **C:** "I'm curious about your (A) statement "too much of its form to functional purposes." Isn't the function of the building foremost here? It is to be an instructional facility and the form needs to accommodate the learning environment. I tend to think that a predictable layout is good when dealing with students who are trying to find classes for the first time. My quest is, what is the alternative for the layout?" **A:** "…this is a wonderful question! I think that is precisely what (Apprentice) and I have commented. The primary focus for this design IS indeed function. However, is this enough? Does this create a pleasurable space? Is it interesting? Has the architect created a "sense of place" or has he/she just oriented a series of boxes in order to accommodate usage?" **C:** "I see what you mean. The "basic" function of the building will fall out of the square footage requirements and the room affinity chart. Maybe one way we can increase the ease of use is to open the place up. The architects at SFO airport did this by not putting walls behind the check in agents."
CM ***understands*** *issues, uses language "sense of space."*	**Understanding:** "I think I understand (A's) view about creating a sense of space. The original architect states that the "highlight of the design is the central atrium around which all the spaces were organized," but it seems to me that this effect is only achieved with the third floor…"--C

An additional key metric is based on a longitudinal assessment that can track the programmatic changes that such a cross-disciplinary education program can lead to. More specifically, a survey posed the following questions: *After this experience, do you plan to take any courses in any of the other disciplines? Which topics*?(Figure 4). Preliminary studies of the past five A/E/C generations indicate that a large percentage of the students exercise the option to take classes in the complementary programs after going through the A/E/C program. For instance, architects take construction classes, structural engineers take costing and scheduling classes, and construction management students take structural design classes).

Before the A/E/C Class After the 1st Quarter of the A/E/C Class

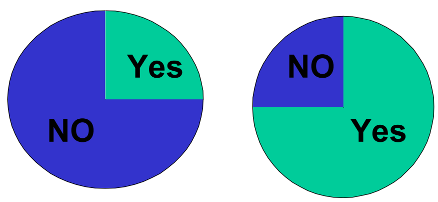

Figure 4: *"Take class(es) in another A/E/C program/discipline as a consequence of the multidisciplinary project-based learning experience"*

Figure 4 shows results of this study, i.e., at the beginning of the course, only 25% of students were interested in taking courses outside of their discipline. At the end of the first quarter, 75% of the students planned to pursue courses in another discipline.

Summary

The study presents a new metric to measure and monitor the students' *cross-disciplinary learning.* The four-tiered classification, *islands of knowledge*, *awareness*, *appreciation*, and *understanding*, offers an assessment tool to measure and monitor the students' knowledge state and learning evolution. An additional key metric is based on a longitudinal assessment that facilitates tracking programmatic changes such a cross-disciplinary education program can lead to. The preliminary results demonstrate the use and effectiveness of the assessment methodology, data collection and analysis. It is important to note the generality of the four-tiered classification in cross-disciplinary learning assessment, i.e., the three disciplines, architecture, structural engineering, and construction management, characteristic to the building industry, can be easily replaced with mechanical engineering, software engineering, and electrical engineering, characteristic to the manufacturing industry. We plan to continue to exercise this assessment metrics and method in the A/E/C PBL program for further validation.

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Addresses

Renate Fruchter (fruchter@ce.stanford.edu)
Stanford University, Project Based Learning Laboratory, Department of Civil and Environmental Engineering, Stanford CA 94305, Tel. (650)725-1549

Katherine Emery (kemery@leland.stanford.edu)
Stanford University, School of Education, Stanford CA 94305