UNDERSTANDING HOW VIRTUAL PROTOTYPES AND WORKSPACES SUPPORT INTERDISCIPLINARY LEARNING IN ARCHITECTURAL, ENGINEERING AND CONSTRUCTION EDUCATION

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ABSTRACT

In this conference paper, the authors present preliminary findings from research on two interdisciplinary studios—problem-based, hands-on classes—conducted at the University of Washington and Penn State. This research is part of a study conducted in 2012 to analyze current interdisciplinary design studio practices and cultures to provide a baseline from which to measure the impact of a variety of technological strategies to improve student engagement and learning. This study suggests that student teams establish norms early in the studio process, these norms reflect how they adapt to the workspaces, and the workspace adaptation may subsequently reinforce the norms around collaboration. We conclude that interdisciplinary learning, learning that occurs across disciplines, needs to be continually reinforced during the studio sessions through shared design ownership and facilitation, coaching, and leadership. We suggest that interdisciplinary learning is better supported through an integrated design pedagogy (such as 4D model development) that requires student to work together across disciplines, but assignments in these types of courses need socio-technical infrastructure—technology, workspaces, training, and facilitation—that encourages interdisciplinary engagement and learning.

Keywords: Interdisciplinary Learning, Collaboration, Education, Design Studio, Building Information Model, Virtual Prototype, Workspaces

1. INTRODUCTION: LEARNING ACROSS THE ARCHITECTURE, ENGINEERING, AND CONSTRUCTION DISCIPLINES

Interdisciplinary learning—incorporating methodology and language from more than one discipline to examine a shared problem or topic—is vital to solve today’s complex engineering problems such as high performance buildings (Schaffer et al. 2008, Orr, 2006). Professionals from a variety of disciplines, architecture, engineering, planning, construction, come together in integrated teams to jointly design and construct high performance infrastructure. Scholars of high performance design, such as Orr (2006), have argued that professions of the built environment need to develop their own mastery as well as develop shared mental models collaboratively. Bucciarelli (1994) defined “design as a social process” wherein teams define the problem and process then negotiate decisions across disciplinary constraints. Industry and education seem to be moving away from cooperative approaches of teamwork towards integrated and collaborative approaches such as Integrated Project Delivery (AIA, 2012) and Integrated Design Studios (Dossick & Pena 2010, Holland et al. 2010).

Teamwork has been shown to improve both learning outcomes and retention in engineering programs (Carlson & Sullivan 1999; Springer et al. 1999). However, teamwork in most engineering curricula has
been pursued through cooperative approaches to team learning; where students in small groups learn from each other under carefully structured situations of accountability yet divide the work among themselves and for the most part work independent of one another (Smith et al. 2005). Collaborative interdisciplinary learning, on the other hand, is characterized by relatively unstructured processes through which participants negotiate goals, define problems, develop procedures, and produce socially constructed knowledge in small groups (Goldsmith & Johnson 1990, Dorsey et al. 1999). In light of the complex nature of building systems and heterarchical project interactions, it will be the context in which young designers learn which will transform the industry (Orr 2006, Dossick and Neff 2011).

As architecture, engineering and construction (AEC) disciplines seek to develop collaborative interdisciplinary practices, questions remain as to how we can foster interdisciplinary learning to improve both the performance of industry teams as well as the education we provide for new engineers, architects and builders. Team-based curriculum in general and in labs (engineering) and studios (architecture) specifically is one approach for interdisciplinary learning by providing projects that require interdisciplinary teams where students practice integrating their domain knowledge thereby supporting team-based collaborative learning particularly (McCuen and Fithian 2010). In AEC programs, interdisciplinary studio design courses—problem-based laboratory courses where students are given design parameters and a team develops a design solution together—are growing in popularity because they reflect professional work environments and support team-based collaborative interdisciplinary learning (McCuen & Fithian 2010; Dossick & Pena 2010; Holland et al. 2010; Dib & Koch 2010; Gardzelewski et al. 2010; Salazar et al. 2010). Conceptually, these interactions allow students to cross boundaries between disciplines, explore approaches and processes for design, and broaden their perspectives. However, in our experience, student and industry teams alike, do not always achieve collaborative norms of interaction and learning (Dossick and Pena, 2010, Dossick and Neff 2010). Research is needed to understand how to develop pedagogical infrastructure, studio spaces, structures and curriculum, to engender collaborative teamwork, as students tend to work cooperatively when left on their own devices. In this paper, we focus on visualization technologies and workspaces to explore how these interrelate to interdisciplinary learning goals in integrated design studio settings.

In this paper, we present a baseline study of two studios, one at Penn State and another at the University of Washington (UW), to develop an understanding of how students work together, use the technology, and learn from each other when given a joint design problem, virtual prototypes and workspaces. We begin with a review of literature. Then we introduce methods and the settings of the studio classes and the participant-observation research from winter/spring 2012. We then discuss the preliminary findings where we see teamwork norms established early and work space utilization that reflects and reinforces these norms. We are able to then discuss the integration of workspaces and displays with the team collaboration and propose ways in which these workspaces and displays both support or hinder interdisciplinary collaborative learning. We conclude that studio classes specifically and interdisciplinary teams generally need facilitation, coaching and support throughout the process.

2. COLLABORATION WORKSPACES AND VIRTUAL PROTOTYPING

New engineering design tools, such as virtual prototyping (VP)—the computer simulation of a physical product that can be presented, analyzed, and tested as if on a physical model (Wang 2002)—are proliferating in the marketplace with the express aim of supporting interdisciplinary teams. Currently, these tools often support sharing interdisciplinary knowledge, better than collaborative problem-solving (Fox et al. 2010; Fruchter 2005; Dossick & Neff 2011). Research is still needed to understand how teams actually use virtual prototyping, how these tools can support collaboration, and what practices and processes around these tools best support problem-solving. Our prior findings suggest that while new virtual prototyping technologies enable collaborative learning studios, improvement and refinement in both the tools and the processes are needed to support team interaction, enable interdisciplinary learning, and potentially improve retention and sustain meaningful student involvement (engagement) in engineering. Our overarching question in this paper is to more clearly identify the “problem”: What
models and technical infrastructure are required for collaborative, team-based, interdisciplinary engineering education?

When designing collaboration workspaces for complex interdependent tasks, technologies must support frequent interactions and meetings (Daft & Lengel 1986); participant awareness of, access to, and relation to the design work of others to their own (Fischer 2006); and real-time activities that enhance the work of co-located designers. These include informal, spontaneous, or coincidental exchanges of information (Kraut et al. 2002), what Dossick and Neff (2011) have termed “messy talk.” Real time interaction has been found critical for timely and rapid iterative design, brainstorming and problem-solving tasks (Fruchter 2005). In specific studies of interactive workspaces, Leicht et al. (2007) found the stages of problem solving that industry members considered the most important for collaboration were the same stages found to be the most valuable for interacting with display or physical media. In his work, Fernando (2003) identified three general areas regarding the characteristics of these future workspaces:

- The integration of the spaces and displays with the virtual prototypes or information;
- The ability to intuitively and seamlessly interact with the information; and
- The integration of the team collaboration and process with the space.

More recent use of virtual prototyping tools in these settings shows unique value through “boundary object” interactions to help teams discover and explore conflicts, assumptions, and intersections of different engineering systems (Neff et al. 2010; Star & Griesmer 1989; Taylor 2007). These findings suggest a new model for teaching engineering: Interdisciplinary design studios with virtual prototyping enabled broad, diverse, and epistemological learning outcomes. Much work needs to be done to understand how and in what ways virtual prototyping technologies support learning in team-based problem-solving settings. Simply put, can we create computing infrastructures that inspire students to interact, collaborate, and co-create new knowledge? What socio-technical infrastructure is required to engender rich interdisciplinary engagement?

3. METHODS AND SETTING

Based on a long-standing collaborative relationship between engineering, construction and architecture, faculty at Penn State and UW have independently created integrated studios that leverage emerging virtual prototyping technologies and integrated work practices to support interdisciplinary learning (Dossick & Pena 2010, Holland et al. 2010). The two classrooms models both have similar student and curricular alignments. Students are organized into interdisciplinary teams of 6–8 students. Both courses were taught starting in 2009, and since have been offered annually. The courses are advanced upper-division courses, where the students are expected to bring their own expertise and experience to engage in the ways that they personally find interesting, challenging and meaningful.

At the University of Washington student teams are provided a collaboration suite with individual work spaces around three perimeter walls, a central table and a shared projector with an interactive whiteboard that toggled from any of the 8 perimeter ports. Students worked with laptops and a desktop computer was provided at one of the workstations. The UW teams could work during and outside of studio hours. At Penn State, student teams had a studio time in a shared architecture computing lab where they occupied the lab during the studio. The clusters of desktop computers are arrayed in groups of four, with some paired computers back-to-back and other clusters in a pinwheel with each computer facing a different direction. There are no large displays or interactive whiteboards for students to share and interact with larger images or content. These workspace arrangements served as a noted differentiator to help determine how the infrastructure, and how the teams reactions to the setups, shaped their interactions.

To study the use of technology, student participant observers took detailed qualitative field notes to capture how students talk about, refer to, and communicate with and through the virtual prototypes. The aim was to provide detailed contextual information about how students apply these technologies for interdisciplinary learning and how the technical infrastructure supported interdisciplinary learning objectives. In the UW studios an undergraduate communication students (“comm students”) joined each team as participant observer to gather qualitative and quantitative data on collaboration. They took
weekly field notes within their teams, and met regularly with faculty for “case analysis meetings” (Miles and Huberman 1994) to understand the dynamics of their particular team. Although they had no disciplinary training in either architecture or construction, the comm students served as peer-facilitators and shared their skills in interpersonal communication and public speaking, providing feedback to their teams as they were gathering research data. The qualitative data they gathered consisted of field notes based on each week’s activities within the studio space and through digital media such as email and chat boards. Additionally, they completed a synthesis research report that compiled main issues and themes that emerged from their field notes.

4. RESULTS

For the 2012 studios, we found that student teams adopted and adapted their virtual workspaces to match their teamwork and collaboration norms. Furthermore, once established, collaborative norms were difficult to change even when team members understood that change was needed. We argue that training and facilitation are needed to establish rich collaborative student interaction with technology, and further research is needed to understand how virtual prototypes and shared displays support collaborative interdisciplinary learning.

4.1 Norms of practice established early

Most teams began in cooperative team modes. And, for both collaborative and cooperative teams, their norms of practice were established early in the collaboration process. Once these norms were established, they proved quite durable throughout the project. UW Team A, for example, “appeared excited to learn from each other,” from the first day, and, “this attitude continued as the quarter progressed.” In contrast UW Team B worked separately, leading the student-researcher to observe that, “At first I attributed this to the strengths of each individual and the dedication to quickly, thoroughly and efficiently finishing tasks. However, it became clear as studio progressed that the independent strengths never coalesced.” From the beginning, leadership and cohesive teamwork was slow to emerge in UW Team C, even though they eventually overcame their organizational hurdles in the end to make the strongest final presentation, but only after very harsh criticism by outside reviewers that motivated the team to pull together.

The Penn State teams integrated more slowly, as noted during their first team design presentation: “one of the judges’ critiques was that [PSU Team A] members presented as individuals, rather than as an integrated group.” Teams worked to organize and integrate, but noted the lack of space and consistent meeting times as a challenge, “Indeed, during their final presentation, one of the members indicated that the team ‘used class time to the best of our ability’ to work together and integrate their individual specializations and knowledge into a coherent, effective design. One team member noted that, since it was difficult to coordinate members’ busy schedules, effective utilization of class time was essential.”

4.2 Co-ownership in design

When all team members, not just the architecture students, felt ownership in the design, the detailed analysis and downstream decision-making were aligned with the concept and the work was more richly collaborative. PSU Team D was noted for their integration in their presentations, with the mechanical engineering student introducing the inspiration for their design. When an industry architect questioned the team on letting the mechanical engineer determine the direction of the design, the team’s student architect commented that “It was the team’s design. While [mechanical engineer] may have inspired the vision, the team all quickly rallied around it and were each critical in the realization of the design.”

For UW Team A, this was illustrated by a unified commitment to the design concept. They came to their concept in the initial charrette. All of the team members contributed to the development of the concept in more detail throughout the studio process. Meanwhile, teams B and C went through several iterations of designs and struggled to come up with a design around which the team, as a whole, could
rally. A unified sense of purpose went a long way in bringing the team together in that it fostered a collaborative environment, in which interdisciplinary exchange, engagement and learning took place.

4.3 Strong relationship between space usage and interaction

While the students at Penn State worked in shared computer lab with computer clusters, and the UW teams had dedicated collaboration suites, teams at each site varied in their adaptation to the virtual workspaces provided for the class. For some, the shared Penn State computer lab with clustered computers “naturally divided” the student teams. For example, “The two sub-groups in [PSU Team B] used one member as a runner to communicate between the two groups separated across the room to different clusters.” The PSU Team C took a completely different tack, typically choosing to “leave the computing lab during their studio time to work together using drawings and sketches, treating the modeling tasks as assignments between team meetings.” While this served to improve the cooperative environment, it led to early conflicts regarding change management in the modeling process, “the architecture student stated that it was the engineers’ responsibility to determine any changes that had been made on their own when they opened the model.” This team resolved this conflict early in the process, negotiated design times, and determined the process of who needed to be involved for each model part. This was noted as one of their most valuable lessons learned in their final presentations.

At the UW site, there was a striking alignment between the collaborative styles of the teams and how they organized themselves in these spaces. Team B for example “typically worked solitarily on their laptops at the outside-facing desks, convening at the central table only during desk “crits” [meeting with the faculty or outside reviewers] or to ask a question of the design students who usually worked there.” “the group-centered technology was not used as much because the individuals of the team worked strongly independently and never fully committed themselves to working side-by-side on any task.” The student researcher in Team C wrote “One of the worst parts about the studio space is that all of the Ethernet connections and power cords are on the outside of the room; this lead to everyone facing away from each other.” Conversely, UW Team A chose to “ignore the layout of the room and sit facing each other at a center table. Although this created a challenging obstacle course of Ethernet and power cords, this seating arrangement also facilitated more frequent face-to-face communication. In fact, the team argued that their use of the space was more conducive to collaboration and had been a significant contributor to cooperative team environment.”

4.4 Established teamwork norms influenced how the virtual workspace tools were used.

This is illustrated in comparing and contrasting UW teams A and B. The 4D models are developed in the last few weeks of the studio, after much of the design work has been completed and the teams have well established norms of practice. In UW Team A, the 4D model was jointly developed by an architecture student and two construction management students. They huddled over their computers together talking through the scenario, working out selective demolition and temporary shoring details. Their intense conversation at times reached out to other team members to confirm the design, or verify with the team the idea that they will “take off the whole roof.” The 4D model was the focus of the student’s exploration into the details of a specific construction sequence that provided for them a vehicle through which to have multiple detailed technical conversations and learn together and from each other. The 4D model also became a topic of conversation when outside experts came to the studio, as the team brainstormed with the expert the selective demolition, shoring and retrofit plans showing the 4D visualization or the story board illustrations in preparation for the 4D model development.

In contrast, UW team B worked separately on their models. An architecture student developed the 3D model, while a construction student developed her 4D model. The only interaction these students had together was when the construction student realized that she needed a different geometry for a slab, and asked the architecture student to change the model to support this change. The students didn’t discuss together their plan of work, the construction sequence or problems. They did not engage together around
the model nor had the same conversations that UW team A had. Each applied their own skills to the problem, but the lack of interaction resulted in a missed opportunity for interdisciplinary learning.

5. DISCUSSION

The intent for the workspaces in the PSU and UW studios aligned with Fernando’s (2003) criteria for virtual workspaces, however these workspaces and modeling exercises did not always support collaborative teamwork along interdisciplinary lines.

1. The integration of the spaces and displays with the virtual prototypes or information: The students were each given a computer on which they worked with the virtual prototypes and other information during the design process. However, they discovered limitations and adapted the space layout. Subsequently, the adaptations seemingly reinforced the collaborative norms [UW outward facing desks, PSU separate computer clusters aligned with more individual work habits]

2. The ability to intuitively and seamlessly interact with the information: when collaborative norms were established, students at both sites were able to interact and engage each other in the modeling activities, in some instances co-creating models sharing one interface and working through problems such as how the final design impacted temporary shoring [UW Team A]. More could be done with model interaction, enabling more real-time interaction with the models.

3. The integration of the team collaboration and process with the space: Although the spaces were specifically designed for collaboration, the students adapted these spaces in a variety of ways that resulted in varied collaborative experiences. Teams that wanted to huddle around their tools [UW Team A’s facing inward and PSU Team C leaving the computer cluster to work together on paper] cultivated more integrated collaborative norms leading to rich interdisciplinary engagement. While other teams, who worked individually on their own computers, did not engage as closely.

Research in engineering education confirms that team-based and interdisciplinary learning is vital to the training of future engineers, helps students meet learning objectives, and improves retention of students in engineering (Carlson & Sullivan 1999). However, in this study we found that teams differed significantly in the depth of interdisciplinary learning they achieved. Interdisciplinary learning was shaped by both the social interactive norms of the teams as well as by the work environment. We found the ways the teams adapted and adopted the team spaces - different studio space usage at Penn State, and different seating arrangements at UW-aligned with their collaborative teamwork norms that emerged in the first few weeks of studio work. At UW, the teams who developed collaborative norms all sitting facing each other around the table had great interdisciplinary engagement around the 4D model, while the other teams, who had their backs to each other divided and concurred with much less interdisciplinary interaction in terms of the 4D model development. Similarly, the manner the PSU teams reacted to the computing lab arrangements and time limitations very quickly differentiated the teams’ collaborative environments and was noted even in the days leading up to final presentations, “one team member was attempting to draw attention to a perceived problem with an aspect of the design; however, he was ignored by the other members of the group, who were working on multiple separate tasks.”

In three UW cases, the teams interpreted the same 4D modeling assignment, which was intended to be an integrative assignment bringing design together with scheduling, in very different ways. (Team A: interdisciplinary conversation and joint model development, Team B: cooperative engagement, design student did the model while the CM student did the 4D model, and Team C: individual work: a single student doing the whole 4D model without much conversation with others). The task alone did not act as a vehicle for integrated interdisciplinary engagement. We can conclude then that in order to improve collaborative learning for all teams, we need to support the student teams with facilitation and training in order for them to lay the foundation for working in integrated and interdisciplinary environments.

When students separately worked on their models, conflict (PSU) or isolation (PSU and UW) occurred with a final studio project that is a collection of individual work (“the right ideas but in the wrong places”); while jointly authored designs lead to tighter integration with intensive interdisciplinary
student interaction. Once collaborative norms are established, tools that make knowledge system conflicts explicit seem to enable high-order student learning by encouraging students to explain their thinking and their work to learn from each other, as illustrated by the 4D model example above.

6. CONCLUSIONS AND FUTURE WORK

Similar to the industry adoption of virtual prototyping, at both the UW and Penn State sites, the use of virtual prototyping, visualization and interactive technologies has been transformative. Using these tools collaboratively reveals emergent relationships in the design, causing students and instructors to adapt their processes and learning when using these technologies for interdisciplinary design. Based on our research and teaching in the context of technology-supported interdisciplinary work, we see an acute need for facilitation to fully leverage these techniques and technologies for all students to accomplish collaborative learning. In this study we only begin to understand how and in what circumstances these technologies support rich interdisciplinary collaboration, and what impact that exploratory, iterative, messy and conversational interactions have on student learning.

To further develop the scope of learning and epistemological outcomes, the use of continued ethnographic approaches of in situ teams using virtual prototypes and interactive workspaces will be coupled with observational quasi-experiments. The use of quasi-experiments will complement the ethnographic approach by bringing together interdisciplinary student teams in a controlled environment in which the influence of specific media and learning outcomes can be more clearly linked. Aligning the influence with the natural evolution of technology use throughout a term project will help define both the short term and long term effects of the technology adoption.

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8. REFERENCES

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