# Knowledge Transfer with Technology: Interdisciplinary team experiences in design and construction education

C. Monson[1] and C. S. Dossick[2]

[1]Doctoral Student, PhD Program in the Built Environment, College of Built Environments, University of Washington, Seattle, WA, USA. cmonson2@uw.edu
[2]Associate Professor, Department of Construction Management, College of Built Environments, University of Washington, Seattle, WA, USA. cdossick@uw.edu

## ABSTRACT

Recognizing the growth of Architecture, Engineering and Construction (AEC) integrated practices and the expanding effect of computational and visualization technologies, this study formulates a relationship between iterative collaboration and the technology mediation that is beginning to typify professional integrated practice. Using the ground of collaborative project-based undergraduate studios between construction management, architecture, engineering, and other allied fields, we argue that transitions in the cycle of the design thinking model are where knowledge transfer is co-located with the affordances provided by technology. These points have historically been part of any learning about ambiguous problem solving; now in integrated studios, students explore joint-problem solving in the context of digital technologies and group collaboration. This context and the integrative skills needed in AEC practice are the issues that must be addressed by contemporary educators.

## INTRODUCTION

In this current era, building performance has taken center stage. New technologies for assessing energy use, sustainability, life-cycle costs, and operations and maintenance, all mean a shift from considering buildings as shelter to acknowledging that buildings are systems with interrelated and often conflicting performance criteria and outcomes. Whether with Building Information Modeling (BIM), energy analysis software, construction sequence visualization, or structural component fabrication, the professional practices of integrated AEC teams are incorporating computer technologies. Successful practice leaders must be able to organize, integrate, and orchestrate synthesis across teams of artistic and technical experts simultaneously setting a vision while creating social mechanisms for teams to reconcile tensions between competing and conflicting building requirements.

As this integration becomes mainstream in professional AEC practice, educators seek new ways of teaching collaboration. In this paper, we present a conceptual model of the *design thinking process* that can be used as a lens to interpret instructional experiences within a technology-mediated integrated studio. *Studio-based learning* is a shared learning environment where students and instructors work using the master/apprentice method to design solutions to ill-structured problems (Monson 2001). The Integrated AEC Studio course examined in this study is part of a multi-year curriculum pilot that includes undergraduate students in architecture, construction management, and engineering. The studio's learning goals are for students to apply their emerging disciplinary knowledge in the context of a team project, to develop a deep appreciation for the allied AEC disciplines, and to demonstrate the strengths of integrating analysis and design. The studio's technology objectives are for students to develop professional skills, to explore the affordances of digital tools (Gaver 1991) and to develop integrated workflows that result in higher quality building design and construction. The goals of the iterative development cycle are to teach students how to formalize the process of refining options while leveraging emerging software tools (e.g. BIM) so as to permit analysis and make design decisions that integrate aesthetics with multiple performance criteria such as construction, cost, and sustainability.

## ITERATIVE COLLABORATION AND THE INTEGRATED STUDIO

**Design thinking and iteration.** AEC professional practice is a *design* process where practitioners engaged in "ill-structured problems that are ambiguous in beginnings, means, and ends" (Monson 2011). While in AEC the term *design* has long been the province of architects and engineers, it has more recently been realized as a more general term—*design thinking*—which is a problem solution process across a wide variety of disciplines (Martin 2009). The design thinking process model is a cyclical pattern of analysis, synthesis, evaluation, and communication that moves from more abstract constructs to more concrete constructs over time (Messarovic 1964; Watts 1966) (Figure 1). This cyclical pattern, or *iteration*, is where each successive engagement with the problem content is revisited in a differing context that is built upon the learning that has come before.

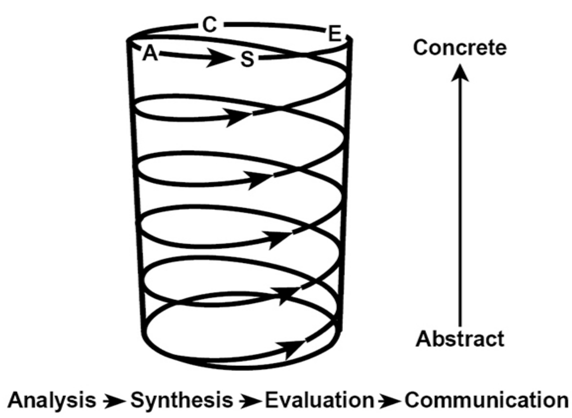


**Figure 1. Design thinking process**

The design thinking process includes four action phases: analysis (taking content apart), synthesis (putting content together), evaluation (reflection on outcomes), and communication (putting outcomes into words and other media). As designers work through this cycle, they move from more abstract levels of work, e.g.

building massing, to more concrete levels, e.g. interior finishes. At the “transfer” points between each of the four action phases (horizontally) and between the cyclical levels (vertically), design issues are engaged through multiple cognitive processes which are made evident through required shifts in thinking, communication, and artifact production. We call the work at these points *cognitive knowledge transfer*.

Scholars apply this process to individuals as well as teams and companies (Martin 2009). However, in the team context, communication occurs in all four action phases as team members exchange knowledge and build shared mental models. When interdisciplinary teams work together through the design thinking process, they co-construct action phases and knowledge transfer and balance the disciplinary content requirements based on the particular part of the problem being addressed.

The issues of cognitive knowledge transfer are most important in both the horizontal and vertical design thinking process transitions. First, at each of the horizontal transitions between the four action phases of analysis, synthesis, evaluation, and communication, practitioners and teams work to “transfer” the problem content from one mode of action to a different mode of action. For example, the thinking action required to analyze all of the options available for structural grid geometries has to be “transferred” to the different cognitive action of synthesizing this content into one proposed solution. Second, at each of the vertical cyclical iterations, practitioners and teams work to “transfer” from a less resolved and more abstract solution state to a more resolved and more concrete solution state. For example, the second iteration of proposed structural grid geometry will involve more constructs and more details than what was considered in the first iteration.

Visual tools are used throughout the design process. Individuals and teams alike draw, write, and model options in the four action phases. First, technological tools are used in the basic activities of analysis, synthesis, evaluation, and communication. For example, an architect may create a 3D model to explore a variety of ramp locations (analysis and synthesis), and then use this model to evaluate options as well as communicate the options and preferred solution to the team. Furthermore, technological tools are used when moving from abstract to concrete. For example, a team may develop an abstract building plan shape and site orientation on paper, but then, when transferring those ideas to a computer model, the software requires the team to make concrete decisions about dimensions and location. In this way, the software affordances shape the transition from abstract to concrete.

Teamwork, by necessity, requires visual tools for knowledge transfer. Consequently, external resources, processes, and tools mediate the design thinking action phases and transfer operations. Whtye, et al. (2008) contend that while some knowledge can be made explicit, other knowledge is not represented visually and therefore is hidden from team members and managers. What team members make visual is intentionally, or at times unintentionally, emphasized and becomes the focus of discussion. In this study, we explore visualized knowledge via BIM technologies in the context of interdisciplinary construction and design studios. Namely, how do students engage the technological tools of BIM to support knowledge transfer in both the action phases and transitions of the design thinking model? How do technological affordances shape student interaction, knowledge transfer, and learning? While integrated practice collaboration can be difficult in any part of the design thinking process, the study here will describe how the locations of knowledge transfer frequently provided the most problematic collaborative episodes and, conversely, the richest resource for team problem-solving and learning.

## STUDYING INTERATIVE COLLABORATION AND TECHNOLOGY

**Methods and setting.** This study arose from the work of the 2012 Integrated Studio offering at the University of Washington. To study the use of BIM and other analytical and visualization technologies by the students in their collaborative work, qualitative and quantitative data was gathered by participant observers through detailed field notes, case analysis meetings with faculty, documentation of chat and email media, and weekly facilitation meetings with studio students. Observers were trained undergraduate communication students who had no disciplinary experience with construction or design but came with skills of interpersonal communication and public speaking. The goal of the data collection was to gather contextual evidence on how students used technologies in their integrated collaborative work, how they worked and communicated through digital prototypes, and how the technology-mediated efforts suggested processes of learning. Analysis was accomplished by compiling data from field notes and studio-student generated documents, building themes, and then synthesizing discovered patterns in research reports. The studio faculty guided communication students in research analysis efforts.

**Integrated studio.** In the design of the Integrated Studio curriculum at the University of Washington (UW), we leveraged iteration—making the design thinking cycle explicit—as a way to organize the collaborative teamwork necessary to produce building design and construction planning. Begun in 2009, the Integrated Studio is a project-based construction management and architecture design studio course offered annually in winter quarter for upper-level undergraduate students. Students work in a collaborative environment to develop and deliver design proposals using a working process modeled on the practice of Integrated Project Delivery (IPD) and less formal collaborative forms of project delivery such as design assist and design-build. IPD is a design approach that integrates people, systems, business structures, and practices for harnessing the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction. Like UW, a number of construction and architecture programs have responded to industry advances in IPD and instituted integrated project coursework in the studio setting (Graham & Geva 2001; Holland, et al. 2010; Homer 2006; Smith 2009; Starzyk, et al. 2011).

Teams of between six and eight UW students were provided collaborative studio space comprised of individual work desks, a central worktable, an interactive whiteboard with a projector, and eight perimeter internet ports. Students worked on laptop computers with BIM and other technical and visualization software. Two faculty—one from construction management and one from architecture—were instructors of record. Professionals from the design and construction industry came to campus and worked regularly with student teams to provide instruction and advice and to critique the ongoing building proposals. Students analyzed, designed, managed, and communicated with BIM and other computational tools such as energy modeling. Students applied skills that they acquired in previous coursework and worked through collaboration exercises. The design and construction proposals developed in collaborative teams achieved a relatively high degree of resolution including the development of major assemblies, selection of materials, development of the building envelope, integration of structural and environmental systems, and preliminary cost estimates and construction schedules.

Over the ten-week studio, the students first worked through a one-week "break-the-ice" problem called a "charrette." During this introductory problem, students got to understand their teammates and the expectations of studio work and culture. The studio term was then divided into three two-week cycles of design and analysis. The first half of each cycle focused on design development, and the second half analyzed the proposals in terms of building performance, cost, and construction logistics. In each subsequent cycle, the student teams were asked to analyze two or more alternatives, diving into and laying out the pros and cons for each, and then recommending direction for future work. At the final review, the students compiled a comprehensive report that covered the design, building performance, cost, and schedule for the project. Digital deliverables included a building information model and a 4D visualization of their final design.

With a cohort of students from different disciplines, the instructors were challenged to coach and guide building design and performance as well as costs and construction logistics. The iteration design of the cycle (Week 1 – "design," Week 2 – "analysis") provided an opportunity for the faculty to focus their conversations in desk critiques and allowed for milestones in the design process where analysis takes place. We also encouraged students to ensure that subsequent design iterations responded to the analysis of the prior cycle, so that each step of the iterative process informed the next. The cycles then helped guide the students through a conceptual design process getting them deep enough into the problem for a detailed construction estimate and schedule.

**Outcomes**. This study suggests that technology tools can ease the difficulty of disciplinary integration by offering affordances to iteration that otherwise would be harder to accomplish by more normative professional means. As a first outcome effect, we saw that content discussions between disciplines were made more synthetic by methods of digital visualization. As a second outcome effect, we also saw that technology tools made differences in disciplinary knowledge explicit, which, in turn, required students to discursively explain their own content knowledge and evaluative reflection to their peers. These moments of conflict were often found at the locations of cognitive knowledge transfer in the design thinking model—the transitions between analysis, synthesis, evaluation, and communication, or where one of those four components was cyclically iterated from abstract to concrete.

An example of the first outcome effect was how the members of Team Alpha experienced an intense cross-disciplinary learning experience in developing a 4D model of their final building design to visualize the planned construction sequence. An architecture student and two construction management students had a content-rich discussion while working over one computer. They discussed ways to organize the selective demolition and temporary shoring details for their design, and in the process made decisions, such as slab edge cut locations, that further refined the design. These decisions impacted both the construction sequence as well as the building design, so all three students were engaged in the collaborative decision making process (Figure 2). Working at the cognitive knowledge transfer point between *synthesis* and *evaluation*, the team brought in other studio students to critique their potential solutions. Furthermore, when industry professionals visited the studio, the team had a visualization of their project that enabled detailed discussion and further refinement from the professional’s feedback. Since the software afforded 4D visualization, the three students were able to deal with the context of design and construction planning considerations that otherwise were simply too abstract for them to communicate or understand. In the software, they had to define objects and construction activities, which catalyzed decisions about specific shapes, locations, and sequences.

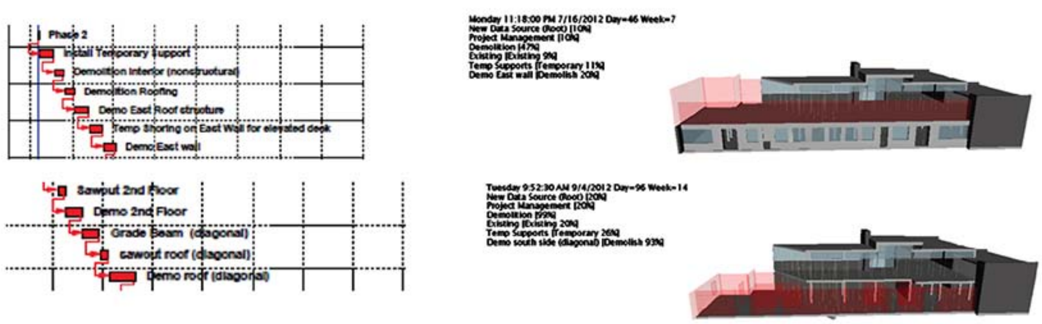


**Figure 2. Team Alpha 4D Model showing selective demolition**

An example of the second outcome effect was when two members of Team Beta addressed a 3D model change to support 4D visualization development. The team had not coalesced around collaborative norms that engendered project development discourses and had largely worked independently. So when the construction student began working on the 4D visualization, she realized that different concrete slab geometries were needed for her construction plan. The construction student had not talked about the plan to the architecture student who had built the 3D model. She had to ask the architecture student to make the change for her—which was a “last minute” change in production for the final. In this instance, the cognitive knowledge transfer between iterative cycles of *synthesis* was missing construction content that would have provided for this necessary design consideration because the students had avoided the collective resolution required to manipulate the animation visualization software. Again, it was the needs of the technology that induced the realization that the slab had been incorrectly designed for construction. However, this team missed the learning opportunity to a large extent by not collectively discussing the plan. In the end, the 4D model was developed to less detail, and this team realized less cross-disciplinary learning than Team Alpha.

The second outcome effect was also reflected in how Team Beta replicated their disciplinary differences in their studio workspace by allowing the internet port arrangement on the outside walls to organize their seating arrangements where they were spread out and sat back to back. The team would generally only convene together after producing individual work. This meant that most of their collaborative discussions were occurring over the naturally difficult cognitive knowledge transfer locations in the design thinking model, which exacerbated disciplinary conflicts.

In subsequent studio iterations (2013 and 2014), the iteration process itself was found to be a key component in developing cross-disciplinary learning. In the first years of offering the Integrated Studio, we did not formalize the iterative process. Architecture students entered the studio with an understanding that their design would evolve over time but had little experience in designing with a group. Conversely, construction management and engineering students saw design as a linear process (e.g. “design a beam for this loading”) and were often frustrated when the design changed during phases of development. This ambiguity often made them want to wait until the design was “finalized” to perform any analysis. Asking teams to analyze multiple design options provided flexibility to design teams interested in exploring different personal ideas and gave clear value to the early stage analysis because it informed and shaped the subsequent design. The iterative cycle (Week 1 – “design,” Week 2 – “analysis”) also allowed the faculty and student teams to focus on architectural design during Week 1 and construction planning during Week 2. This focus enabled students to see how to apply their own discipline’s knowledge base to the problem as well as understand how the other discipline’s knowledge base contributes to solutions. Furthermore, we found ways to transition from individual design exploration to team-based design activities; while analysis and synthesis actions may be individual, evaluation and communication became team-based actions. This iterative cycle of instruction also accomplished a significant learning goal about disciplinary collaboration. Students were enabled to understand and conceptualize the design thinking activities within iterative teamwork in a way that fostered their own management capabilities of integrated project activities.

## CONCLUSION

Acknowledging the contemporary drive behind AEC integrated practices and the expanding effect of computational and visualization technologies, this study attempts to understand the relationship between iterative collaboration and the technology mediation that is beginning to typify professional integrated practice. Using the ground of collaborative project-based undergraduate studios between construction management, architecture, engineering, and other allied fields, we have recognized a number of potential points in the cycle of the design thinking model where knowledge transfer is co-located with the technology affordances of 3D object formation, visualization, and simulation. These points have historically been part of any learning about ambiguous problem solving; that they now include the context of digital technologies and group collaboration is the issue that must be addressed by contemporary educators. More faculty need to engage in collaborative project-based instruction across AEC disciplines, and this ongoing effort—admittedly difficult—needs to be complimented with further study of technology integration.

We have found that knowledge transfer with technology proves advantageous for learning but is problematic for professional practice. In the integrated classroom as well as in integrated practice, technology often has a characteristic friction—

affordances that allow only particular types of action (Gaver 1991)—which can operate as an impediment to discursive understanding. This is because the complexity of AEC technology can be misaligned with the communicative requirements of human collaboration (Whyte, et al. 2008). In the classroom, this friction can be an important opportunity for learning, as it necessitates conversations about conceptual constructs of the professions that the students are themselves just learning. Conversely in the world of professional practice, this friction is often simply a source of inefficiency. Further work in this realm of technologically-mediated integrated collaboration will offer both education and industry better means to realize both improved undergraduate learning and increased practice efficiencies.

## REFERENCES

Gaver, W. W. (1991). Technology affordances. *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 79-84). ACM.

Graham, C. W., & Geva, A. (2001). Evaluation of an interdisciplinary studio experience to teach architecture and construction science students the design-build project delivery system. *International Journal of Construction Education and Research, 6* (2), 75-90.

Holland, R., Messner, J., Parfitt, K., Poerschke, U., Pilak, M., & Solnosky, R. (2010) Integrated design courses using BIM as the technology platform. *Proceedings of the BIM–Related Academic Workshop, Ecobuild America 2010,* December 7–9, Washington, DC.

Homer, J. (2006). Integrating architecture and structural design in the comprehensive design studio. *Proceedings of the 2006 Architectural Engineering Conference.*

Martin, R. (2009). *The design of business: Why design thinking is the next competitive advantage*. Cambridge, MA: Harvard Business Press.

Messarovic, M. D. (1964). *Views on general systems theory*. New York: John Wiley and Sons.

Monson, C. (2011). Concepts of inquiry, constructivist learning, and the potentials of studio in construction education. *Proceedings of the 47th ASC Annual International Conference.*

Smith, J. C. (2009). Teaching the capstone course using interdisciplinary student teams. *Proceedings of the 46th Annual Conference of the Associated Schools of Construction.*

Starzyk, G., McDonald, M., Nuttall, B., Mwangi, J., & Clay, G. (2011). Instructional design for an integrated project delivery studio. *Proceedings of the 47th Annual Conference of the Associated Schools of Construction.*

Watts, R. D. (1966). The elements of design. In S. A. Gregory (Ed.), *The Design Method*, (p. 85). London: Butterworths.

Whyte, J., Ewenstein, B., Hales, M., & Tidd, J. (2008). Visualizing knowledge in project-based work. *Long Range Planning, 41*(1), 74-92.