MATERIAL TEACHING

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ABSTRACT

This paper reflects a shift in technology teaching from lecture-format to project-based experiential learning. The pedagogical approach described has two underpinnings: teaching technology through inquiry-based design methods and using working models as a primary pedagogical tool. The teaching method draws from a line of educators including James, Dewey, Bergson, and Schön, with the intent to dissolve the perceived incongruity between technological and creative thinking. Presented here is a range of work from the Materials and Assembly course, taught to second-year students at the Carnegie Mellon University School of Architecture, that balances creative inquiry and technical competence. Examples are given of pedagogy derived from the construction of working models to further associative thinking and discovery.

KEYWORDS

Creativity, Pedagogy, Technical, Architecture, Materials, Assembly

INTRODUCTION - QUESTIONS

Questions of how to teach are quickly followed by how one learns, retains, and applies knowledge. Generally, technical courses cover a wide range of information that students need to know in order to make ethical design decisions and become competent practitioners. In architecture curricula, technical information has been conveyed to large groups of students through textbooks and the lecture format. In most schools of architecture, there is a trend to view technical subject matter as support for the design studio, and though this is a reasonable notion, the segregation of design from the technology stream has taken a critical approach to learning—that of experiential learning—away from the technical coursework (Figure 1). There is a shift among technology educators toward project-based experiential learning that recognizes design as the primary means of contextualizing, synthesizing, and applying technical information. The work of this paper is firmly in this category and posits physical modeling and experiential learning as integral to this process. The projects described are not seamlessly integrated into the design studio;

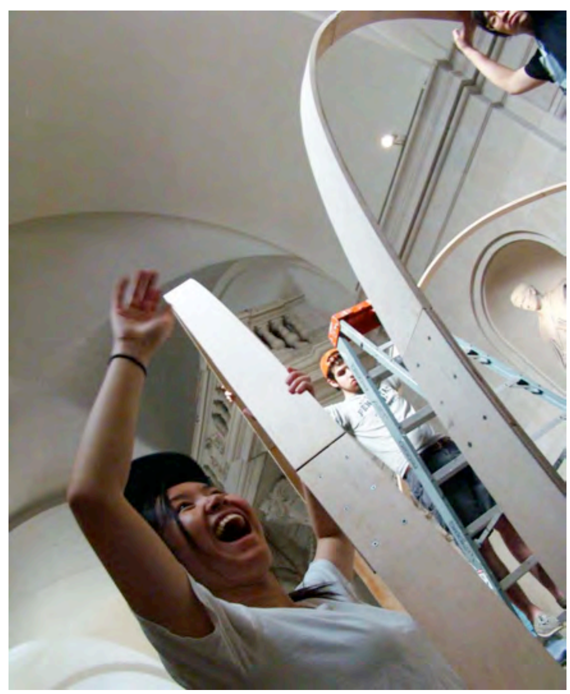

Figure 1 The benefits of technical subject matter conveyed visually.

rather the Materials and Assembly course remains autonomous, but is taught (and learned) with recognition that design is a highly recursive process that involves working iteratively between drawing and modeling. This recursive process is nonlinear, time-consuming, and challenging to fit within the normal constructs of technology teaching.

As technology teachers prepare to teach design thinking and the acquisition of knowledge through direct engagement, it is helpful to review the location where most design teaching occurs: the studio. Design studio courses are the most time-intensive in the architecture curriculum. In studio culture, students are often taught that the design process is individual in nature and must emerge from within themselves over time. There may be some truth to this position, but it tends to leave the student without a pedagogical scaffold. Numerous researchers have noted “it is the rare teacher indeed who shows students how to follow a systematic method” (Gross and Do, 1997). As a counterpoint, technology teaching is usually quite systematic and is almost exclusively taught from a textbook that sequences information according to topic. It is common for readings and exercises to build upon previous knowledge. In the design studio, there exists no such text, and problems are often presented as open-ended “wicked problems” where students grapple to synthesize a wide range of variables simultaneously. As the design process unfolds, the work produced does not necessarily verify an initial intent, but intent is an emergent and plastic notion that develops through immersion in the design process itself.

Studios that have an underlying pedagogy, not simply a topic, enable students to work within a framework, make discoveries, and confidently apply knowledge. If a pedagogical scaffold is formed, students will be more able to apply their skills to novel scenarios.

Often, a primary role of the studio instructor is to remain cognizant of a student’s progress and interject according to their assessment of the student’s needs at any given time. Generally, studio pedagogy is not a prescriptive method of teaching in which students are led through the process of design. Usually, studio instruction is based in inquiry, and students develop the confidence to be invested, take risks, and rapidly iterate. This is critical to the design process, as students are continually in “search mode,” looking for alternate partial solutions to further a design prospect, echoing Henri Bergson’s belief that reality is best viewed subjectively, not reassembled through a series of reductionist experiments.

These issues are brought to light as a query for how technology teaching may be enhanced not only through project-based learning but also through design thinking. Even in the best cases of design instruction, reflection is a significant component of the pedagogy, and reflection takes time, a commodity that is in short supply in the architecture curriculum.

PEDAGOGY
Hand, Eye, Intuition, and Material

In the field of design, visual learning has long been a key aspect in the curriculum. Haptic In the field of design, visual learning has long been a key aspect in the curriculum. Haptic learning, though less studied, is a powerful companion. The Materials and Assembly coursework applies both visual and haptic learning methods as a scaffold for creative inquiry. In this course, the activity of physical modeling serves as a key sensorial and intellectual instrument; thus modeling is posited as a physical mode of knowing. This line of thinking emanates from the educational philosophy of William James and from John Dewey’s certainty that learning is based on discovery and mentoring, not the blind transfer of information from teacher to student.

The pedagogy draws from the efficacy of logic and intuition of Henri Bergson, which is conveyed best in his words: “there are things that intelligence alone is able to seek, but which, by itself, it will never find. These things, instinct alone could find; but it will never seek them” (Bergson, 1907). More recently, influence is taken literally from Donald Schön’s discussion of the design process as “a reflective conversation with the materials of a design situation” and that design is a tacit means of “knowing-in-action” (Schön, 1991) In the context of teaching technology coursework through design in Materials and Assembly, Schön’s observation is translated to the physicality of making, specifically through the modeling and experiential learning as integral to construction of working models, as an inductive teaching methodology that enables feedback, privileges discovery, and leads students to value experimentation in the design process.

METHOD – A Digression on Modeling

Surprisingly little has been written about modeling as a mode of thought within the field of architecture. In the sciences, physical models have an historic position as a means to elucidate complex relationships and interactions. Models—physical and mathematical—have contributed to the progressive stream of effort aimed at a more comprehensive understanding of the natural world. Models are vehicles that enable prediction of unanticipated occurrences that contribute new knowledge, either supporting or disproving existing theories. Models encourage questions to be asked that were previously unthinkable. For example, it was Kepler's combined physical observation and mathematical insight that led to models that challenged the fixity of prevailing thought and confirmed the Copernican view that the Earth does not hold a privileged central position within the universe. His models shifted the thinking of his time from circular planetary orbits to elliptical planetary orbits and fluctuating planetary speed, initiating a paradigm shift by approximating the dynamic organization of the solar system. Kepler's models became powerful instruments and contributed, nearly 100 years later, to Newton's laws of motion and gravitation.

In architecture, models are often not so heady, yet they significantly contribute to architectural vision, both physical and theoretical. In contrast to the sciences, models in architecture are often representational and serve as a medium to communicate ideas from one to another. This type of modeling has communication value but does not serve as an instrument of design thinking. These models do not transcribe reality but offer broader understanding based on physical principles, synthesizing facts so that new relationships emerge. For Kepler, there was a moment when the model became an instrument and thus served to extend the range of human perception.

In the context of this paper, the term working model refers to a model that is physically responsive, enables direct feedback, and, in the best case, supports the structuring of an idea. The working model may not always be constructed with precision, and may even benefit from an ambiguity that presents multiple readings, associative thought, and insight thinking. The term working model is apt, as the model is not at rest but itself is an activity engaging the maker in the tangible prospect of uncovering new knowledge, often in direct response to physical phenomena. Ideally, the working model can provide the student with the constraints of a specific starting point and an open-ended, rule-based system that promotes discovery. The specific starting point in the Materials and Assembly course is a hanging string and the rules that govern its form. As a result, students begin the project without an intense period of conceptual development; concepts emerge from the dynamic act of modeling itself. Students then have a scaffold to make discoveries, make evaluative statements, further the depth of inquiry, and become better informed in order to make more speculative propositions.

48215 MATERIALS AND ASSEMBLY
Course Description

48215 Materials and Assembly is a three-credit core technology course that meets biweekly and is taught to second year students as a combination of lecture and workshop. Addressing issues relevant to contemporary teaching and practice, the intent is to dissolve the perceived opposition between technological and creative thinking. In this course, students work in teams to construct and test an iterative series of working models and ultimately fabricate projects at full scale. This collaborative team-building experience teaches tolerance and team decision-making skills. The iterative project format serves to sharpen critical-thinking skills and is a means for architectural proof of concept. Students are immersed in creative methods of team management concurrent with the process of design; it is this nonstandard practice in architectural technology education that enables students to work collectively to develop creative technological solutions.

The first weekly meeting (1.5 hours) is a lecture dedicated the properties and potentials of wood, steel, concrete, and composites and their associated logic of assembly. The second weekly meeting (1.5 hours), and the focus of this paper, is a workshop where students gain hands-on experience with materials and methods of fabrication. Plywood was chosen as a construction material for each project because it is relatively low cost and easily worked. The workshop component meets in the design studio and consists of 60 students organized into five teams of 12. Teams are organized according to the studio assignments of the school administration. There is a warm-up material exploration project followed by a 10-week construction project, which is exhibited in the College of Fine Arts.

Team Building Skills

Team management is an ongoing task throughout the semester-long project. Each team has a dedicated teaching assistant (approximately five hours per week) who supervises project content and workflow. The word team is used rather than group to reflect that members are working toward a common goal. At the start of the course, team management skills are emphasized with a carrot rather than a stick approach, and teams are given the responsibility to draft a contract that delineates the guidelines of individual performance, conflict resolution, respect, and trust. The documents that emerge are thoughtful, carefully written, and referred to by students and the instructor during the course of the term to maintain team performance.

Constraints and Creativity

Giving student teams constraints coupled with a definite starting point that enables immediate team response and imaginative thinking is vital to design-based technical coursework. In this course students are given three points of departure: In terms of materials, plywood is specified (teams are given a maximum volume of 5.5 cubic feet of material so that thicknesses of stock may be chosen by each team); in terms of material processing, traditional and CNC (computer numerical control) tools are available; and perhaps the strictest constraint is geometry as each team begins design exploration by constructing physical models of the catenary. Students directly interact with the physical forces of the string models, working from two-dimensional beginnings to three-dimensional models. Each model is parametric and readjusts itself to find internal equilibrium as design choices are made. In this sense, student teams are not honing a form toward an ideal—but searching, like Dewey, for effective learning experiences through action.

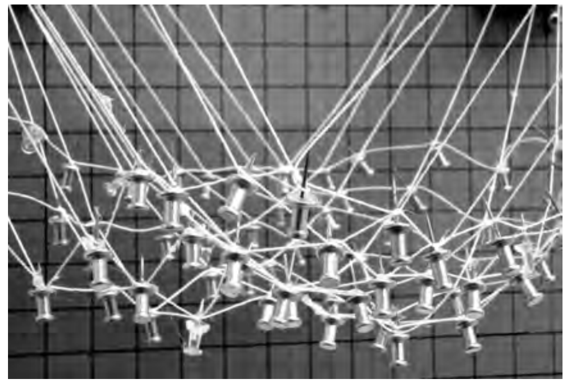

Figure 2 Interactive working model made from weighted string.

PROJECT
Iterative Modeling and Physical Computing

MIT Professor Waclaw Zalewski spoke often of equilibrium, both static and dynamic. He considered equilibrium in the biologic sense, as a continual interaction between the internal forces of a structural system and fluctuating external forces. For Professor Zalewski, a simple length of string, when loaded, was an instantaneous physical form-finding computational system. As a pedagogical tool, there is an immediate visual mathematical conveyance of structural principles. Following in the footsteps of Zalewski and Gaudi, modeling begins as an exercise in material behavior subject to the forces of gravity.

On one hand, the course imposes significant constraints, such as reducing geometric possibilities to catenaries, and on the other, the process enables students to begin to design and experiment immediately. Students discover that there is a great deal of freedom within the system as both symmetric and asymmetric forms emerge, and they are engaged in physical computing that is responsive and parametric. Understanding and comprehension occur from this physical activity, somewhat similar to the realization that a plumb bob effortlessly locates the mass center of the Earth. It is a simple working model that is intellectually appealing.

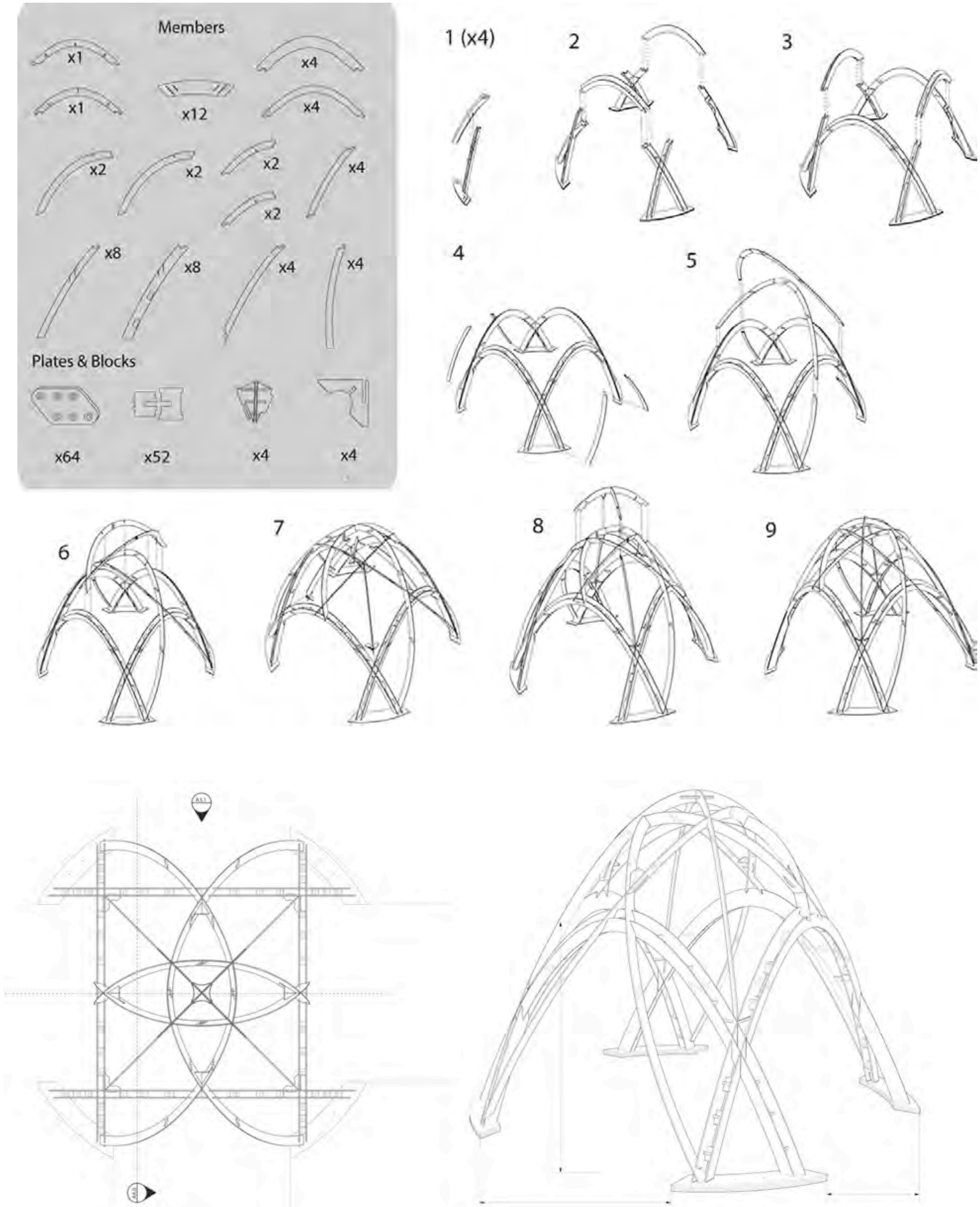

Figure 3 Assembly drawing to determine number of parts and construction sequence.

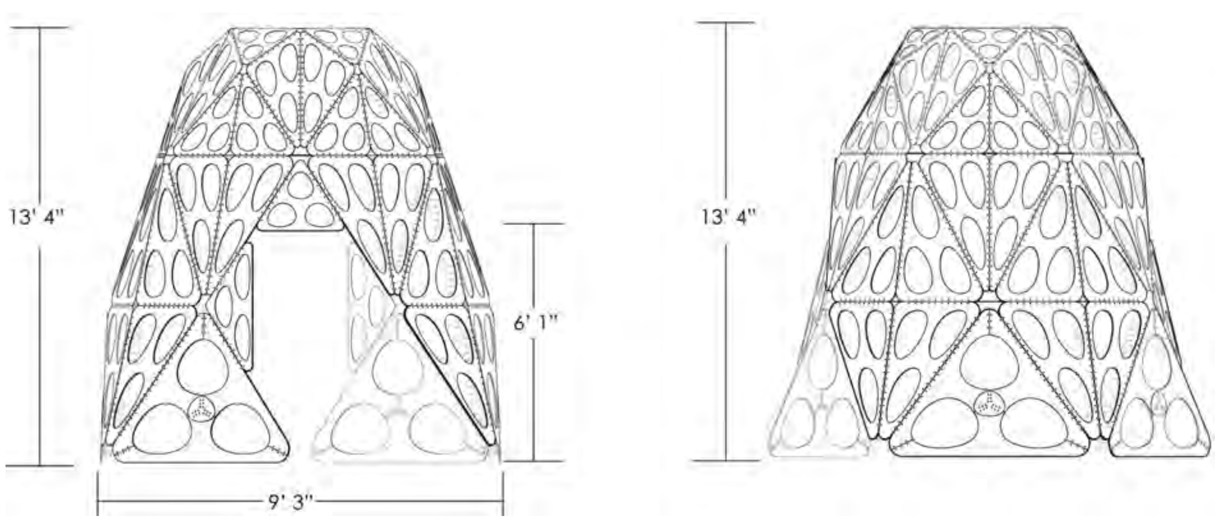

Figure 4 Drawing series of final model iteration. Team 1, 10 students.

at 1:10 scale. Models progress to more complex conditions, including multiple anchor points and out-of-plane loading. These simple models reveal lines of force that serve as the structural lines of the future 1:1 scale construction (Figure 5). As the string models increase in complexity and resolution, they are built at 1:5 scale. Plywood is introduced as a construction material, and students shift to 1:1 scale components and a 1:1 scale system (a build volume not to exceed 10' × 10' × 10'.

Design Development—Drawing

The main deliverables each week are a revised physical model and drawing set (Figures 3 + 4). Each Friday teaching assistants make

Figure 5 Built assemblies.

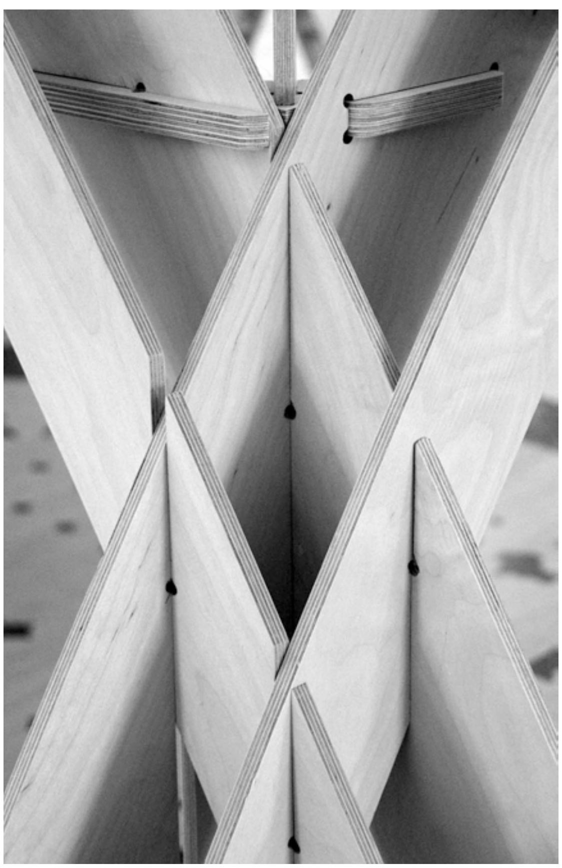

Figure 6 Joint detail constructed without mechanical fasteners.

preliminary red lines, then forward the drawings to the instructor for comments. In this system, there is a continuous and documented exchange of information that leads to skill development. Feedback is given to each team by discussion and review of the drawing set during weekly meetings. The instructor is present for each weekly feedback session, and the team-dedicated teaching assistant is responsible for the organization and constructive tone of the meeting. By the 10th week of the 16-week term, students submit their latest models and drawing sets for approval to build at full scale. This threshold is taken seriously because this is the time when materials are ordered and resources consumed.

For this meeting, students produce material cut-sheets to convey part dimensions to other students for fabrication on the analogue tools in the woodshop or to develop tool paths for CNC machining. Assembly diagrams (Figure 3) are a crucial component of the drawing set, as they describe the sequence of assembly, the tools and staging space required, tram safety, and the time commitment required for each task. The document serves as a graphic workflow diagram to assemble the structure within the specified six-hour timeline.

Design Development—Joinery

Students undertake a series of detailing investigations, increasing in scale from 1:10 to 1:1. The full-scale joints (Figure 6) are constructed from materials and manufacturing process that will be used in the final construction. Joints are accessed for economic use of material, structural legibility and use of tools to help develop the material expression.

DISCUSSION

This study employs the ancient notion of praxis, the practice of experiential learning in order to test fundamental architectural principles, by encouraging students to construct methods of inquiry that test, refine, and advance theoretical speculation.

The pedagogy presented is inquiry-based and intended to position students to make discoveries through direct interaction with the physicality of working models. The Materials and Assembly course reviewed in this paper is not an example of seamless integration with the design studio but is an ongoing experiment to teach technology through design thinking and the dynamics of teamwork. The results are anecdotal and contribute to the growing body of work committed to experiential learning in the technology streams in architectural education.

The Materials and Assembly course seeks to contribute to the growing interest in shaping learning environments that incite the imagination through the integration of technology and design. In the author's experience, the course pedagogy has enabled students to apply technology through the tangible experience of thinking and making, an experience that privileges discovery as the foundation of learning. It is proposed that this course instills an inductive method of learning that leads to the valuation of experimentation as central to the design process through the practice of making working models.

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REFERENCES

1. Bergson, H. 1907. Creative Evolution. New York: Henry Holt.

2. Gross, M., and E. Do. 1997. “The Design Studio Approach: Learning Design in Architecture Education. In Design Education Workshop, edited by J. Kolodner and M. Guzdial. Georgia Institute of Technology, Atlanta, September 8–9.

3. Schön, D. A. 1991. Design as a Reflective Conversation with the Materials of a Design Situation. Keynote address at the Edinburgh Conference on Artificial Intelligence in Design, Edinburgh, Scotland.

Bibliography

1. Kuhn, S. 2001. “Learning from the Architecture Studio: Implications for Project-Based Pedagogy.” International Journal of Engineering Education 17 (4–5).

2. Goldstone, R. 1998. “Perceptual Learning.” Annual Review of Psychology 49: 585–612.

3. Porro, C., M. P. Francescato, V, Cettolo, M. E. Diamond, P. Baraldi, C. Zuiani, M. Bazzocchi, and P. E. di Prampero. 1996. “Primary Motor and Sensory Cortex Activation During Motor Performance and Motor Imagery: A Functional Magnetic Resonance Imaging Study.” Journal of Neuroscience 16 (23): 7688–7698.

4. Simon, H. 1966. Sciences of the Artificial. Cambridge, MA: MIT Press.