Educat ing architects in building science and building technology is a long-standing disciplinary concern. The increasing complexity of shaping a sustainable and resilient future makes their education even more pressing. The U.S. Department of Energy (DOE) succinctly captures this sense of urgency, stating: “A key barrier to true market transformation for high-performance buildings is the limited knowledge-base of the professionals.” It goes on to cite lack of integration, inaccurate information and curricular inconsistencies as causes. These pages outline the efforts at Northeastern University (NU) to teach building science knowledge and skills by integrating them into design studio through the lens of well-regarded learning science principles (select principles introduce each section in this article).

Knowledge

“Prior knowledge can help or hinder learning” and “the organization of that knowledge influences how students learn.” In architecture school, students typically use site and program as the main generators of the plan. Meanwhile, students study construction, structural and environmental systems in separate lecture courses, which connect to design studios only in very limited moments, if at all. Thus, the students’ prior knowledge about the design process and the division of systems knowledge hinders their ability to see building systems as a generative and essential aspect of design. Left unchallenged, students go on thinking that material systems are applied after the fact, based on superficial aesthetic preferences, without considering their performance or their role in shaping form and space. Similarly, limited experience in practice may suggest that technical designs for building enclosure and mechanical, electrical and plumbing (MEP) systems lie in the

Figure 1: This integrated diagram illustrates the interaction of multiple forces and building systems.
Mastery
Acquiring component skills, practicing integration and understanding applicability are important to develop mastery. Task-decomposition is a key strategy to develop mastery.\[4\] Starting with the design of a simple structural bay unencumbered by program or site, students focus on the parametric relationships among structural, environmental and enclosure systems. This process encourages students to practice systems integration by clearly understanding performative consequences of design choices. Emphasizing relationships among parameters—like depth-to-span ratio for structure or window area to daylight penetration—underlines the importance of integration. Furthermore, this process highlights design constraints that are subsequently tested using more rigorous analysis and calculation; for example, by sizing typical members or measuring a physical daylighting model.

Throughout the course, complexity gradually increases in order to avoid cognitive overload. The second phase assigns a site, prompting students to integrate larger systems (e.g., ecological, cultural, infrastructural). Students transform the prototype into a full building with additional performance requirements: lateral stability, egress organization and response to the site’s microclimate to deliver desirable interior conditions. For example, designers sculpt air movement or respond to adjacent structures blocking and reflecting solar radiation. The third phase introduces the integration of active systems and technologies by using scenario planning to explore the adaptability of these systems over time.

One of the critical strategies from learning science is identifying when students lack the component skills needed to achieve a higher learning objective. Unlike a typical lecture course, studio affords one-on-one interaction, which allows instructors to identify specific deficiencies in skills or knowledge of structural, environmental or construction systems. The time for in-depth research at the start of each phase permits the instructor to assign tailored corrective assignments for students to catch up with background knowledge or skills.

To reinforce component skills, performance criteria explicitly includes integration,\[4\] with the ultimate goal of integrating—rather than mindlessly layering—passive (structure, enclosure) and active (power-operated) solutions (see “Figure 2,” above). Students learn about the applicability of particular systems by comparing their solutions to those approaches developed by other students.

All design processes require multiple cycles of research, application, feedback, revision and learning. These cycles characterize architectural education over the past century.\[5\] The studio format creates a multilitered instructional scaffolding for practice and feedback. Students work in pairs to help each other understand concepts, develop ideas.

Figure 2: These diagrams illustrate the integration of prefabricated structural systems and active comfort systems (left) and the integration of envelope and living systems to provide passive comfort.
and practice arguments. In this studio, unlike other technology courses, teams larger than two students seem to result in problems. Often, larger groups yield non-cohesive work and/or resentment at uneven alliances over design vision. Assignments purposely require odd numbers of deliverables so that students cannot simply divide the work in half. Instead, students must balance and integrate their individual efforts through conversation and critique. In weekly desk critiques, the instructor provides formative feedback, informing students’ subsequent learning.⁴ At critical moments, students meet with domain experts (e.g., engineers, façade consultants) to review designs and approaches for specific systems (e.g., structural, mechanical, landscape), thus targeting both the content and timing of the feedback. The timing demands careful consideration. Conducting a review too early precludes the desirable difficulty of students’ self-discovery, but too late simply identifies errors without guiding future learning and development. Empirically, two-thirds of the way through a project or phase seems to be about right. A regular pool of highly qualified local practitioners works with the curriculum to tailor their critique to course objectives. As in most studios, formal reviews at the end of each phase complement these exercises. During formal reviews, external critics (primarily practicing professionals) critique the work to provide holistic summative feedback regarding student work and development.

**Motivation and Metacognition**

Students’ motivation determines and sustains what they do to learn. Sometimes, critics view the studio-centered system of architectural education as a barrier to achieving technical proficiency, as architecture students often prioritize design studio over other courses.¹¹ This emphasis on studio at the exclusion of other content has real consequences. The American Institute of Architects Committee on the Environment (COTE) notes that “when the environment is discussed only in ‘support’ courses, students are likely to see it as inconsequential.”¹⁶ To address this challenge, an integrated model harness-
es the motivation of the creative process. The integrated model makes technical knowledge more relevant to students’ current interests and better connects this knowledge to their future professional experience. Integrating building systems and building science into design studio changes their perceived value to students in architectural design and education.

One student wrote in an anonymous course survey: “[This] studio was intense, but it was through that rigor that I learned an incredible amount about architecture...I feel like our previous courses...would benefit greatly to have more technical design involved.” The capstone course is a highly visible moment in the time and space of the school and program. Doing this during the capstone course contributes to learning and to design culture by motivating younger students engaged in the foundational system courses to see value in their current work, effectively demonstrating “relevance to students’ current academic lives.”[4] The display of artifacts, such as large and dramatic models and technical drawings in studio (see “Figure 3,” opposite page), makes this rigor visible as integral to design.

Strategies of “flexibility and control” and “opportunity to reflect” help improve student motivation.[4] A semester-long design project offers students many choices about the systems they explore, the parameters they prioritize and the ultimate design. The coordination of a theory-focused lecture course with a practice-focused studio course provides students opportunities to reflect on their own work in context of the broader disciplinary discourse. In the course Integrated Building Systems, students read theory and analyze in-depth case studies that highlight the importance of systems thinking, technical knowledge, multidisciplinary expertise and detail development in the production of significant architecture. The assigned readings and questions prompt students to consider broader issues (e.g., economic, ecological and political). At the end of each phase, students write a reflection on their own design process and outcomes in studio. These strategies apply another learning-science principle: providing opportunities to apply metacognition skills so students become self-directed learners.[4]

Students build on foundational knowledge to gain fluency with building science and learn to apply that knowledge through design. Following the revised Bloom’s Taxonomy,[7] the DOE’s “Guidelines for Building Science Education” defines proficiency levels ranging from low levels like “remember” and “understand” to the highest level of “create.”[8] While students recall or apply fundamental concepts, the studio also affords—indeed, requires—faculty to assess the process by which students rigorously analyze, evaluate and integrate knowledge to create novel solutions.

Measuring the effectiveness of design education is always difficult, but instructors solicit formal feedback from expert guest reviewers after each critique, and from students via course surveys. Alumni and employers also contribute. These sources suggest this studio helps students develop technical knowledge about building science and, more importantly, begin applying those lessons creatively through integrated design, both in school and practice.

In his 2005 Topaz Medallion presentation, Edward Allen challenged educators, concluding, “We must learn, we must learn, to teach technology as design.”[8] In efforts to answer this call, engaging building and building systems in the creative design process improves transfer and organization of knowledge, increases motivation and enables the development of student mastery. The centuries-old studio model is not the problem for building science education, but rather, a part of the solution.

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