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Rebuilding a Framework for Learning: Rethinking Structural Design Instruction in an Architectural Curriculum

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Disciplines
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Comments
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RE-BUILDING A FRAMEWORK FOR LEARNING:
Rethinking Structural Design Instruction in an Architectural Curriculum

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ABSTRACT
Architectural design relies upon structural design principles to help gracefully resist the stresses of building elements that enclose spaces. This discipline and expertise of integration typically takes years to develop but unfortunately, instead of teaching these skills side-by-side with coordinated expectations for escalating levels of expertise, representation, and analysis, these courses have frequently been separated from each other in architectural curricula. The oppositional pedagogical methodologies and differential expectations for development that occur as a result of this have adverse consequences for student learning and practical preparedness.

This paper, intended for a national target audience of university faculty and practitioners, will outline a series of major curricular changes made to Iowa State University's structural design course for architecture students which was explicitly reconfigured to address these concerns. Three specific lab assignments will be presented—one from the beginning, middle, and end of the new structural modules—to show how this new sequence has expanded and coordinated the range of curricular considerations within the structural coursework through the use of interactive, design-based learning activities and elevated expectations for course content.

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INTEGRATION NOT OPPOSITION
Although the formal relationships between structures and building forms are inseparable in practice, the traditional pedagogical models for teaching these skills have been explicitly separate in pedagogical "silos." There are several critical discrepancies between an architectural design education and an architectural "technology" education that have developed as a result of this separation that are disruptive to student development: conflicts between teaching methods and learning preferences, divergent assessment methods for student development, and unnecessary segregation of common course topics.

First, the problems with traditional educational models aren't simply an issue of what information is taught, but *how* it is taught. Many structural design courses rely on engineering-based teaching methods that favor abstract representations of physical behavior, calculation-based analysis, and assessments of student performance based on the accuracy of those calculations—a far cry from the interactive design environment pervasive in architecture schools. Architecture students rarely share the same self-diagnosed learning preferences as engineers so these courses are difficult (and perhaps boring) for many students and this directly affects their enthusiasm for learning (Cross, Durling, Johnson 1996).

Design courses in an architectural curriculum are traditionally arranged with a progressive level of course complexity to allow students to develop and refine their skills incrementally throughout their education. Alternatively, structures courses often require a consistent level of demonstrated acumen throughout—the development of a growing set of skills isn't necessarily required as separate courses simply focus on analysis/sizing of different materials using similar methods. The student work is assessed as either right or wrong, with seemingly no middle ground to demonstrate improvement or skill development within that overall regiment.

By focusing on the development of specific technical acumen, traditional structures classes emphasize the importance of quantitative understanding of very particular, often discrete, building elements (e.g., sizing of reinforcing bars) with little concern about the qualitative aspects of the structures being designed. Students are rightly suspicious about whether or not these calculations will be required of them in practice or whether this information is simply related to completing registration exams.

Additionally damaging is the fact that certain structures courses operate independently from other building technology courses in the *same curriculum* even though they share the same subjects. One common curricular model divides the structures courses by different materials (wood, steel, and concrete) and yet these same architecture students are required to take a separate set of courses that focus on the same materials and their assemblies. Because these courses operate independently, there is little opportunity for shared learning objectives that demonstrate the critical common lessons about structural materials, form, behavior, its manner of construction, and sustainability.

These problems aren't simply a matter of inconvenience or missed opportunities; there is evidence that these are very real and persistent problems. The lack of student preparedness to critically integrate building technologies into design has been consistently listed atop the complaints from practitioners and students alike in the yearly NCARB Practice Analysis of Architecture reports (NCARB, 2013). The problems seem to begin in school as research shows that when building technology courses are taught ineffectively, it adversely impacts efficacy of information retention, enthusiasm for learning, and preparedness for practice—a daunting problem for a profession committed to protecting the health, safety, and welfare of the built environment (Felder, Silverman, 1988).

A NEW FRAMEWORK FOR DEVELOPMENT

Five years ago, in an attempt to more effectively prepare architecture students for an integrated professional practice environment, Iowa State University's Department of Architecture dramatically reconfigured the entire undergraduate building technology course sequence by combining all three architectural building technologies (structural design, environmental forces/systems, and materials/assembly) into one coalesced five-semester course sequence. Under this new system, architecture students are presented information about all three building sciences in intense five-week modules of lecture and lab activities that feature active-learning environments, applied design exercises and integrated cross-module lessons. The new course format is more akin to the interactive, comprehensive, and collaboratively evaluated design environments pervasive in an integrative practice (Figure 1).

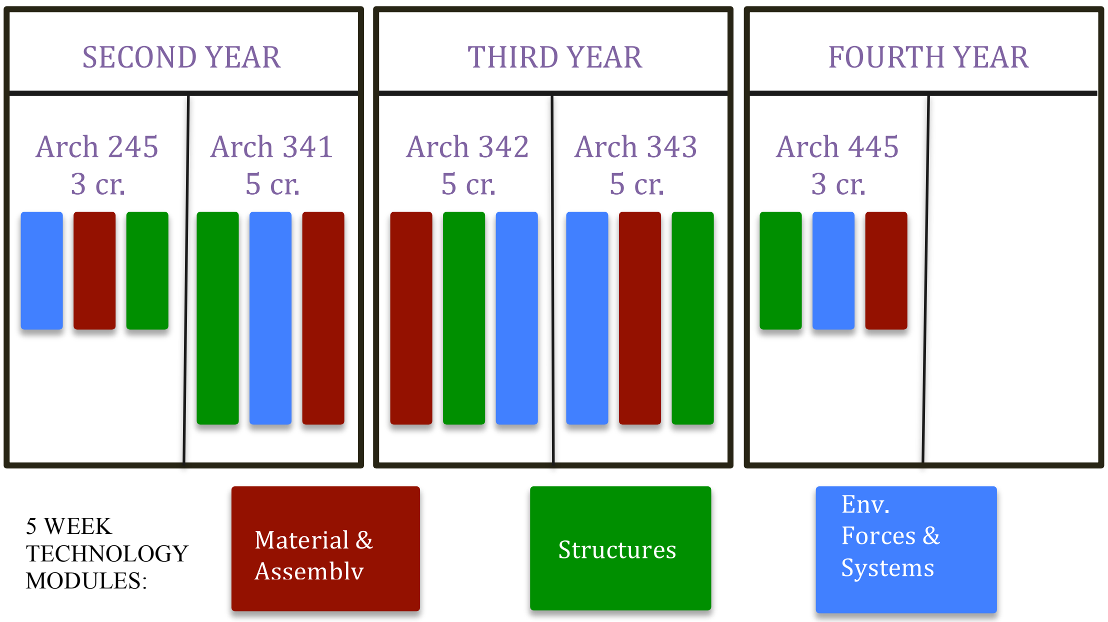

Figure 1: Revised Undergraduate Technology Sequence, Iowa State University, Dept. of Arch.

One benefit of intentionally removing the traditional "silos" between technology topics is that students can now be asked to draw information from a broader range of subjects about architectural design and technology while still holding them accountable to a core level of demonstrated competency for each subject. By combining the courses together, there is an immediately accessible opportunity to present shared lessons across all modules with a coordinated correspondence of skills and expertise. As an example, in one semester of our sequence students learn about masonry assemblies, compressive structures, and thermal mass properties by participating in a series of related design exercises (Nelson, Whitehead, 2014).

The teaching and learning methods have also evolved correspondingly. By combining the courses together, we have increased the length of class time to include both lectures and labs during the same class period—an important opportunity to present a diversity of learning opportunities and exercises. This lab environment is more akin to a design studio, in which qualitative and quantitative understandings are mutually emphasized and students are taught to develop different strategies for creating and assessing their work (Kuhn, 2001). As a result, instead of expecting simply the right and wrong answers, these design-based lab exercises allow students to consider 'how and why' certain choices were made in their work—a critical skill pervasive in practice. As an example, in addition to the mandatory lessons about structural behavior and component sizing, the new courses expect students to address the relationship between the proposed structure and building form and related implications for construction and sustainability. In other words, students are now asked to demonstrate a more holistic level of consideration more in line with their eventual professional responsibilities thanks to a project-based approach to learning (Mills, J., and Treagust, D., 2003).

These lessons are difficult, and take years of practice to refine and so perhaps the most important opportunity for student development that this new pedagogical model offers is the ability to craft a series of coordinated lessons and exercises across their entire educational development. Importantly, these lessons can be reintroduced and reinforced throughout their education with an escalating level of complexity and refinement. Beginning students can learn essential foundational lessons while advanced students can be asked to demonstrate more comprehensive understanding.

This paper will discuss three representative assignments from the course's structural design sequence—one from the beginning, middle, and end of the sequence. In these labs, students were asked to design and analyze certain structural configurations and to discuss their work in relationship to an expanded range of architectural considerations. Given the inherent benefits of the curricular format and opportunities for design-based exercises, the following labs were developed with a basic research question in mind: How should a coordinated series of design-based lab exercises be created to teach critical structural lessons at benchmark levels of their education while also offering students opportunities to demonstrate escalating levels of development and integration with architectural design and technology considerations?

ANTHROPOMORPHIC LAB: SUPPORTING STUDENTS

The first lab in their entire structural design sequence is intentionally unconventional, and hopefully unexpected. Instead of asking students to create or analyze any new types of architectural structures, students were asked to focus on the relationship of form and forces related to the structure they know the best—their bodies. Students were asked to join with their teammates to "construct" lightweight structural conditions using only their bodies to stack themselves high and to span across a space as far as possible. Although they have a life-time of accumulated intuitive knowledge about how to adjust their bodies to achieve the stability and overall equilibrium of balance in certain situations, they have never been asked to translate these experiences into structurally focused descriptions or analyses.

The idea for this anthropomorphic structures lab was based on the simple, but profound idea that structural education relies on a fundamental ability to visualize and understand the physical behavior of static elements that are primarily hidden. When the means of presenting and processing information is too abstract, or hidden, students are unable to visualize the concepts being presented and the relevance of what is being taught is unintentionally obscured (diSessa, 1993). Teaching the behavior of physical phenomena, like structures, without offering students a chance to physically experience it, results in a deficit of understanding about the principles of the subject so offering a means to experience these phenomena, like acting out these scenarios with their bodies, is an effective option.

Figure 2: Examples of body structures exercises of spanning, stacking, and cantilevering. Note the importance of considering construction "process" to achieve equilibrium.

Because the main learning objective was to conceptually connect abstract terminology of structural behavior (e.g., forces, loads, stresses, and states of equilibrium) with the various physical actions undertaken in each scenario. After completing the structures, students were asked to develop multimodal representations of what they experienced (pictures, diagrams, and descriptions) in a lab reports. In the written report, they were asked to include information about a broad, somewhat complex interrelated set of elemental structural terms and conditions: loads (dead & live, point & distributed), force vectors (sense, direction, and magnitude of components and their resultant), stress (compressive, tensile, bending, shear, and torsion), states of equilibrium (translational and rotational), and finally how the process of "constructing" these structures added certain complications (Figure 2).

Although the lab reports were undeniably at a novice level of understanding about structural conditions, the assignment imparts a methodology for self-taught examination and analysis for more advance structural topics covered in subsequent labs. In fact, in many of the lab reports completed in later semesters, students make frequent references, both in their descriptions of behavior and modes of representations, to the "body structure" as a way of explaining their conclusions. Typically these are found in form-active structural analysis labs (cables and arches), in the description of "buckling" in column and beam behavior, and in relation to structural connections (e.g., equating pin connections performing like ankles in a body).

As a first structures lab, these activities are intended to immediately improve student motivation, not only by the interactive nature of the classroom environment, but because an advanced capacity for visualization allows for a more diverse means for representing the lessons. As their sequence progressed towards more difficult structural design work, these lessons will be reintroduced and reinforced, albeit in lab assignment more akin to an expected type of architectural structure.

TOWER LAB: MAKING, BREAKING, AND EVALUATING

The Tower lab, occurs at the mid-point in their structural education and represents an important curricular and pedagogical transition in their education between previous introductory exercises and ensuing advanced structural typologies and assemblies. Although the lab ostensibly is about designing a tower, it is really about introducing (or reintroducing) the benefits of using alternative methodologies to better visualize and evaluate the behavior of complex structures to help improve design choices.

In the class periods leading up to this lab, the students have completed a series of exercises focused on calculating, sizing and understanding the behavior of discrete structural elements (e.g., columns, beams, slabs, and foundations), but like most architectural schools, these calculations are all incredibly elemental, based on idealized situations with only determinant conditions. When the subsequent structural lessons necessarily shift towards more complex structural typologies and assemblies that require an engineering level of analysis, it poses a daunting challenge to an architectural curriculum: How can architectural students be taught to study, analyze, and hopefully better understand how these more complex and holistic structures work within the limits of their abilities? The answer this lab suggests builds upon the strategy used in the anthropomorphic labs— engaging students in haptic augmented simulations to enhance conceptual learning by using physical activity as a cognitive anchor to comprehend abstract concepts (Barsalou, 2008). In other words, by requiring students to physically interact with the act of making *and breaking* the structure, they can better visualize the complicated indeterminate behaviors that occur in a complex structural design (Whitehead, 2013).

Students are asked to design an observational tower located on a geometrically difficult site set deep in the woods. They are asked to build, and test, a scaled mock-up of the tower (approx. 18” high upon completion) and then revised the design as needed. In order to avoid over-designed elements and to encourage them to experiment with efficiency and material sustainability of resources, they are told that it is a competition to see who can create the lightest compliant structure (i.e., Fuller’s “How much does your building weigh?” exercise). Ultimately a lab report is due that includes structural diagrams and component sizing data alongside their description of the design process and an evaluation of the behavior of the structure.

Like the anthropomorphic lab at the beginning of the sequence, one of the key challenges in the design process was given students formal activities to help them more effectively visualize the potential behavior of the constructs. To help improve spatial visualization, they were encouraged to immediately start sketching and building (Alias, Black, Grey, 2002). The main theme of the structural sequence is “think, make, break, evaluate” and so students are conditioned to testing their structural proposals but this particular testing exercises is perhaps the most formal and participatory of all labs. Students line up their work across a large table in the middle of the lab room (Figure 3) and are required to look at everyone else's proposal, ask questions of other teams and make predictions about the means of failure—all proven ways of creating more engaged learning (Dale, 1974). Because the students have consistently been encouraged to build and test mock-ups of their structural ideas throughout the labs of the previous three semesters, student groups typically set about building models immediately.

Figure 3: All tower structures before testing.

Building a tower with a regular (and predictable) framing system wouldn't have been a good test of the more integrated architectural and structural design skills that were being cultivating, so there is one highly influential constraint given in the program—they are given 6 potential footing locations (they can use only 3) and none of these footing locations occur directly below any of the corners of the platform above (its orientation is also a set condition). Students all immediately recognize the apparent structural challenge of creating stability for the rectangular upper platform using only a triangulated base. Only weeks before, students completed labs that required them to build and test beams and slabs and so they typically design and build these elements first—often times to their detriment. They quickly find out that an irregular triangular base of support creates vertical support elements that are inclined (not truly vertical) and quite long, making these elements incredibly susceptible to buckling and rotation. In other words, the critical structural design element isn't the platforms, but the "columns" and lateral stability. The lab doesn't explicitly warn them of this challenge and most groups find this out during the first round of testing, in which, quite intentionally most of their structures fail (Whitehead, 2013).

Figure 4: Students test their structures and make observations about its performance.

Once a significant amount of weight is placed upon the tower, certain structural phenomena, like punching shear, buckling, and torsion, become readily apparent.

Design teams surround the structure with cameras and notebooks looking to record critical observations of behaviors typically hidden to them (Figure 4). Many of the structures do fail after initial testing, mostly as a result of the framework buckling or twisting but they are required to redesign and rebuild the towers again based on this information to create a final proposal. Rarely does a part simply break in two, unless a column buckles; more often the causes of failures are obscured by the interconnected set of variables inherent in the process of design and construction. Guiding the students through the process of evaluating how to learn from their failures is critically important. Accepting certain types of failures as a desired component of a structural design teaching methodology may seem counter-intuitive, but this promotes the interactive, design-based attitude towards structural design central to the coursework and the architectural profession.

During the redesign phase of their work, the students are given all of the testing equipment to use for themselves to help ensure the compliance of their final design and many groups do, in fact, run a series of tests on their structure during this phase and adjust the orientation or size of certain elements accordingly. One of the interesting paradoxes in the redesign phases is that successful design strives to understand how/why something fails in order to reveal strategies for its improvement—but the causes are not always obvious and we often ironically fail to discern the proper lessons (Dorner, 1996). This is why their lab reports are so critical to the successful evaluation of their overall work. By explicitly articulating why they made certain choices in their lab report, based on cognitively grounded haptic exercises, and observations of failure, it helps embed certain key lessons.

As a benchmark of their "mid-term" structural education, the lab meets and surpasses many of the internally established learning objectives. It clearly presents an opportunity to integrate architectural and structural design priorities while still allowing for a clear demonstration and assessment of student knowledge about the design and behavior of various types of essential structural components. The level of structural analysis demonstrated is on par with traditional means of education, but these labs demonstrate a *much* higher level of understanding about how the interplay /connections between the different elements affects the overall performance of the structure and often alters the anticipated performance; winning structures typically weigh less than 1 pound and hold 40 pounds of weight (Figure 5).

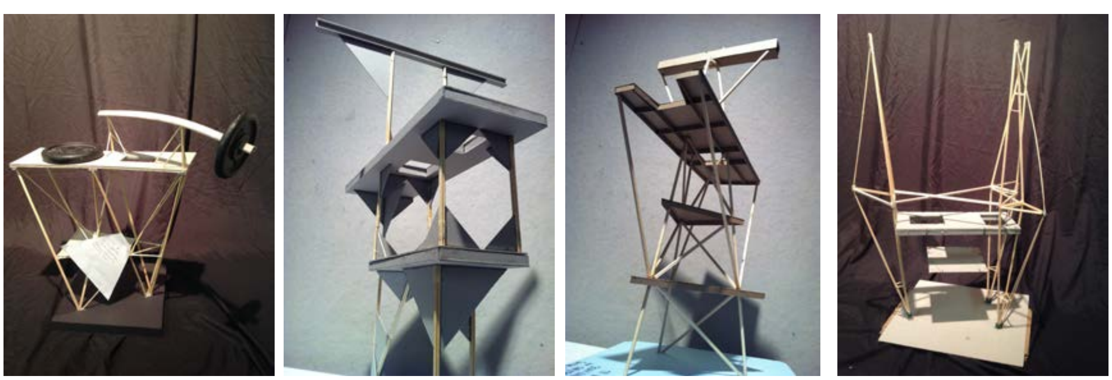

Figure 5: A diversity of structural strategies for form, structural strategy, and detailing.

Gratifyingly, student evaluations and surveys list this lab as one of the most memorable and effective exercises in the sequence. Students cite the "real-world" and comprehensive nature of the architectural design challenge as something important to them (i.e., it isn't just the analysis of a single element). Many also comment upon how "difficult" the lab was to complete and how the process of building, testing, and redesigning their work made the accomplishment of "passing a test" feel significant. Ultimately the lab clearly helps transition to the more advanced considerations found in upcoming labs, including the last lab in their sequence, and the final lab discussed in this paper, a long span Student Innovation Center building.

A LONG SPAN AND CONFIDENT CONCLUSIONS

The last five weeks of classes in their structural education focuses on long span structures and advanced systems: trusses, structural shells, folded plates, geodesics, pneumatics, and lamella structures. Pros and cons of these different systems and key aspects of their behaviors are practically discussed. However, because in practice the use of long span structures must deal with the associated complications of cost and construction, these sorts of issues are presented side-by-side.

Once again, an architectural program was presented to them as the basis for their work. Student teams (up to 6 people) were given a handout for a hypothetical building with particular requirements for area (80' x 250' column-free space) and clearance (40' height for the middle 25% of the area). Teams were asked to select a long span structural system for the project, develop the design in drawings and details (of a connection), and (once again) produce a testable scale model. This assignment is more explicit in the technical requirements for documentation and more straightforward in its pedagogical approach but it relies upon the previous lessons of design integration taught throughout the sequence.

The assignment required that students address four main points of emphasis in their designs: Options for finding and developing proper forms, Structural performance (span, deflection, strength, relationship to form), Issues of constructability (cost, economy, relative complication of process), and Overall level of sustainability (materials, shape, building orientation, thermal transfer, etc.). Importantly, these *same four points of emphasis* were presented as design priorities in the anthropomorphic and tower labs, but only in this lab were they explicitly required as lab talking points, to compel students to transfer comprehensive learning from their other tech courses to bear upon their structural assignments (i.e., to promote integrated design).

Using 3D models and drawings, students were asked to test and analyze the structural performance and behavior of various long-span systems and to draw at least one detailed section at a structural connection and building enclosure location to show the interaction between the structure and the building shell. Overall, there was a great deal of variety or work produced for this lab, not only in terms of the types of systems selected (folded plates, shells, and lamella structures are the most popular), but also in the amount of effort, resolution, and expertise displayed (Figure 6).

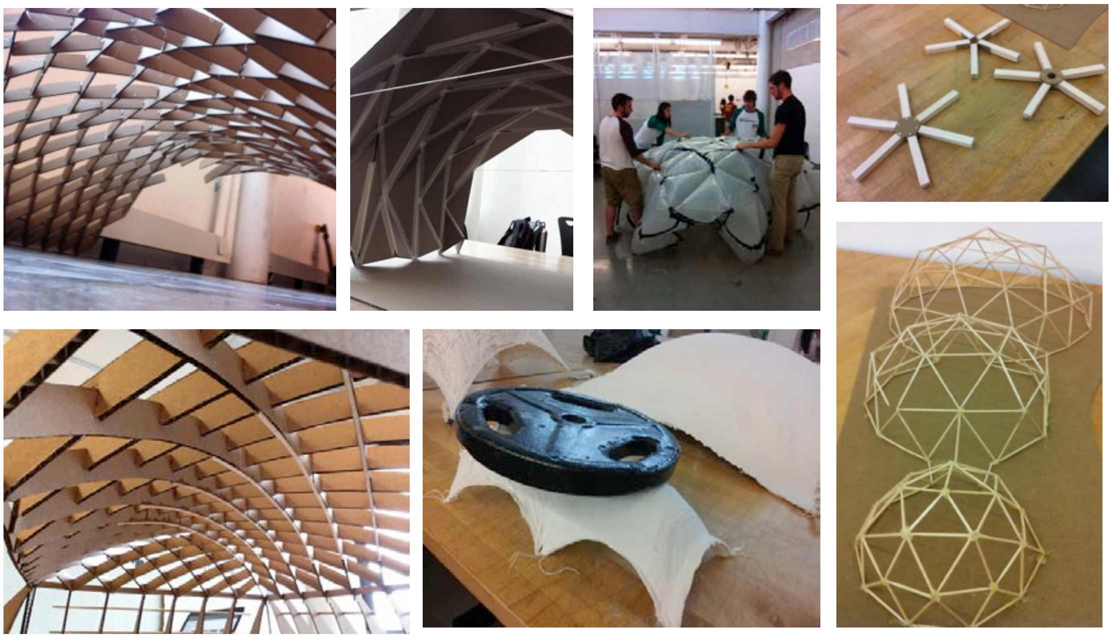

Figure 6: A variety of solutions proposed for the building design.

These four points of emphasis helped establish a common set of assessment and comparative criteria for the groups to begin their work. As a result, unlike the tower lab, much of the initial work on these designs was produced graphically (or argued verbally) based on the compliance with these points of emphasis. Because each group focused on constructing a single structural system type, there was a concern that they may not get a chance to understand the pros/cons of their system compared to others. For that reason, there was a system of evaluation where the teams were asked to go around and talk with three other groups, interview them about their structures, and summarize their findings and comparisons as part of their lab report. This is, of course, the same type of peer-review exercise utilized in the Tower lab, but in this lab, their review work was written, codified, and assessed as part of the lab.

Not all systems were a good fit for the lab: folded plates can only span approximately 100', geodesics may enclose too much volume if domes are used, pneumatics have environmental concerns in a cold climate, and the form of anticlastic shells can be very difficult to generate. A comprehensive understanding of the structural behavior of some systems was simply too difficult to fully comprehend in the brief amount of time spent on the lab. However, in general, the lab reports were the most thoroughly considered and thoughtful of any other assignment completed in the sequence—an observation supported by median grade levels and student assessments (Figure 7). There are many contributing factors to this success, such as the elevated level of relative expertise on the subject matter, lab writing experience, and years of experience developing integrated thinking.

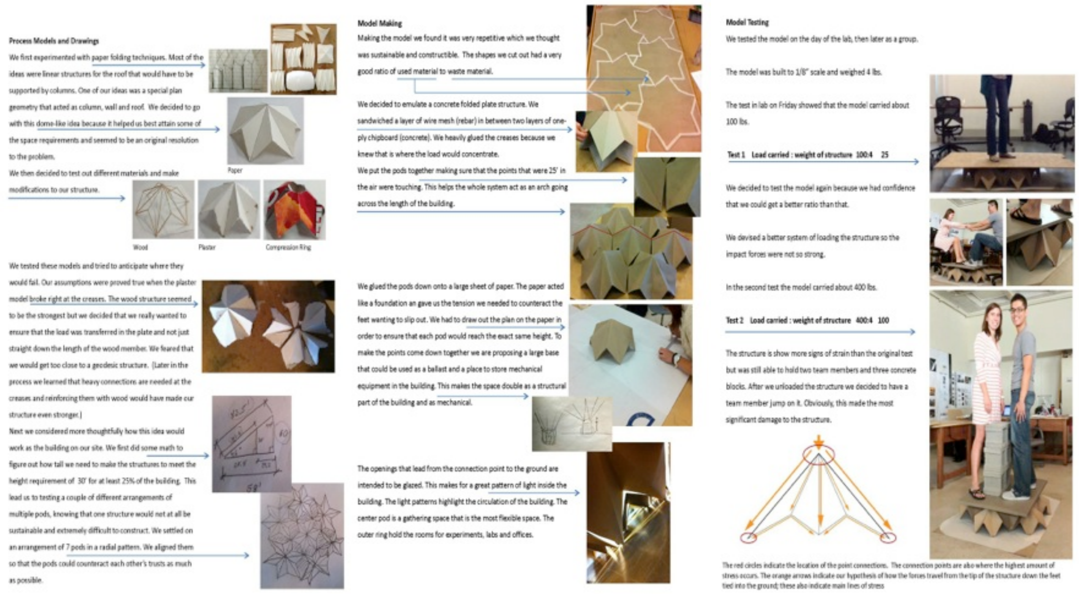

Figure 7: A lab report showing the process of designing, testing, and assessing a folded plate structure.

ASSESSMENT OF EFFECTIVENESS

One of the fundamental goals of reconfiguring the structural sequence was to create effective learning environments and activities that fostered a greater level of informed integration between architectural design and structures. The hypothesis was that, by implementing a coordinated series of design-based learning activities aimed at teaching students how to apply and evaluate quantitative information about structures into qualitative architectural designs, students would acquire a required level of technical acumen, apply these skills in an integrated manner to their design courses with a demonstrable level of improvement, and ideally profess an increased level of enthusiasm for the integrated design that resulted from the activities.

Assessing the effectiveness of the learning-activities, and the overall program, is an ongoing formative and summative evaluation process that looked at: Test scores, student evaluations and surveys, feedback from peer and professional reviewers and formal assessments of student work from design studios that ran parallel to the sequence (to assess integration). As the sequence has only been implemented for five years, there is currently no available, measureable data on the effectiveness of these lessons in practice or on registration exams, although this information is currently being collected. However, with the information we have gathered we have been able to determine the following conclusions:

- *Testing:* Every semester, students are tested on structural problems similar in scope, content, and complexity of that found on professional registration exams and in-line with accreditation standards. On these tests, the overall grading curve for the students follows a conventional, and acceptable, trajectory of performance (e.g., on average approximately 20% As, 45% Bs, 20% Cs, and 15% Ds or Fs). Student test scores can't be compared back to the previous educational model because the course structure, content, and means of assessment are too different to provide meaningful feedback. It is important to note that conventional tests pose great problems for many students because they struggle with how to translate information learned in labs to a more objective question and answer means of assessment; consistently students who have done quite well in labs may fail certain exams—and unintended consequence of promoting a primary learning method.

-*Design Integration with Studio:* Internally, instructors of building technology and studio (at times the same people) have observed an increased level of demonstrable competency and knowledge for the integration of building technologies into design projects, most profoundly at the advanced level/comprehensive studios. Importantly, the requirements to consider, and document these technologies alongside other design work no longer needs to be as frequently prompted (or required) by instructors—this type of work is more frequently student-initiated than in the past which may perhaps be a result of the lab activities in the technology sequence.

-*Student Perception and Enthusiasm:* Formal student evaluations and an anonymous survey about the effective of certain lab activities have both been primarily very positive although there are both extreme levels of enthusiasm and disappointment expressed. From evaluations we can tell that certain students, particularly in the first two classes of the sequence, don't see the whole picture of what they are being taught and why they are being taught with this particular project-based learning method (e.g., some ask why they aren't just learning "practical" information like calculations) but these comments rarely persist in later courses. Interestingly, later in the sequence, student evaluation comments typically praise the design-based, active-learning format, but lament its inherent limitations of integration between technology topics and in studio (it isn't integrated enough for many).

-*Peer and Professional Review:* Peer review of the program's success by fellow educators at other universities has been overwhelmingly positive. The technology sequence was specifically praised by the National Architectural Accreditation Board (NAAB) during Iowa State's recently successful visit, the structural portion of the course has been honored with a NCARB grant for the integration of practice into academy, and the course was awarded the 2013 Association for Collegiate Schools of Architecture (ACSA) esteemed Creative Achievement Award. At regular intervals, student work is reviewed by practicing architects and structural engineers. Overwhelmingly, their response has been positive to the type of classroom activities being presented (as a reflection of the realities of practice) and the core competency of student work displayed.

As the paper has demonstrated by describing labs from the beginning, middle, and end of the sequence, these lab activities were intentionally coordinated across the span of their education to help reinforce many of the same lessons. Because these lessons increased in complexity, student retention of previous course information was paramount, so the pedagogical approach relied upon several established means of assisting retention—active-learning environments, visualization technics, multi-modal representations, and peer participation in creating and evaluating the work. These activities and expectations were clear throughout the sequence. From the very first class, structural design students were asked to maintain the appropriate level of technical expertise related to the field, but were introduced to new methods by which they can better comprehend these technical requirements. This new framework for expanded expectations of learning will continue to be built and improved.

RESOURCES

Alias, M., Black, T., and Gray, D. (2002), "Effect of Instruction on Spatial Visualization Ability in Civil Engineering Students," *Int. Ed. Journal,* Vol. 3, No. 1.

Barsalou, L.W. (2008) "Grounded Cognition." *Annual Review of Psychology*, Volume 59, 1-21.

Cross, N., Durling, D., and Johnson, J. (1996) "Personality and Learning Preferences of Students in Design and Design-Related Disciplines*",* Loughborough University.

Dale, E., (1974) *Audiovisual Methods in Teaching*, Dryden Press, New York

Felder, R., and Silverman, L., (1988) "Learning and Teaching Styles in Engineering Education." *Int. J. Engng Ed.*, Vol. 78, 674-681.

Kuhn, S., (2001) "Learning from the Architecture Studio: Implications for Project-Based Pedagogy." *Int. J. Engng Ed.* Vol 17, Nos. 4 and 5, 349-352. Great Britain.

National Architectural Accrediting Board, Inc. (NAAB) (2013) "2014 Conditions for Accreditation (First Draft)." Washington, D.C.

National Council of Architectural Registration Boards (NCARB) (2013) "Practice Analysis of Architecture 2013." Washington D.C.

Nelson, K., and Whitehead, R., (2014) "Brick by Brick: Improved Outcomes Through Linked Learning Objectives in Beginning Technology Labs." *National Conference for Beginning Design Students Conference Proceedings*, Chicago.

Mills, J., and Treagust, D., (2003) "Engineering Education—Is Problem Based or Project-Based Learning the Answer?" *Australasian J. Engng. Ed.,* 2-16.

Whitehead, R. (2013) "Breaking (A)Way: The Role of Productive Failures in a new Structural Design Pedagogy." *Building Technology Educators Society (BTES) 2013 Conference Proceedings.*

Whitehead, R. (2014) "Pedagogical Progressions: Reflections from an "Integrated" Technology Sequence." *Building Technology Educators Society (BTES/ACSA) 2014 Conference Proceedings.*