In Support of Pre-Professional Relations: Guidelines for Effective Education Collaborations Between Architecture and Engineering

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> "Architecture is in the process of a revolutionary transformation. There is now momentum for a revitalized involvement with sources in material practice and technologies. This cultural evolution is pre-eminently expressed in the expanded collaborative relationships that have developed in the past decade between architects and structural engineers..."[1] – Rivka Oxman and Robert Oxman

As many architectural education conferences have acknowledged for years, design education is evolving to reflect the growing complexity and multiplicity of contemporary practice. Bottom-up, course-focused changes can have large-scale effects. In the current economy, schools rarely have the opportunity to overhaul or start anew. Such was the opportunity for the Bauhaus, created through German government funding in 1919. The initial premise of the school grew out of similar ideological challenges that we have today—how can architecture pedagogy reflect and influence contemporary practice and industry? As Bergdoll describes in the forward to the 2009 Bauhaus exhibition catalogue, "In challenging the way traditional academies taught students through the imitation of historical models, the Bauhaus worked as a laboratory for ongoing experiment. In his 1919 program for the Bauhaus, Gropius wrote that the arts had become 'isolated' in the modern age and the school had to forge a 'new unity'." Bergdoll goes on to add that, "The school's structural and teaching practices posed fundamental challenges to the distinction between art and design, and irrevocably changed the terms of both. Such crossing of the boundaries gets to the heart of what we feel is central to the Bauhaus's legacy today."[2]

The Bauhaus teaching model holds relevancy for contemporary educational curricula for a host of reasons. In the case of architecture, cutting edge practices are becoming increasingly collaborative at early stages of the design process. As digital design and manufacturing tools proliferate, architects are forging new ground thereby relying on their structural engineering partners in order to realize their designs. Evidence of positive collaborations in the synergy between Rem Koolhaas and Cecil Balmond, and Toyo Ito and Mutsuro Sasaki, for example, demonstrates that design partnerships that begin early in project phasing can be incredibly rewarding. Koolhaas began collaborating with Cecil Balmond at Ove Arup in 1985. Of this partnership, Koolhaas has said, "Our growing intimacy with each other's disciplines- in fact, a mutual invasion of territory- and corresponding blurring of specific professional identities (not always painless) allowed us, at the end of the eighties…to defrost earlier ambitions and to explore the redesign and demystification of architecture, this time experimenting on ourselves."[3]

Despite this increasing reliance on architecture-engineering collaboration in the professional world, in the United States, students from the disciplines generally have few opportunities to mingle. Although the NAAB encourages Interdisciplinary Collaborative Skills[4] and design teams are becoming more common[5], engineering and architecture collaborations are not as widespread.[6] This departmental isolation is attributable to the emphasis on increasing specialization, overloaded curriculums, and also resultant of the fact that there are vastly different pedagogical approaches to teaching architecture and engineering.

Interdisciplinary courses have the potential to prepare students for meaningful cross-disciplinary design collaborations in the working world. As schools forge ahead to prepare students for practice by offering interdisciplinary courses, it is helpful to first understand the differences, both positive and negative, of the recent educational traditions of the two disciplines.

A SHORT SUMMARY OF COMMON PEDAGOGICAL PRACTICES IN ARCHITECTURE AND ENGINEERING

Broadly speaking, in core engineering courses the same textbook is used for decades and the answers to homework problems are in the back of the book.[7] The curricula result in a predictable and solid foundation for science and math knowledge, but this knowledge is derived from linear methods of thinking and resolution.[8] Depending on the number of by-the-book engineering courses in the curriculum, it is very possible for students to graduate without having developed their creative problem-solving abilities, despite that the working world is full of open-ended, ambiguous problems.

In many Civil Engineering programs throughout the country (and also at Syracuse University where the authors co-taught two years of an architecture and engineering design course), there are few "design" opportunities for students except for a freshman design course and a final Capstone design course, which is required by the Accreditation Board for Engineering and Technology (ABET), saying: "Students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints."[9] The Capstone is often 1-2 semesters long, consisting of about 5-7 hours of work per week with 3 hours or less in contact with advisor(s).[10] The contact hours and number of occurrences in the curriculum demonstrate the marked differences in design education in architecture and engineering.

The content of the architecture and engineering design courses differ in several ways: architecture studios (at least early in the core curriculum) often emphasize conceptual design and innovation without requiring technical resolution, whereas the engineering design course is necessarily focused on codes and constraints, typically comprised of a normative design problem from the region i.e., a new highway overpass or a water supply system for a nearby suburb. Due to the emphasis on "realistic constraints" (more than 50% of projects come from Industry[10]), architectural notions of creativity, such as aesthetics and ease of use, are not foregrounded. Historically at Syracuse University, for example, the engineering capstone projects have not displayed a wide range of approaches or markedly innovative designs.[11] The projects have, however, emphasized a high degree of technical resolution across a number of engineering sub-specialties.[10]

Creative Learning through Collaboration: A Course Case Study

Recognizing the potential benefits for interdisciplinary course work for professional programs to (1) integrate creativity in engineering education, (2) encourage architecture students to strive for greater technical resolution, and to (3) align pedagogy with practice, the Syracuse University Schools of Engineering and Architecture applied and were granted a three year National Science Foundation Innovations in Engineering Education grant. There are three main priorities under the grant, one of which is to develop a transdisciplinary design studio (TDS), which was taught as an elective in both 2010 and 2011. For the first iteration of this initiative, 24 students, (11 engineers, 13 architects) and in the second, 18 students, (9 engineers, 9 architects) came together for a 3 credit technical design seminar that was taught by a structural engineer and an architectural designer.

Surveys were conducted at the beginning of both iterations of the course and when asked why they registered for the course, many of the responses referred to the desire to prepare for the profession:

- ".. the interaction between architecture and engineering. This is a unique experience that I haven't seen anywhere else." (student, TDS, Spring 2010)
- "I hope to learn how the other half works, and I hope this will help in the future begin to understand architects in the workplace." (student, TDS, Spring 2010)
- "I hope to experience what architecture majors call 'hard'." (student, TDS, Spring 2010)

- "I hope to learn how engineers respond to an architect's design and the tools they use to do so." (student, TDS, Spring 2010)
- "In the actual world, architects and engineers work together. It would be good practice." (student, TDS, Spring 2011)

The TDS elective was developed as a design seminar focused on Shell Structures (based on expertise of the faculty). The topic proved serendipitous for a number of reasons. As Bechthold has acknowledged, "The study of shells demonstrates that [digital manufacturing and customization] may enable structurally efficient construction systems, provide a rich spatial experience, and use material resources responsibly."[12] Furthermore, a shell structure represents a pure integration of structure and form—the two are inseparable and must be considered simultaneously to achieve material efficiency and experiential dynamism (two valuations we discussed). We also found that it was a relatively new topic for all the students involved, which allowed for a common starting ground for the learning process.

We approached lectures on this topic from the perspective of our respective fields. We discussed historical and contemporary precedents, provided technical tutorials (on structural efficiencies, materiality and math) and software instruction. There were also a number of sessions devoted to design charrettes and reviews. The faculty attempted to integrate creative and research activities such as open-ended problem solving, resolving competing goals in a complex problem, balancing technical merit against architectural design values, and positing speculative designs.

The students completed almost all assignments in integrated pairs, or in the case of the final project, teams of four or three (half architect, half engineering). The individuals were paired differently for each assignment. In the first TDS, there were an uneven number of architecture and engineering students, so there was the occasional architect-architect pairing (interestingly, we found this often resulted in less compelling design work). Further, later in the semester (in both iterations) we gave the students one opportunity to pick their own partner (inside or outside their discipline), and three quarters of the class (both times) chose to form an interdisciplinary team.[13]

The course posed interesting challenges to teaching students with diverse types and levels of expertise. By recognizing and building upon the differences amongst the students' understanding, we sought to establish a common ground for communication and design through a shared vocabulary and skill set. This was no easy task: how does one communicate to half the class the principles of the other discipline without inciting complete boredom amongst the other group of students? This was attempted through lectures that combined both basic and advanced content about the values held by both disciplines in contemporary practice. Throughout these lectures and discussions, the faculty endeavored to acknowledge discipline-specific vocabulary and discuss it amongst the group. Through this continual reinforcement, we hoped to acknowledge the importance of communication in the collaborative design process. As Kloft, a structural engineer with Bollinger and Grohmann acknowledges from his own experiences collaborating with architects, "It is essential that architects and engineers collaborate from the very beginning of a project. In the case of freeform architecture an important aspect of this collaboration is that the structural engineer has to 'speak the language' of the architect and fully support the particular design approach."[14] Because of the shells content, much of the vocabulary and methods of discussing curvilinear form happened to be new for both groups of students, and as the students acknowledged in post-course interviews, building an understanding of disciplinary vocabulary proved to be pivotal to students' learning.

The mathematics behind shell structures was also mostly new content for both the architecture and engineering students. In order to lay a foundation for design development, students were introduced to both mathematical principles of dome and shell design as well as structurally guided form-finding techniques. As a pre-cursor to digital instruction, we described the analog form-finding methodologies of engineers such as Heinz Isler and Antoni Gaudi. One assignment asked the students to repeat an experiment very much like Isler's where they created "frozen forms" from fabric hung from a frame and manipulated (through pinching, folding, sewing, etc.) to create a form in pure tension and then sprayed with water (during winter in Syracuse, the fabric froze very quickly) and flipped to become a shell in pure compression. (See Figure 1)

Figure 1. “Frozen Form” project showing Ekaterina Makarova and Jaeyun Kim, Spring 2011.

Since the formal complexities evident in contemporary practice are enabled by new technologies, it is logical that software should be taught and supported in the classroom. Using the case studies by architects such as Frank Gehry, Kloft states that, “Besides the formal freedom that new computer technologies offer, digital design tools also hold the promise of new collaborative design synergies for architects and engineers… Understanding individual design values is essential for a promising integration of engineering potential in architectural design.”[14] The software tutorials included designing using Rhinoceros (which the engineers picked up very quickly because of the logical, AutoCAD-like interface) and SAP 2000, a Finite Element Analysis software. Although the translation between the two programs was not always smooth and could be better integrated in future courses [15], it was incredibly helpful for all of students to be able to translate ideas into 3d information using the same software. Digital models were modified by both team members as ideas progressed and analysis provoked design changes.

Students were also instructed how to translate the CAD models into physical models through CNC milling and vacuum forming (a productive example of the potential for mold-making in the real world). (See Figure 2). Model making was crucial for the process of design communication between partners. What was difficult to describe, could often be modeled. Because of its emphasis in the course, physical models were the primary focus of design critiques and grading.

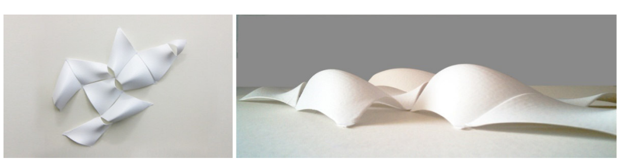

Figure 2. Eli Goldman and Jack Solomon, Apertures and Aggregations, Spring 2010.

We attempted to highlight the importance of making both digitally and physically in a continual feedback loop between design and analysis. The potential of this process was especially evident in the final project, a Regional Transportation Center, which teams of three or four had four weeks to complete. In one project, for example, the engineering students encouraged the architecture students to add apertures between stress paths to allow for increased day lighting and experiential effect. (See Figure 3). Since one of the major goals of the grant is to develop the course into a generalized model for engineering and architecture course collaborations, a portion of the NSF funding supported an analysis of the courses’ successes and failures by the Office of Professional Research and Development in the School of Education at Syracuse University. The education evaluation team conducted surveys and focus groups that have been incredibly helpful in developing guidelines for future courses. The evaluation reports for each course included a review of the written materials, pre and post surveys, diagnostic tests, interviews, and classroom observations. Students were surveyed at the start of the semester about their expectations of the course; their perceptions of their own discipline as related to a variety of attributes (including creativity, logic, ability to solve complex problems, etc.); their perceptions of themselves as related to the same attributes; and their cross-professional perceptions. The students repeated the survey about disciplinary and cross-disciplinary perceptions after the course was over (and grades had been posted). At that time students were also asked some direct questions about whether the course changed their opinions about the opposing discipline. For specific information about the findings from both iterations of the course, please see a previous paper on the topic.[16]

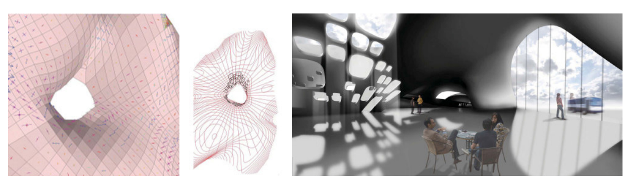

Figure 3. Goldman, Ingersoll, Lipezker, Solomon. Final Project, Syracuse Regional Transportation Center, Spring 2010.

Lessons Learned: Guidelines for Interdisciplinary Design Pedagogy

The education evaluation reports have enabled us to develop several guidelines for future engineering and architecture collaborative courses:

Logistics/Course Structure

1. Interdisciplinary design can be taught at any point in the curriculum to either the same level of students or a mix of levels.

In our experience where both classes were composed of engineers from the third year and architecture students from a wide range of years, we found no clear indicators that interdisciplinary design should be taught at a particular moment in the curriculum. Although intuitively, it may seem that communication would improve amongst students who are at about the same level, at least in the Syracuse context, the dominant personalities were not necessarily those in the higher age group.

2. The course structure works well as a hybrid of the design studio, seminar and technical lecture models, but because of time, should (ideally) run as a studio.

Lectures, lab instruction (on software or other technical topics) and group critiques enable general knowledge to be dispersed about vocabulary, history, precedents for the work, and technical skills. The group critiques are also an essential part of the design course so that students can understand the range of possibilities and learn from one another. At the same time, small group critiques, desk critiques and working sessions allow the instructors to give individual attention to groups and observe group dynamics more closely, which also facilitates intervention if there are communication issues in the group.

3. Instructors from each of the disciplines should (ideally) be present in the classroom together as much as possible.

Given tight budgets, this may be difficult to achieve, however, key learning (on a part of the students and instructors) occurs when multiple perspectives are voiced in the classroom. In order to address communication dynamics amongst students, it is helpful to understand their perspective and the instructor's understanding can be gained, in large part, from observing and talking to the other instructor.

4. Invite outside experts – equally – from both disciplines.

Emphasize that each discipline is complex and that feedback from colleagues is an essential part of the design and learning processes. We would usually invite outside critics to review the work (as presented by the students), but we found that some engineering colleagues were unaccustomed to the review process and did not always provide constructive feedback, especially regarding technical concerns. It may be helpful to invite colleagues who have some experience with design teaching or even interdisciplinary collaboration.

5. Meet in a classroom housed in the engineering school.

The Shells Structures courses met in the architecture school both years, and we now recognize (through the course evaluations) that the context alone provides comfort and sets a tone. Our goal was to emphasize creative thinking for the engineers, which naturally took them out of their mental comfort zone. Confidence-building and emotional comfort may result from teaching the engineers on their "home turf".

Content

1. Choose a topic that is relatively new to the curriculum of both disciplines.

As already described in the introduction, Shells Structures turned out to be a well-suited topic for the Syracuse University curricula because it was new for both the engineering and architecture students. Although it is important to recognize and harness varying types of expertise amongst the students, it is also helpful to achieve a level playing field—a sensibility that everyone is "in it together". When growth is happening in parallel amongst a diverse group of students, they tend to forge bonds and help one another through the process.

2. In a fifteen-week semester scenario, we recommend no more than three short assignments (without a high degree of resolution) and a final project of about six weeks, which is more resolved.

In the case of the Shells collaboration, which emphasized open-ended problem solving and creativity, we introduced a series of short projects so that there would be multiple opportunities for collaborating with different partners. We attempted to isolate the key design elements for the group to tackle, acknowledging very clearly what was being left out to avoid misconceptions about the design process.[17] On the positive side, we observed that the short assignments were helpful in building confidence through multiple attempts. However, student surveys revealed that the students were frustrated by the lack of time to delve deeply into design (especially later in the semester when we had allotted four weeks for the final project).

Tip for Teaching

1. Allow for working sessions during class time in order to observe group dynamics and tactfully intervene when necessary.

As many readers of this paper already know, the complex craft of teaching involves nuances that change from student to student. In our experience, teaching an interdisciplinary course requires even more close observation and attention to psychology than other non-collaborative courses. Observing group dynamics during working sessions is an important evaluative tool to assess communication and learning.

CONCLUSIONS

In our experience of teaching, analyzing the course content and structure, as well as students' learning and responses, we found that the benefits of the cross-disciplinary collaborations far outweighed the courses' growing pains. Most obvious were the benefits for engineers, which included an increased comfort level in approaching open-ended problems and a marked change in their ability to communicate architectural ideas both verbally and representationally. Throughout the semester and four assignments, there was an easily recognizable change amongst the attitudes of the engineering students in the way that they presented projects, and even in the how they carried themselves.[18] Towards the end of both semesters, it was difficult for educators visiting the classes to distinguish between the architecture and engineering students when they presented their designs.[18] However, after both courses, student surveys indicated that we could have tapped the engineers' disciplinary knowledge more deeply. Both student groups felt that there was more of an emphasis on the formal and experiential qualities of their designs rather than technical efficiency.

The architecture students, in general, gained less with regards to their technical skill base; however, students were appreciative of the exposure to FEM and the opportunity to learn communication skills for their professional lives. The course could be more productive for the architecture students if they were required to analyze projects on their own, thereby gaining a more in-depth understanding of FEM software. Perhaps by incorporating an analysis of case studies, students would be exposed to the software without the additional process of design, which can be prioritized when architecture students are faced with workload choices when meeting deadlines.

Another benefit for the architecture students, although never discussed or foregrounded in the course are the skills in translating digitally designed, curvilinear forms into actual, buildable constructs. As educators in the post-digital world, we need to teach that the promise of digital design has real-world possibility, achievable through analysis, material and technological research and experimentation. "To materialize the digital world creates the chance for new arrangements and compositions of materials, so-called nonstandard constructions, which has the potential to lead to a more differentiated and appealing, as well as more resource-efficient, building culture." (p126)[14] For schools that strive to impart creativity and technical skills to produce innovative design proposals, it seems crucial to incorporate interdisciplinary collaboration to instill confidence in the formal project while placing importance on material efficiency as a consideration in sustainable design.

Perhaps the future of interdisciplinary education will look more like that of the past. As the conference brief mentions, the Werkbund was initially developed with the intent of increasing industry competitiveness. Perhaps academically focused partnerships with industry will become more the norm and will further expand upon pre-professional goals in curricula. A few examples of promising partnerships are Joe Meppelink's and Andrew Vrana's work with the University of Houston Green Building Components Initiative, which has multiple patents, and Neil Denari's UCLA studio which was sponsored by Toyota Motor Sales, Inc. and sought to develop models for sustainable suburban housing. These examples demonstrate the potential of collaborative design to pursue forward-thinking projects with real-world applicability. We hope this trend becomes more widespread. Now is the time for joyous interdisciplinary experimentation.

ACKNOWLEDGEMENTS

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ENDNOTES

1 Oxman, Rivka and Robert Oxman, "The New Structuralism: Design, Engineering and Architectural Technologies," in The New Structuralism: Design, Engineering and Architectural Technologies. AD, Volume 80, Issue 4, July/August 2010. p14–23

2 Berdoll, Barry. Bauhaus 1919-1933: Workshops for Modernity. Museum of Modern Art, 2009. p13

3 Koolhaas, Rem. "Speculations on Structure and Services," reprinted in Rethinking Technology: A Reader in Architectural Theory. Ed. William Braham and Johathan Hale. Routledge: London, 2007. P354-357

4 NAAB: Integrated Practice Skills and Knowledge Teaming:
7b. Interdisciplinary Collaborative Skills - Ability to work on interdisciplinary design teams in collaboration with other disciplines to successfully complete integrated design projects.

5 Smith, Robert. "2009 and Beyond: Revisiting the Report on Integrated Practice: Suggestions for an Integrative Education." http://www.aia.org/about/initiatives/AIAB082222. Smith paraphrases Renee Cheng in her comment that "…more and more students all across the country are working on design projects in teams – which has been a big change in the past few years."

6 In a survey of architecture programs (cited in Table 2, p43 of the following article), 4 out of 54 had some form of interdisciplinary coursework.
De La Harpe, B., Peterson, J. F., Frankham, N., Zehner, R., Neale, D., Musgrave, E. and McDermott, R. (2009), Assessment Focus in Studio: What is Most Prominent in Architecture, Art and Design?. International Journal of Art & Design Education, 28: 37–51. doi: 10.1111/j.1476-8070.2009.01591.x

7 Bucciarelli, L. and Kuhn, S. "Engineering Education and Engineering Practice: Improving the Fit," Between Craft and Science: Technical Work in U.S. Settings, S. Barley, & J. Orr (Eds.), Ithaca, NY: Cornell University, 1997, pp.210—229.

8 Felder, Richard M. "Learning and Teaching Styles in Engineering Education," Engineering Education, Vol 78(7), 1988, pp. 674-681.

[9] ABET Criteria for Accrediting Engineering Programs, 2010-2011. Criterion 5: Curriculum, p4

10 Todd, R. H., S. P. Magleby, C. D. Sorensen, B. R. Swan and D. K. Anthony, "A Survey of Capstone Engineering Courses in North America," Journal of Engineering Education, Vol. 84, No. 2, 1995, pp. 165-174.

11 Observations of author, as well as discussions with other engineering faculty.

12 Bechthold, Martin. "On Shells and Blobs: Structural Surfaces in the Digital Age," in Fabricating Architecture: Selected Readings in Digital Design and Manufacturing. ed. Robert Corser. Princeton Architectural Press: New York, 2010. p168-177

13 For a more detailed description of the course, see, for example, C.J. Olsen and S.C. Mac Namara, The Value of Collaborative Design Education for Structural Engineers and Architects, 2011 ICEE Conference on Engineering Education, University of Ulster Belfast, Ireland, August 21-26, 2011.

14 Kloft, Harald. "Engineering of Freeform Architecture," in Fabricating Architecture: Selected Readings in Digital Design and Manufacturing. ed. Robert Corser. Princeton Architectural Press: New York, 2010. p110-127

15 It should be noted that the translation between Rhino and SAP was not self-evident. In some cases where models had been trimmed in Rhino, considerable rebuilding was required in the SAP environment in order to replicate the desired form. If continuing to teach the Rhino platform, recent developments in the Rhino plug-in Scan & Solve may prove invaluable when similar collaborations are taught in the future.

16 S.C. Mac Namara, C.J. Olsen, Scott L. Shablak, Carolina B. Harris, Merging Engineering and Architectural Pedagogy - A Trans-disciplinary Opportunity?, 2010 ICEE Conference on Engineering Education, Silesian University of Technology, Gliwice, Poland, July 18-22, 2010

17 For example, in the first assignment in Shell Structures, we asked for five connected shells with specific square footages, but the site and program (type of function or activity of the space) were abstract and materiality was ambiguous.

18 Observations from Scott Shablak and Carolina Harris, project leaders for the evaluation component of the NSF grant.