2006-1096: “PUTTING A FENCE AROUND” ARCHITECTURAL ENGINEERING UNDERGRADUATE RESEARCH PROJECTS

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"Putting a fence around" architectural engineering undergraduate research projects

Background and Literature Review:

The purpose of this paper is to provide practical suggestions of how to design and most importantly, how to limit the scope of proposed projects such that that an architectural engineering student can successfully participate in undergraduate research. Throughout the paper, the pedagogical benefits of such research projects will be emphasized. This paper will provide ideas and encouragement to faculty who may be hesitant to undertake research with undergraduate students. The paper closes with several successful case studies.

Several studies have pointed out the benefits of the undergraduate research experience. Gates et al. found that participation in research helps undergraduate students attain a higher level of competence in science and mathematics. They also found that lifelong learning skills such as teamwork and improved communication are strengthened by the undergraduate research experience[1]. The Boyer Commission Report has encouraged educators to re-evaluate traditional practices by specifically urging that faculty "make research-based learning the standard" for the education of their undergraduates[2].

Zydyney et al. summarized findings of surveys eliciting satisfaction of undergraduate researchers. Some surveys found significant improvement in technical skills, problem-solving skills, and professional self-confidence; others did not. But Zydyney did conclude that undergraduate research was hugely influential in pursuit of a graduate degree[3]. Of those respondents who pursued a doctoral degree (57 in total), more than 87% had participated in undergraduate research while at the university. An earlier study by Jemison et al.[4] similarly found that undergraduate researchers were more likely to attend graduate programs.

Zydyney et al.[5] conducted a second study regarding faculty perceptions of undergraduate research. The most significant factor motivating faculty to involve undergraduates in their research programs was the desire to influence the careers of talented young students. This desire to work with and help aspiring undergraduate students is noble and altruistic. If junior faculty can mentor such projects with a resulting attainment, (for instance a refereed paper or conference proceeding), such research is truly a "win-win" situation. This paper will suggest methods of reaching this noble goal.

One set of beneficial guidelines has been provided by Thompson et al. in their very interesting and highly structured approach for teaching undergraduate researchers to participate in "authentic written oral, and graphical communications" [6]. The goal of these formal group structures is to encourage undergraduates to pursue research, and to foster an encouraging and supportive atmosphere for these undergraduate researchers. Undergraduate institutions would do well to implement at least some of these practices, for instance weekly update roundtable meetings, scheduled poster presentations and the like.

Another set of findings on undergraduate research was reported by Sanford Bernhardt and Roth[7] who concluded that:

- Both students and faculty are most satisfied with one-on-one mentored research experiences.
- Faculty members are least satisfied with Independent Study research experiences.
- Faculty members should be careful both with selecting projects and selecting students.

This is telling because ***selectivity*** is highlighted by their award winning paper. Selectivity, or "putting a fence around" undergraduate engineering research projects is the focus of this paper. Such selectivity or delimiting of projects is critical to a successful experience for both the faculty member and the student.

Before discussing these items in detail, it may be helpful to itemize what does not constitute a research project. Senior design projects such as capstone projects typically are not considered research, since they usually work on a design problem that can be otherwise classified as large, complicated class assignments. A word of caution is called for when setting up undergraduate research projects that would probably take more than two semesters of work; projects that could reasonably be considered to be master thesis work; projects that involve much pure theoretical mechanics. Such projects are hugely important and meritorious, but the mentor should be prepared for a long term commitment with the student in these cases. Ideally, if a junior level student could be found to take on such projects, then the relationship could carry over to his or her senior year. More will be said about identifying such students later in this paper.

Suggestions for delimiting projects:

The following suggestions are guidelines that may help faculty members in delimiting architectural engineering undergraduate research projects:

1. *The student should have a clear understanding of the goals of the project and a well defined list of what constitutes a finished project.*

This clearly requires planning on the faculty member's part. While this item may seem obvious, it is easy to avoid actually writing down a list of attainments that would constitute a finished project. Yet, articulating such a list is important for the faculty mentor when designing the project, and of course the list is extremely useful to the student. For example, if the project is a finite element model of a historically significant structure, a list may entail:

- a coarsely meshed model to capture global behavior

- a refined mesh in areas of interest
- a report summarizing behavior at particular locations
- a list of areas needing future study by subsequent students

Weekly meetings with the student should always touch on the "big picture" of where the week's work is in relation to the final goal.

2. *The student should take some ownership of the project.*

Again, this may seem obvious but the subtlety here is to have students accept projects that they are at least reasonably interested in. To better ensure student ownership, the faculty member may need to recruit potential candidates. This can happen even during 2nd year mechanics courses. Bright eager students can be readily identified, and informal discussions about your own research will elicit obvious responses (either positive or lukewarm) in the student. Another vehicle for helping promote student interest is to give the student options within a theme. For example, I recently recruited a student to work on the study of the historically significant thin shell masonry structures by the Guastavino's. I gave the student the choice of either going through archival material, or looking at constructability issues, or researching the folk tradition in the Catalan region of Spain, where this method originated. The student chose the last option, because he is a native speaker of Spanish and is interested in studying that region.

3. *At the undergraduate level, analysis problems are much easier to work on than more open-ended structural mechanics problems.*

Parametric studies are an excellent choice for undergraduate research. Undergraduate students are capable of refining existing computer models of structures to do parametric studies, and usually they can create models themselves which they can then modify. Another example of a delimited analysis research problem is to have the students run models with and without nonlinearities, to quantify the effects of the nonlinear capabilities. Students can also modify structural models to research the limits of when simplified Uniform Building Code (UBC) seismic rules are valid. Or, students can research the difference between wind provisions in the International Building Code (IBC), the American Society of Civil Engineers (ASCE/7), and the UBC. All of these examples fall under the rubric of prescribed analysis problems, yet they also constitute valid research projects. Note that some of the mentioned examples may qualify as senior capstone projects, but it is easier to envision them as research projects. The difference is that capstone projects are typically wider in scope, and they tend to summarize several undergraduate courses.

4. *The faculty mentor may try to complement the student work, rather than supplement it*

It is natural to want to supplement the student's research. Inevitably, some of the research must involve the mentor's direct contributions and such supplements will be necessary to get research into a journal publication format. What is being suggested here however, is that during the semester of work, the mentor must allow the student's work to be truly his or her own. An elegant way of fostering this is for the faculty mentor to work on a complementary portion of the project. For instance, the mentor could work on computer models of a structure, if the student is responsible for experimental work on the structure. Or, the mentor could work on theoretical behavior if the student uses a commercial structural analysis program. Or the mentor could work with one finite element program, while the student could be working with a separate piece of software to verify or to gain new insights into the structural behavior being investigated. Yet another example is having the student perform seismic analyses on a model that you or another student had previously created. All these examples allow the student and the faculty member to work, more or less, in parallel.

5. *If you have a senior colleague at another institution, or at your own institution, consider partnering with him or her in mentoring their student.*

The benefits of this practice are clear. You immediately can become part of a team, increasing your productivity without inventing a whole new project from scratch. You can limit your involvement to a practicable level, since the student is primarily being mentored by your colleague. In this setup, you can also clearly supplement the student's work, since you won't necessarily be involved in one-on-one mentoring of him or her.

6. *Some projects will result in attainments such a publications, other projects are focused on having students be inspired by the undergraduate experience. Junior faculty members must be judicious in selecting such projects due to their limited time.*

This topic was briefly discussed in the literature. There should be an overarching concern that the student profits intellectually from the research experience. This is the basis of the Boyer Commission's recommendations, since such research experiences are hugely beneficial to undergraduates. The excitement of one on one research with faculty members has been shown to greatly encourage students to seek graduate degrees. These student/faculty interactions are at the heart of successful undergraduate teaching. Yet junior faculty members are always pressed for time and may be reluctant to work with undergraduates. If the goals of the project are clearly stated up front, then it becomes easier to evaluate the potential for the project to be published. Thus it is important to weigh the tangible benefits (publications) as well as the intangible benefits (good will, helping out a student) when deciding whether or not to accept such mentoring roles.

Suggestions for selecting projects:

Thus we arrive at a number of workable suggestions for architectural engineering faculty and student research. This list is not meant to be exhaustive or complete. These are items that either I have been able to study with the help of undergraduate researchers, or that I consider reasonable, potentially publishable projects.

- parametric studies of engineering mechanics problems
- analysis of historically significant structures
- applying new tools (i.e. finite element analysis, push-over analyses, nonlinear analysis) to traditional, archived calculations
- research in archives for historically significant calculation, drawings, building conceptions/development
- analyzing the rise and fall of certain construction practices, for example thin shell construction, with respect to labor cost, office practice, architectural taste

- constructability of new forms (tensile fabric structures, straw bale, reinforced adobe, shredded tire)
- constructability of old forms with new materials, i.e. composites

I conclude with several case studies that exemplify some of the points previously discussed.

Case 1: Finite element modeling of thin shell masonry arches.

This was a one semester project for a senior student. The student was given the task of using the spreadsheet EXCEL to create meshes for the finite element program ANSYS. EXCEL was used since we were doing a parametric study on various aspect ratios of arches (rise to width). To manually create the many meshes would have been tedious. EXCEL was a natural tool to use. I supervised the actual analyses, but the student was able to work independently practically the entire semester and she really enjoyed the project since she was a very detail oriented and meticulous student. The work was eventually part of a published conference proceeding [8].

Case 2: Buckling of cooling towers.

This was a two semester project. The student in this case was a dual major, civil engineering and mathematics. The student was brilliant and quickly took ownership of the problem. His mathematical work went far beyond my area of expertise, consequently that portion was mentored by a colleague in the math department. The work that I mentored was a finite element buckling analysis of hyperbolic paraboloid cooling towers. I showed the student how to create the models and how to run the analyses. Since this was a two semester project, I felt it was a good investment of my time to initially walk him through the intricate steps. Soon, he was able to run analyses with little assistance needed from me. The work we did got published in a conference proceeding[9]. This project had the additional bonus of working with a colleague in another department.

Case 3. Analysis of a historically significant thin shell structure.

This was a fairly complicated project that was a follow-up to a previous study of the work of the master designer Anton Tedesko[10]. In this study, I had the able assistance of a student who worked for me the summer between her sophomore and junior year. We worked together combing through archival material, and creating a computer model of the structure we were researching. The project has carried over to the student's junior year and we have collaborated on a journal article which will soon be published [11]. This project also relied heavily on collaboration with my own mentor, at another university.

Case 4. Combining structural analysis with aesthetic critiques.

This project was a true collaboration. I worked with my mentor's student and I complemented his excellent structural analysis work with my own aesthetic critiques of several historically significant structures. My mentor then brought in his own ethical insights, thus we had three people working very much in parallel. This project was complicated because it was initially unclear how each party would contribute. But frequent communication involving “brainstorming sessions” allowed us to explore various options and ultimately resulted in a valuable paper. We will present this work at the ASCE Architectural Engineering Conference in the summer of 2006[12].

Conclusions:

While previous literature has explored some of the benefits of undergraduate research, this paper has outlined some practical suggestions of how to design and limit the scope of such projects within the discipline of architectural engineering. Throughout this paper, emphasis has been placed on framing such a project with the hope of a publication emanating from the research. This is especially important for junior faculty members who are so greatly pressed for time. The other benefit of tangible attainments is that they heighten the prestige of the undergraduate research program, which consequently enlarges the pool of capable and interested student researchers. Another important outcome of these projects, regardless of whether or not there is a publication, is that the students greatly benefit from the research experience. They enjoy working one on one with faculty members, they get more excited about their chosen profession and oftentimes, they go on to pursue graduate degrees. These outcomes are among the most satisfying experiences one can have as a mentor.

References:

(1) Gates, A., Teller, P., Bernat, A., Delgado N. and Kubo Della-Piana, C. (1999) “Expanding Participation in Undergraduate Research Using the Affinity Group Model”, Journal of Engineering Education, Oct., 409-414.

(2) Boyer Commission on Education of Undergraduates in the Research University. 1998. *Reinventing Undergraduate Education: A Blueprint for America’s Research Universities*. New York.

(3) Zydyney, A., Bennett, J., Shahid, A. and Bauer, K. (2002) “Impact of Undergraduate Research Experience in Engineering”, Journal of Engineering Education, April, 151-157.

(4) Jemison, W., Hornfeck, W. and Schaffer, J. (2001) “The Role of Undergraduate Research in Engineering Education”, Proceedings of the 2001 American Society for Engineering Education Annual Conference and Exposition.

(5) Zydyney, A., Bennett, J., Shahid, A. and Bauer, K. (2002) “Faculty Perspectives Regarding the Undergraduate Research Experience in Science and Engineering”, Journal of Engineering Education, July, 291-297.

(6) Thompson, N., Alford, E., Liao, C., Johnson, R. and Matthews, M. (2005) "Integrating Undergraduate Research into Engineering: A Communications Approach to Holistic Education", Journal of Engineering Education, July, 297-307.

(7) Sanford Bernhardt, K. and Roth, M. (2004) "Undergraduate Research: The Lafayette Experience", Proceedings of the 2004 American Society for Engineering Education Annual Conference and Exposition.

(8) Saliklis, E., Kurtz, S. and Furnbach, S. (2003) "Finite Element Modeling of Guastavino Tiled Arches", Proceedings of the Eighth International Conference on Structural Studies, Repairs and Maintenance of Heritage Architecture, Halkidiki, Greece, pp. 257-266.

(9) Saliklis, E., Billington, D. and Tregger, N. (2004) "Buckling Studies of the Trojan Tower" Proceedings of the Fifth International Symposium on Natural Draught Cooling Towers, May 20-22, Istanbul, Turkey, 115-120.

(10) Saliklis, E. and Billington D. (2003) "The Hershey Arena: Anton Tedesko's Pioneering Form", ASCE Journal of Structural Engineering (129)3, 278-285.

(11) Saliklis, E., Billington, D. and Carmalt, A. (2005) "The Refinement of an Idea: Tedesko's Philadelphia Skating Club", accepted for publication in the ASCE Journal of Architectural Engineering.

(12) Saliklis, E., Billington, D. and Bauer, M. (2005) "Scale, Simplicity and Surprise: Evaluating Structural Form", accepted for presentation at the ASCE Architectural Engineering Conference, July 2006, Nebraska.