Networking to Advance Undergraduate Engineering Research and Achieve more Balanced EC2000 Outcomes

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Everyone who has been part of an accreditation review under EC2000 would agree that ABET's stated objectives that the accreditation process *"(2) stimulate the improvement of engineering education; (3) encourage new and innovative approaches to engineering education"*[1] are being well served by program assessment under EC2000. In particular, those faculty who strive to make engineering curricula more authentic by using open-ended problems in classes and embedding inquiry-based learning in course labs and projects know that they are helping students to develop knowledge and skills that variously include *"(b) an ability to design and conduct experiments, as well as to analyze and interpret data; (d) an ability to function on multi-disciplinary teams; (f) an understanding of professional and ethical responsibility; (g) an ability to communicate effectively; (h) the broad education necessary to understand the impact of engineering solutions in a global/societal context; (i) a recognition of the need for and an ability to engage in life-long learning; (j) a knowledge of contemporary issues;"*[1] in a way that traditional lecture-homework-exam instruction formerly supported only sporadically. And while one can still reasonably argue about the implied scope or relative importance of these Criterion 3 outcomes, Undergraduate Research, broadly construed to encompass all inquiry-based teaching from open-ended classroom problems to self-directed research theses, can be an effective means of achieving many of them.

But Undergraduate Research is more than a teaching tool or instructional vehicle. It is also a means of introducing young engineers to the processes of discovery and design that accompany the search for new technological tools and the drive to solve persistent and difficult problems, and simultaneously a means of advancing the professional, disciplinary and institutional careers of faculty who enable and supervise undergraduate student researchers. This paper is about how networking among engineering faculty involved in undergraduate research can serve to advance both their educational effectiveness and personal career interests.

Networking is a trendy and overused word. Nevertheless, it properly describes the variety and extent of contacts and connections used by faculty who are successful at conducting research with undergraduates. Much effort goes into establishing and maintaining such connections, and few faculty members start off with a skill set adequate for the job. Mentoring by more experienced colleagues is a traditional way to transmit the necessary skills and information, but faculty at small and/or entirely undergraduate institutions often lack access to an effective mentor in their field of interest. Collaboration and mutual self-education with local colleagues is another way, but most departments at small schools are well below critical mass for ready collaboration, except in cases of interdisciplinary work. So what alternatives are there for faculty in such circumstances?

Three general avenues exist for making and keeping contacts with potential mentors and research colleagues: these are professional disciplinary organizations, such as ASME or IEEE; multidisciplinary organizations like ASEE, SAE or NCIIA; and mutual-assistance or cooperative organizations, of which CUR is a good example. These differ substantially in relevance to and usefulness in support of undergraduate research.

Professional disciplinary organizations are typically organized in at least two dimensions, of which the one is local operational function and the other professional sub-discipline. Because the engineering profession is centered primarily in industry, where Continuing Education in technology and/or management is the primary tool for members' career development, Education and Career Development are often a combined local function. So whether a separate function or a subset of Education, College/University Relations activity is directed chiefly toward students as future employees of senior members' firms. Seldom is there any recognition that career development for organization members who are college or university *faculty* typically follows a very different path from that of industrial members. So faculty pursuing undergraduate research must cultivate and maintain industrial and academic member contacts in local chapters of professional organizations *on their own initiative* to discuss potential research topics suitable for exploration with the assistance of undergraduates - and sometimes to solicit equipment donations from local industry.

Multidisciplinary organizations in Engineering typically focus on a particular industry, such as SAE for the transportation vehicle industry or ACI for the concrete industry. These usually have local chapters only in areas where the relevant industry is heavily concentrated, and are nationally structured along product, application or process lines. They typically also have national-level cross-cutting functional units like Education, Research, Information Services or New Product Development. Faculty networking within these organizations usually occurs via attendance at national conferences and by participation on technical committees that develop application codes or material and process standards - an important activity in our market-driven economy. These organizations usually have very strong industrial bases that employ many engineers, and several sponsor annual undergraduate student design competitions that can serve as excellent vehicles for team and/or capstone design projects that address challenging problems under real constraints of time and budget.

A number of industry-based multidsciplinary groups that are organized around a particular class of industrial material or process also advertise grants to faculty for research that addresses topics of continuing concern or that holds promise of expansion into new markets. Such grants offer faculty and their students the opportunity for a more traditional, extended research experience, with adequate time to reflect on alternative approaches, design of experiments, interpretation of data and the technical and societal significance of findings. While undergraduate faculty are at some disadvantage in proposing such research unless their laboratories are particularly well-equipped by virtue of ongoing graduate research activity, faculty who are willing to pursue research on industrially-significant topics that "fall in the cracks" among higher-priority R&D goals can use these sources to develop a program of specialized, frequently methodological research work as a means of steady support for undergraduate research effort.

The sole multidisciplinary organization focused on engineering education is ASEE, which is primarily devoted to advancing the collective professional interest of engineering students and faculty. Because it is very large, ASEE's organization is quite complex. It includes multidisciplinary regional units, and both national disciplinary divisions and cross-cutting functional units addressing instrumentation, laboratory-oriented studies, liberal education, entrepreneurship, libraries and freshman programs among others. For faculty doing undergraduate research, there is a wide range of opportunity to network casually through ASEE, either with colleagues in similar disciplines or on similar applications. Nevertheless, the organization's focus is on advancing the quality of educational program content and delivery, and not on research *per se* or as a primary means of promoting educational achievement or faculty career development. Notable exceptions are the programs of summer faculty research fellowships administered by ASEE for NASA and the US Navy, and a Navy-sponsored faculty sabbatical research program. Yet none of these involve research with undergraduate students at the faculty member's home institution. Faculty who want to promote such ongoing undergraduate research at their home institutions must look elsewhere for organizational support.

The National Collegiate Inventors and Innovators Alliance, an initiative of the Lemelson Foundation, is a relatively young organization whose goal is to reinvigorate US higher education with the spirit of entrepreneurship by funding courses, program development and faculty-mentored student team projects that focus on bringing new products to market. NCIIA offers funding not only for so-called E-Team projects, but also for the market research and legal professional services needed to properly assess and protect the value of intellectual property that students and faculty mentors may develop with its sponsorship. Inasmuch as product development very frequently involves applied research and sometimes even basic research, NCIIA's funding programs, annual conferences and workshops offer all faculty (not just engineers and business school types) who are involved with market-driven kinds of undergraduate research an opportunity to interact through competition for project funding, through collaboration in conference presentations and through attendance at summer workshops. Yet as vigorous and educationally relevant as it is, NCIIA's work is focused on entrepreneurship, not on research *per se* or on faculty or student career advancement through research.

There is, however, one multidisciplinary organization devoted entirely to the advancement of undergraduate research, both as an educational modality and as a means for faculty career advancement. That is the Council on Undergraduate Research, established as a membership organization in 1978 and presently comprising seven disciplinary divisions spanning the sciences, mathematics and engineering. Quoting CUR's "about" webpage <www.cur.org>, its mission is "to encourage science, engineering, and mathematics research involving undergraduate students at primarily undergraduate institutions." It "seeks to strengthen undergraduate science, mathematics, and engineering education through faculty-student collaborative research combined with investigative teaching strategies." CUR "provides avenues for faculty development and helps administrators to improve and assess the research environments of their institutions."[2]

CUR is an organization of more than 3000 faculty from primarily undergraduate schools whose joint purpose is to jointly promote collaborative research by undergraduate students and faculty. Within eight divisions and across eleven functional committees, research-active faculty and research-sympathetic administrators work together to improve funding opportunities for undergraduate faculty and student research and to provide mentoring, advisory and assessment services to its individual and institutional members.

Because it originated among chemists, then added biologists and only recently (1998) initiated an engineering division, CUR is not well-known across the engineering faculty community, and that is one reason for this paper and presentation - outreach by CUR to ASEE members. But the main motivation is to encourage engineering faculty at primarily or entirely undergraduate schools who use collaborative research with students as an educational and/or career development tool to be aware of the opportunities that exist in CUR to network with others in support of those goals and their own research efforts. The relatively well-known Research at Undergraduate Institutions (RUI) and Research Experience for Undergraduates (REU) programs of NSF's Division of Undergraduate Education (DUE) were first established in response to effective joint lobbying by chemistry faculty from primarily undergraduate institutions - who later became CUR's founders.

Like ASEE, CUR is a member-service organization that has a minimal headquarters staff in DC and relies almost entirely upon volunteer effort to create and administer its programs. It mounts a biennial conference in June of odd-numbered years that usually concludes the day before the ASEE Annual Conference begins. CUR conferences focus on the processes of starting, growing, maintaining and assessing programs of undergraduate research by faculty with student collaboration, and of promoting research as a teaching modality in undergraduate science, math and engineering education. CUR also sponsors an annual undergraduate student research poster day on Capitol Hill for Congress members and staff, and a separate April Dialog day of workshops for faculty with federal and private funding organizations.

Networking - among research-active faculty at primarily undergraduate institutions (PUIs) - is what CUR is all about. While its members are mostly scientists, it welcomes new engineering members and invites them to share the work of advancing and advocating undergraduate research for faculty career development and for students' more effective and complete education.

So much for opportunites to network in support of undergraduate research. Now for the second part of this paper: undergraduate research as a means to achieve more balanced EC2000 educational program outcomes.

From the student's point of view, *Research* is what you do whenever the answer's not in the back of the book: solve your problem using an appropriate and hopefully effective combination of all the knowledge and tools at your disposal. But from a curricular standpoint, much of what student research involves can be summarized by the subset of EC2000 Criteria 3a-k quoted earlier: *"(b) design and conduct experiments... analyze and interpret data; (d) function on multi-disciplinary teams; (f) understand professional and ethical responsibility; (g) communicate effectively; (h) understand the impact of your solution in a global/societal context; (i) recognize the need for and engage in life-long learning; (j) know contemporary issues;"*[1]

This is **not** the complete list of 3a-k criteria, but rather a selection that includes some outcomes that are notoriously difficult to achieve in a conventional classroom or complementary lab-course setting, chiefly because they involve interaction, discussion, argument and reflection over time rather than a one-shot or progressive one-way transfer of facts or proven methodology. Nor can one claim that undergraduate research experience will, on its own, achieve all the 3a-k or even the foregoing subset b-d-f-g-h-i-j of outcomes. But it can help engineering faculty to address that subset more effectively. How effectively depends strongly on how much time for geniune student inquiry - most of which will occur outside of scheduled class or lab - one can build into one's undergraduate program.

Most important changes start small. Faculty can capture the essence of research as investigative learning, even within the confines of a lecture course, simply by not replicating textbook derivations in front of a class - and instead using the time to pose "what if?" questions for students to work on in groups after having done or distributed a demo problem for them. One can ask "what if" and "what else" questions as part of homework problem sets; assign "what's important about this" or "how does this relate to" essay(!) questions as homework; distribute news articles and photos and ask those same questions about them in class. If you have a weekly recitation or lab session as part of a course, you can conclude each session with a few "what if" or "why/why not" questions to be written up and discussed for ten minutes at the start of the following week's session. Or have each lab group develop and present a single consensus response within another five minutes. And don't be surprised if you discover that the group gets together on their own time to thrash out a joint response for next week's session.

In an upper-division elective, using half of the scheduled lab sessions for the conduct and reporting of individual or group research projects is a great way to have students "get real" about their work and begin to appreciate how much extra effort has to occur outside each lab session in order to use that session time effectively. You will have to "let go" of some former content and perhaps some instruction in technique to make time, but your students will retain much more of what they develop and do themselves, and they will come out ahead, partcularly in terms of setting their work within a larger techical or societal context. They'll be vastly more aware of what it takes to get closure on a project and to present their findings effectively. You can also help them learn about peer review by having them fill out critique sheets for all oral presentations, poster presentations and written reports for immediate return to presenters and authors as an independent complement to your own assessment and evaluation. A valuable bonus is the greater variety of course-related topics and current technical issues that your students will acquire some knowledge about while learning their role as a responsibly critical audience of professional peers.

Finally, there are institutionally pre-approved ways to provide course credit as an incentive to undergraduate engineering research during the academic year. In most programs' course catalogs there appear catch-all upper-division electives like *Directed Reading, Independent Study* and *Thesis*. Students who are sufficiently motivated can propose and pursue individual or group investigative study under one of these elective options that includes some combination of literature review, problem definition and analysis, laboratory experimentation, data reduction, analysis and interpretation or design synthesis with weekly faculty supervision or coaching. To what degree their work is collaborative with your own faculty research, how much time you spend consulting with them each week, and specified deadlines, deliverables and evaluation standards can be set by prior negotiation. You can also require specific attention to whichever of the 3b-d-f-g-h-i-j topics you and your students think are strongly relevant to their subject. Under such full-course rubrics, you can enable students to have a varied and authentic research experience as part of their degree program that will not only improve their knowledge and skill bases but also contribute strongly to their achievement of the more challenging EC2000 program outcomes and strengthen their confidence as contributors to the advance of the engineering profession.

The downside of the elective-course research experience is that, unlike smaller inquiry-based modules in required courses, it cannot reasonably be made available to all students, unless your department has a policy of requiring a research or project experience that is distinct from a capstone design project. That is the tradeoff for getting reasonably competent student collaboration with your own program of research - not every student has the interest, skills and curricular flexibility to become an effective undergraduate researcher.

Traditional summer research collaboration of faculty and students, while every bit as productive and educational as academic-year experiences, is not generally required or included within degree requirements, so while it provides all of the benefits discussed above, it cannot routinely be considered as contributing to a program's claimed EC2000 outcomes. If, however, each student's summer experiences can be routinely documented, submitted for assessment and evaluated by engineering faculty under a locally institutionalized and periodically reviewed process, there is no *a priori* reason why the associated outcomes, whether or not rewarded by program credit, cannot be included among those claimed for its students by an engineering degree program.

For each of the past five years, the author has coached teams of engineering (and, more recently, economics and psychology) majors working on joint market research and product (*not* software) development projects under *Senior Design Project* and *Special Topics* course rubrics. In working with these teams, he has used ideas and techniques picked up over years of networking with colleagues in ASEE, CUR and NCIIA to considerable effect. Students describe these largely self-directed experiences as the most arduous, intense and exciting work they have yet attempted as young professional people. They also begin to recognize that engineering does not exist in a cultural or societal vacuum, and that everything they do - well or otherwise - throughout their careers will have some effect in the larger world. Ultimately, that recognition is the best outcome of all.

The following two pages are heavily edited versions of a project course description and EC2000 outcomes matrix prepared by the author in 1998 for a program Self Study Report; references to local program goals have been deleted in the interest of generality - and brevity.

1. Course Title: **Research Project**

2. Catalog Data: Under the guidance of a faculty member, students investigate a problem in an area of interest to them. A formal written report and an oral presentation are required.
Offered as student interest and faculty availability permit

3. Prerequisite: Junior or Senior standing in Engineering.

4. Textbook: none Reference: Martin, J. Campbell, *The Successful Engineer: Personal and Professional Skills - a Sourcebook*, McGraw-Hill, 1993. ISBN 0-07-040725-8

5. Course Objectives: To give Engineering students the opportunity to select, plan, execute, complete and report a significant open-ended project intended to confront and, if possible, solve a significant problem of interest to them under the guidance of an Engineering faculty member. See Course Outcomes Matrix.

6. Topics Covered (actual experiences):
Selecting a problem of interest within one's range of competence and of suitable scope
Preparing a pre-proposal letter of intent
Drafting, revising and submitting a finished project proposal, including critical path diagram, activity schedule and bill of materials/equipment list
Executing the project and reporting weekly on progress and problems
Overcoming difficulties and/or adjusting project scope for setbacks encountered during execution
Preparing a draft project report and revising it with supervisor's criticism
Preparing a final formal report and an archival (with addenda as appropriate) version
Preparing, practicing and delivering a final oral presentation and project defense
Decommissioning a project setup as appropriate.

7. Class/Lab Schedule: At least weekly meetings during the semester for a total of at least 20 hours of face-to face discussion and assessment. Participants are each expected to spend at least 170 hours on the project, exclusive of advisory meetings and presentation rehearsals.

8. Professional Component Contribution:
Students are successful to the extent that their projects: 1) integrate material from their course preparation and demonstrate competence in math, science, engineering and the liberal arts, 2) adequately consider EC2000 Criterion 4 impacts and constraints, and 3) demonstrate their achievements with respect to EC2000 Criterion 3 categories and local Engineering program objectives as appropriate to their particular topic.

9. Relationship to Program Objectives
- Analytic work contributing to the project design activity reinforces analytic proficiency.
- Problem definition, project planning and monitoring, and synthesis and evaluation of the solution relative to original specifications or goals demonstrates synthesis/design proficiency .
- Background research into related prior problems and solutions, defining the present project needs and benefits of the desired outcomes, and evaluating the actual project outcomes, particularly indirect ones, all reinforce two-way connections between the engineer and society.
- The full range of project selection, planning, proposal preparation and justification, weekly progress reports and advisory conferences, draft and final report preparation and, ultimately, formal oral presentations *significantly* improve communications skills.
- Being responsible for the entire planning and prosecution of this open-ended project is not only a demonstration of competence but also a personal and a technical challenge that students work steadily to meet.

10. Prepared by: John A. Doe Date: Just in time

Engineering Project - Course Outcomes Matrix

Specific Outcome or Skill	How Acquired	How Assessed and Evaluated	ABET 3 categories
Can select a project topic/problem within his/her capabilities and propose a project to address/solve it	Joint student-faculty meeting and discussion with potential advisor	Discussion with advisor and review of letter of intent	a b c e g h j k
Can draft, revise and submit a project plan/schedule including a literature search, Critical Path analysis and appropriate equipment and materials lists	Reading the literature and references; discussion with advisor	Review of draft and final proposals by advisor	b c e f i k
Can organize, pursue and document a project in a safe, responsible and professional manner, and adjust to difficulties/setbacks in appropriate ways	Regular work schedule, safety advice from tech, and submission of progress reports	Weekly review of reports in meetings with advisor	a b c d e f g k
Can organize and draft a technical report that includes proper documentation, presentation and analysis of experimental data and/or other findings	Preliminary writing and review with peers and with advisor	Critique of draft report by advisor and discussion with student at weekly meetings	a b c e g k
Can produce a formal technical report that properly presents, documents and assesses project results in appropriate style and format	Review of draft report and editing of /addition to content; checking of format and graphics	Review of final report by advisor prior to final presentations	a b c e f g h k
Can organize and deliver a formal technical presentation of the project conduct and findings to an audience of peers and supervisors	Preparation and practice with criticism from peers and advisor	Multi-day formal presentations with Q&A and critique by advisor and faculty	b e f g i j k
Can decommission a project setup in a safe and orderly manner	Personal effort with advice from technician and advisor	Review by advisor; not formally evaluated	a e f g k

Note: If a project in the joint effort of several students, then ABET Criterion 3d also applies to all listed Outcomes.

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There is only one inevitable downside to all these means of facilitating research by and for undergraduates: they almost always take more faculty time and effort per student credit-hour than conventional classroom teaching, particularly when you must train new student researchers in the use of specialized equipment or software. You as faculty researcher, collaborator or mentor must decide whether the difference in outcomes, both for the students and for yourself, is worth the additional effort. Ultimately, networking with your faculty peers at other institutions will help to increase the return on that investment.

References:
1) Engineering Accreditation Commission, Accreditation Board for Engineering and Technology; Criteria for Accrediting Programs in Engineering in the United States; see <http://www.abet.org/downloads/2001-02_Engineering_Criteria.pdf>
2) Council On Undergraduate Research, 734 15th Street N.W. Suite 550 Washington, D.C. 20005; extract from <http://www.cur.org/about.html>; see also <http://www.cur.org/membership.html>

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