Something for Everyone via NCIIA E-Team Development Projects - Introducing Innovation and Entrepreneurship to Students, Augmenting your Design Lab Budget, and Exploring Parallels between Design Innovation and Program Assessment.

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Abstract

This paper looks back over three successive NCIIA-sponsored product development project courses, discusses some positive outcomes for faculty and student participants, and draws some parallels between background research, problem definition, specification setting, project planning and evaluation phases of a project-based design course and analogous stages of information gathering, program description, goal and outcomes identification, performance measurement and evaluation that comprise an engineering program assessment task. NCIIA-designated level I, II and III projects are covered, including both embedded laboratory modules and full semester efforts. Students not only benefit from interdisciplinary interaction among and outside of engineering fields, but also get to specify, acquire, use and evaluate components and equipment items not commonly found in many undergraduate labs, particularly at smaller institutions. In developing their own project plans, reports and proposals for further support, student entrepreneurial teams gather, evaluate and interpret both technical and market information using processes that surprisingly resemble those that engineering faculty must now learn to assess the state of existing engineering programs and plan for continuous improvement under ABET EC2000. Both sets of tasks involve conceptual integration at a higher level than is usual in undergraduate engineering education, but is more commonly practiced in the liberal arts.

1. Product Development as Design Instruction

Providing authentic instruction and experience in design-based engineering entrepreneurship is always a challenge. Set-piece design innovation problems may be new to individual students, but they cannot incorporate the same technological uncertainty and economic risk as a real product development effort, nor can they serve as a basis for truly open and spontaneous interaction between students and outside resource-people expert in marketing and market research, patents and intellectual property, venture capital, etc. - these consultative processes degenerate into role-playing after the first iteration of any given problem. Industrially-sponsored engineering clinics provide real tasks and more realistic interaction with experts, but the tasks are almost never crucial to the sponsor's business success. Because decision-making authority and budgetary control ultimately rest with the sponsor, students are insulated from entreprereurial angst. Only when students themselves have control of project funding and schedule and are entirely responsible for the deliverables is their entrepreneurial experience

nearly real and their learning best reinforced. But how can faculty responsibly transfer control of significant financial and equipment resources to student project engineers? Getting outside money that is intended to support such independent projects is key - so that no institutional resources need be expended and minimal institutional control need be maintained - only as much oversight as may be necessary to ensure regularity and propriety in material, service and information transactions with contributors and vendors. But who has the financial resources and the intent to fund such student entrepreneurial projects?

The National Collegiate Inventors and Innovators Alliance is a program of the Lemelson Foundation, operated by Hampshire College, that has precisely those qualities. It provides support on a competitive basis for courses and projects that significantly incorporate entrepreneurship education at the undergraduate level. Although not expressly focused on engineering programs or projects, the NCIIA offers engineering faculty and students some modest resources and unique opportunities to create and sustain an authentic educational experience in design-based entrepreneurship.

The NCIIA program offers support at three Levels: Level I provides very small seed grants to faculty to assemble information resources and develop curricular elements involving entrepreneurship, invention and innovation, whether as part of existing courses or as new offerings. Level II provides logistic support grants to faculty to deliver content or entire courses about entrepreneurship-invention-innovation that include the formation and operation of mutidisciplinary student E(ntrepreneurship)-Teams. Level III provides larger follow-on grants directly to student E-Teams to pursue toward commercialization their concepts or products, usually originating in Level II efforts, with NCIIA taking a small share of any eventual commercial income.

Grant monies may be used to buy materials and equipment, patent searches, student professional travel and consulting support in marketing, intellectual property and business development, and to pay summer stipends for students, but NCIIA will not fund any faculty or staff salaries, which are presumed to be part of the insitution's ongoing instructional process. Proposal and project documentaion requirements are very modest, the goal being to put additional direct support and its control into the hands of faculty and students whose institutions are willing to provide the labor and overhead resources for entrepreneurial education. In this way, NCIIA intends to foster the activity and growth of an enlarging community of entrepreneurially-minded undergraduate faculty and alumni, and thereby inject a lasting leavening of entrepreneurship and design creativity into the mix of US undergraduate education.

So - what happens when Engineering faculty and students apply for and receive NCIIA grants? How are their programs and experiences enhanced? Are the results worth everyone's effort?

2. NCIIA-Funded Student Product Development Efforts

The first NCIIA-assisted course offered at Swarthmore was our Fall 1996 offering of Solar Energy Systems, an elective for juniors and seniors that had been devoted chiefly to the analysis and design of active thermal solar energy collection and storage systems. During the summer of 1996, the author had developed with Level I funding an additional laboratory module on performance testing and evaluation of photovoltaic (PV) panels, and assembled some hardcopy and web information dealing with solar PV and thermophotovoltaic (TPV) technology, including research-oriented, application-oriented and patent-related resources.

The class schedule included individual guest presentations by two local manufacturing small-business entrepreneurs and a recent-alumna patent attorney, at the cost of reduced coverage of computer models for solar thermal system dynamic simulation. The schedule of weekly labs was changed so as to introduce the E-Team concept, organize E-Teams and generate lists of potential team project topics very early in the semester. Reporting requirements for set-piece labs on site-specific solar resource estimation, thermal collector performance and PV panel performance testing were relaxed a bit in order to make time during the first half of the semester for students to acquaint themselves with the new course library of PV/TPV, invention and entrepreneurship information resources and to get comfortable with using at least two patent-archive websites.

A full hour of additional weekly meeting time was also scheduled for each of the two E-Teams that formed for the course, with agendas prepared by team leaders and distributed by email the day before each meeting. Each team leader then met with faculty once a week to review progress and address difficulties. Weekly homework assignments included questions intended to encourage students to routinely think about where innovation and invention might most profitably be focused with regard to solar thermal and PV collector and energy storage subsystems. Several times during the semester, students were reuiqred to check patent archive websites to see how others might have already perceived and pursued similar opportunities.

Two projects based upon the perceived technical and economic feasibility of solar PV power for high value applications were pursued by E-Teams in Solar Energy Systems, using NCIIA funds totalling about $7k to purchase equipment and supplies specific to their needs. One project involved a backup power inverter system for hurricane-disaster recovery; it centered on a critical-load characterization and prioritization scheme that used a programmable logic controller to schedule rotating load outages so as to achieve optimal battery subsystem performance. The other project explored the feasibility of using actively cooled TPV modules, illuminated by wavelength-shifted natural gas hydronic boiler flame, to generate heating system control power and to permit continued space heating during extended electric utility grid outages.

Both projects resulted in prototype hardware, albeit with different levels of design integration and practical success. But more importantly, both E-Teams learned a lot about the product development process, the usefulness of patent and journal archives, and the importance of organization, communication and teamwork in achieving project goals. Members of both teams also learned what extraordinary amounts of time and effort a project can absorb in crash mode as a critical deadline approaches, and what immense joint satisfaction results from having met such a deadline.

3. What Students Think about E-Teams

Course evaluation feedback was strongly positive about the effectiveness of the E-Team projects and about having funds for project hardware, supplies and operations as factors contributing to strong engagement with course content and high levels of satisfaction with project and course outcomes. The leader of the space-heating team was sufficiently motivated to write and submit a Level III proposal to NCIIA to continue the project through the succeeding spring and summer, constituting her senior design project. That proposal was funded for $18k, and a slightly modified team of four juniors and seniors carried the work forward [1]. In March 1997, that team presented their project at the National Museum of

American History as part of the first National Conference of NCIIA in Washington DC. Since fall 1997, the project has sporadically continued, albeit with emphasis shifted from the supply side (TPV generation) to the demand side (reducing system operating power requirements) in response to the high present cost of TPV cells.

In a near-repetition of earlier events, one member of the second space-heating E-Team who had led the summer 1997 followup effort got together with a classmate who had spent two summers working for a manufacturer of Proton Exchange Membrane (PEM) fuel cells. Together they recruited a third classmate interested in control applications and submitted a Level II proposal to NCIIA. They proposed to develop, as a joint senior design project, a prototype solar PV-powered system to produce hydrogen and oxygen by electrolysis of water, to clean and store the gases (with hydrogen stored by absorption in metal hydrides) and to recombine them on demand using a PEM fuel cell.

That proposal for $14k was also funded, and beginning in December 1997, a nominal 500 watt system was designed, fabricated and tested by May 1998; at lower power (40W) it achieved a 26% electricity-in to electricity-out efficiency, not accounting for parasitic power losses [2]. This team also presented its work at the Smithsonian in March '98 as part of the 2nd National Conference of the NCIIA. At this writing, the solar-hydrogen-fuel cell system is integral but mothballed (while this author is on sabbatical), awaiting a future E-Team to continue development, whether as another joint senior design project or as a semester project in either our Thermal Energy Conversion or Solar Energy Systems elective courses.

4. How E-Team Development Projects Differ

Two kinds of differences are evident in E-Team projects as compared to conventional design projects or semester projects within courses. First, E-Team projects tend to be open at *both* ends, because they frequently involve relatively new technologies in search of problems to solve, and because students with widely differing backgrounds who are seeking to define opportunities for new applications of any particular technology can converge on some possibilities that simply will not have occured to the faculty member who obtains and manages a Level II grant. In our first Level II grant, the post-hurricane emergency power management system was a more enticing opportunity in the view of several students than the post-winter storm space heating system concept that had been identified in the grant proposal. The hurricane-like ferocity with which that E-Team pursued its own concept and product development really demonstrated the value of such freedom of choice. It also greatly enlivened our periodic joint development review meetings, because the two teams were not competing against one another and thus all the students felt more free to accept and to give serious criticism of each design and its accompanying marketing plan.

Second, where an E-Team project is part of a thematic course, students' post-introductory approach to course content, both disciplinary and entrepreneurial, appears to be significantly more need-based and "just in time" as the semester progresses than in regular offerings of that course. Consequently, there must be some reduction in depth of coverage of less "relevent" topics and a sharper focus on others more closely related to project needs. Where the E-Team project *is* the entire course, entrepreneurial and intellectual property aspects of the project serve constantly to remind students that their work has real value far beyond any grade being earned. The faculty member's work with a team can then become more a coaching than a judging function, again with a distinct "need to learn" and "just in time" consultative character.

In Level III projects, virtually all authority and repsonsiblity rests with the E-Team members; the nominal faculty advisor merely maintains access to and institutional oversight of project financial accounts, and keeps communications links open to NCIIA. For less experienced students, administrative responsibility may be an unwelcome burden, but it ultimately reinforces the reality of the team enterprise. Staying in touch with former E-Team members, particularly after they graduate, turns out to be a valuable faculty function that effectively complements project intellectual and financial recordkeeping.

The annual National Conference of NCIIA in Washington DC provides an important opportunity for E-Teams to present their projects to an audience of "real" people - early-spring Saturday visitors to the Smithsonian Institution's Museum of American History on the Mall. In making continuous presentations to the public that day, and to invited guests and the media the night before, team members get a better sense of the public's attitude toward them and toward their projects, and are invariably pleasantly surprised by the media coverage and by intense interest shown by a small but knowledgable subset of visitors to their exhibit area. Technical sessions of the two-day conference, which is scheduled in early March to coincide with the spring vacation break of most colleges and universities, are open to team members as well as to conference registrants, and typically include talks by nationally recognized technical entrepreneurs and entrpreneurship educators. E-Team meetings just after the NCIIA conference can be occasions for both inspiration and celebration as the spring semester rushes toward completion.

Although NCIIA grants are small - typically around $15k per project, the difference they can make in students' undergraduate engineering education is sometimes quite profound. Having responsible control of project resources other than their own labor can stimulate students to levels of effort and professionalism that result in their gaining significant technical and managerial expertise, even within the span of a single academic semester.

5. Augmenting Lab Equipment Budgets

Compared to research grants usually sought by engineering faculty, NCIIA funding is quite modest. Hovever, it has some advantage in being very flexible and easy to administer, as befits its intention to encourage student entrpreneurship. Project goals and constraints may change significantly as students continually research the state of the art; sometimes an E-Team discovers new patents, new products or new information in mid-project that very substantially alter its entrepreneurial situation. But as changed circumstances may require a different developmental tack, so project funds may be spent to acquire different supplies, materials or equipment. One particularly nice characteristic of NCIIA grants is that no matching funds are required; an E-Team and it's faculty advisor can simply say "Let's spend it for *this* instead" without having to obtain institutional authorization to redirect any matching funds.

The flexibility afforded by NCIIA grants is very attractive at smaller, primarily undergraduate institutions where lab funds tend to be quite limited, and dollar threshholds for supervisory approval of expenditures are frequently quite low. Getting a "booster shot" of $10-20k in project funds for precisely the materials and equipment needed to support an innovative development project can enable a team to acquire items that would ordinarily not be available to students in the operating stock of a teaching lab, and almost certainly not in support of a small-group senior design project.

Moreover, over a relatively short span of time, the aggregate improvement in lab capability that can result from just one, two or a few NCIIA-funded projects can help to invigorate and enrich the lab experience of students in whatever courses eventually make use of those improvements. So while not a stated goal of the NCIIA program, the modest facilities improvements it enables can have a sustained positive impact on the motivation and achievement of many more students than those actively involved in the funded E-Team projects.

6. Assessing Development Projects and Academic Programs

E-Team students planning and pursuing the development of an innovative technology application must first identify and analyze opportunities for innovation and then synthesize, realize, test and evaluate a product or system that represents a step beyond what's currently available in the market. Viewed as a means for making an incremental (albeit perhaps substantial) improvement in the effectiveness of solutions available to customers confronted by the underlying problem, a one-time entrepreneurial development effort bears a strong resemblance to the continuous educational program improvement process that ABET EC2000 is intended to stimulate and support.

Technology-based entrepreneurs often sense a new opportunity by learning about or personally observing some shortcoming of current technology that simply cries out (to them) for improvement. But to assess the development potential of that opportunity with some reliability, the entrepreneur must throughly research the state of the art and the relevant market to generate information that will allow him/her to estimate the potential income and profit that the product or process innovation might generate. Opportunities for academic program improvement similarly arise when faculty or students perceive program shortcomings that need attention or benefits that the program does not currently capture.

Surveying the technological state of the art and the needs of current or potential customers is necessary for an entrepreneur to determine whether any nard evidence supports his or her perception of opportunity. Data in the form of faculty-generated course descriptions and outcomes assessments, student course evaluations, annual, senior and/or alumni surveys about program structure and outcomes help to depict both the state of an academic program and its customers' needs. Like the entrepreneur, the academic program manager (typically a department chair or departmental curriculum committee) needs to "read the tea leaves" and discern patterns evident across the data that indicate which aspects of a program are most in need of change, and what needs, traditional or emerging, are not being well met. Interestingly, while the demand side of both analyses indicates what the customer wants most, it is the supply side that is easier to measure and which naturally attracts the attention of engineers.

Once the potential of each distinct opportunity is known, the entrepreneur can proceed to develop specifications for a new or improved process or product that targets one or more of those opportunities. Student E-Teams have some difficulty with this phase of a project because it is seldom possible in one or even two semesters to develop a product that meets more than a few of the many desired specs, and students naively resist restricting the scope of their project to what can be fully accomplished in the time available. An academic program manager likewise can develop new objectives that address unfulfilled needs that can either be modified from or added to current program objectives in a periodic review process.

Once specifications or objectives are set, planning and execution of a development project can begin in earnest; modified curricular and service elements of an academic program can be

created and delivered whose unit objectives are consistent with the evolved set of program objectives. But to achieve a high probability of success in either theater, it is critically important that all actors agree that the new set of specifications or objectives do appropriately and adequately address the needs recently made evident in the information-gathering phase.

At appropriate project milestones, entrepreneurs and development managers routinely gather data that describes both the state and rate of progress and conduct reviews to assess and evaluate projects and to decide what changes if any should be made in activities, schedules or budget to best facilitate rapid progress. With E-Teams, the duration of projects is so short that weekly team and advisor meetings adequate serve this function. In the larger academic setting, program managers can examine information gathered from students, faculty, employers and others having interests in the program, both routinely (usually annually) when no significant changes have recently been made and on a before-and-after basis when they have.

Because there are often delays of one or more years in the academic environment between making program changes and obtaining feedback about them from graduating students or employers, there is some danger of oscillatory program instability unless reports on the effects of changes made earlier are strongly associated with only those changes and not used to characterize the program generally. More frequent sampling via annual post-summer or post co-op reports can help to stabilize the ongoing process of continuous change.

7. Closing the Assessment Loop

When a well-planned project is complete or a product is released to the market, a retrospective evaluation of the entire development effort is usually conducted in order to learn from both errors and successes experienced enroute to completion. The final written project report and presentation for a student's semester, NCIIA or senior design project serves both the assessment and evaluation function. While academic program assessment instruments may (surveys and interviews) or may not (grades, test scores or pass rates) include evaluative information, it is important that the program assessment/improvement loop be closed by periodic evaluation of the outcomes assessments that includes documentation of evident errors and successes, decisions taken and plans made for appropriate program adjustments. Realistically, such adjustments will include changes to both the program content and delivery, and to the assessment and evaluation plan, at least until the latter is agreed by providers and customers to have achieved an acceptable equlibrium between intrusiveness and effectiveness.
Table 1 summarizes the approximate parallels presented above. It is not intended to artificially partition what are in fact overlapping process elements, or to serialize what are often parallel activities that, for a continuous process, must recur with a sufficiently high sampling frequency to produce an accurate trace of the underlying process dynamic.

Table 1 - Parallels between Entrepreneurial Development Projects and Academic Program Improvement

Product/Process Development Project (one iteration)	**Academic Program Improvement** (continuous)
Background Research	Information Gathering
Opportunity Evaluation	Data/Info. Analysis
Specification Setting	Objectives Review

Project Execution	Program Delivery
Product/Process Evaluation	Outcomes assessment
Project Evaluation	Program Review

8. Design and Entrepreneurship Experience as Preparation for Program Assessment

Having laid out these rough parallels between the discrete development project and the continuous academic program review and improvement process, it occurs to the author that engineers in academe whose training and experience includes a substantial fraction of design, development or entrepreneurship activity should be better qualified to explain and manage the continuous assessment, evaluation and improvement of academic engineering programs as practiced under EC2000. Conversely, it should be no surprise that engineering professors whose background includes little or no design or product development experience may be less well prepared or even inclined to accept the program assessment and evaluation rubrics of EC2000 as necessary or even appropriate to achieve the desired outcomes. But given the general advance of program improvement strategies such as EC2000 and ISO9000 in academe and industry respectively, it is becoming increasingly clear that engineering academic programs that include some instruction in innovation and entrepreneurship as well as more conventional engineering design are likely to be more successful in preparing graduates for productive careers as engineers in the 21st century.

References:

1. Paynter, N.; Flame Illuminated Photovoltaics for Off-Grid Boiler; senior Engineering Design project report, Swarthmore College - Cornell Library, Swarthmore PA; May 1997

2. Mas, C., Lucks, G., and Francis, J.; The Design, Development and Testing of a Solar-Hydrogen Power System; senior Engineering Design project report, Swarthmore College - Cornell Library, Swarthmore PA; May 1998

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