# Infusing Real World Experiences into ENGINEERING EDUCATION

NATIONAL ACADEMY OF ENGINEERING
*OF THE NATIONAL ACADEMIES*

This project is a collaboration between the National Academy of Engineering (NAE; www.nae.edu) and Advanced Micro Devices, Inc. (AMD) in support of the AMD NextGen Engineer initiative (http://nextgenengineer.amd.com).

The National Academy of Engineering was established in 1964 under the charter of the National Academy of Sciences as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with NAS the responsibility for advising the federal government. The mission of NAE is to advance the well-being of the nation by promoting a vibrant engineering profession and by marshalling the expertise and insights of eminent engineers to provide independent advice to the federal government on matters involving engineering and technology.

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The introductory overview of this publication has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Academies. The purpose of the independent review is to provide candid and critical comments to assist the NAE in making its published report as sound as possible and to ensure that the manuscript meets institutional standards for objectivity, evidence, and responsiveness to the project's charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We thank the following individuals for their review of the manuscript:

Michael Corradini, Professor, Department of Engineering Physics, University of Wisconsin – Madison
Lueny Morell, Director of University Relations for Latin America, Hewlett-Packard Company

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the views expressed in the introductory overview, nor did they see the final draft of the overview before its release. The review of this publication was overseen by Lance A. Davis, NAE Executive Officer. He was responsible for making certain that an independent examination of this manuscript was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this publication rests entirely with the authors and NAE.

**Real World Engineering Education Committee**

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# Infusing Real World Experiences into Engineering Education

NATIONAL ACADEMY OF ENGINEERING
*OF THE NATIONAL ACADEMIES*

AMD
NextGen Engineer

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## Preface

The aim of this report is to encourage enhanced richness and relevance of the undergraduate engineering education experience, and thus produce better-prepared and more globally competitive graduates, by providing practical guidance for incorporating real world experience in US engineering programs. The report, a collaborative effort of the National Academy of Engineering (NAE) and Advanced Micro Devices, Inc. (AMD), builds on two NAE reports on *The Engineer of 2020* (NAE, 2004; 2005) that cited the importance of grounding engineering education in real world experience. This project also aligns with other NAE efforts in engineering education, such as the Grand Challenges of Engineering, Changing the Conversation, and Frontiers of Engineering Education.

The Real World Engineering Education (RWEE) committee invited nominations from US universities and colleges that offer programs in undergraduate engineering, some of which involved partnerships with other types of institutions, corporations, or community members. The committee gave preference to 4-year programs that could be adopted or adapted at other institutions. Nominating institutions were asked to provide a description of the program, its start date, anticipated and actual outcomes, original and current funding, number and diversity of students and faculty involved in the program, partners, and methods of assessment (to facilitate ongoing improvement of new programs).

The number of nominated programs—89, at 73 public and private universities and colleges around the country—indicates the importance many institutions place on the incorporation of real world experiences for their engineering students. Furthermore, we are pleased to note that, although some of the nominated programs have been operational for several decades, over half were launched since 2006, which suggests an increasing interest in enhancing US undergraduate engineering education through the inclusion of practical, real world experience.

The 29 selections described in the following pages feature a diverse range of model programs in terms of institution type, program category and scope, geographic location, and longevity. The report also includes a section on potential barriers to implementation, as described by engineering and engineering technology deans, together with suggested methods of overcoming those barriers.

We are excited about the potential of this report to promote awareness and adoption of programs that incorporate real world experiences in engineering education. We believe the report will be useful to both academic and industry professionals interested in engaging and better preparing engineering students for the workplace and for competition in the global economy.

Charles M. Vest
President
National Academy of Engineering

## Summary

This publication presents 29 programs that have successfully infused real world experiences into engineering or engineering technology undergraduate education. The Real World Engineering Education committee acknowledges the vision of AMD in supporting this project, which provides useful exemplars for institutions of higher education who seek model programs for infusing real world experiences in their programs. The NAE selection committee was impressed by the number of institutions committed to grounding their programs in real world experience and by the quality, creativity, and diversity of approaches reflected in the submissions.

*"Historically, engineers have received excellent technical education, but have generally lacked formal training in the additional skills required to succeed in today's globally connected, rapidly evolving workplace. Young engineers need to be taught how to think independently, communicate clearly and adapt to change to become leaders in the global marketplace."*

***Mark Papermaster,***
***Senior VP and CTO,***
***AMD***

A call for nominations sent to engineering and engineering technology deans, chairs, and faculty yielded 95 high-quality submissions. Two conditions were required of the nominations: (1) an accredited 4-year undergraduate engineering or engineering technology program was the lead institution, and (2) the nominated program started operation no later than the fall 2010 semester. Within these broad parameters, nominations ranged from those based on innovations within a single course to enhancements across an entire curriculum or institution. The full list is provided beginning on page 36.

Committee members assessed the nominations based on each program's creativity, innovation, attention to diversity (geographic, institutional, racial/ethnic, gender), anticipated vs. actual outcomes, sustainability plan, assessment of student learning, and level of real world experience.* Although all nominated programs received good scores for one or more of the assessment criteria, the programs chosen as exemplars were rated highly on all or most of the aforementioned factors and were particularly distinguished by their plans and/or performance with respect to sustainability, assessment, and diversity. In making its selections, the committee also considered the ease of replication of a particular program at another institution, and/or its scalability to include more students and faculty. Finally, the committee chose to highlight a variety of program types (e.g., courses, full curricula, extracurricular programs) and a variety of institution types to illustrate a diversity of effective approaches to infusing real world experiences into engineering education.

This publication is intended to provide sufficient information to enable engineering and engineering technology faculty and administrators to assess and adapt effective, innovative models of programs to their own institution's objectives. Recognizing that change is rarely trivial, the project included a brief survey of selected engineering deans concerning the adoption of such programs, and, based on their feedback, the report briefly addresses possible impediments and workarounds.

## Organization of This Publication

A summary of the barriers to implementation begins on page 4. The list of nominated programs begins on page 36 and a list of selected exemplar programs is on pages 5-6. The program descriptions begin on page 7 and are organized according to broad categories: *Capstone* (senior design courses), *Course/Curricular* (courses other than capstone or first-year design, or programs that encompass entire curricula), *Co-Op* (students receive course credit working for industry partners), *Extracurricular* (not for course credit), *First Year* (program is focused entirely on first-year students), *Global* (includes an international travel component), and *Service-Learning* (courses include projects for community partners). Programs that qualify for more than one category are organized according to their primary designation.

* It should be noted that two members of the committee recused themselves from the discussions and rating of nominations from their home institutions: Dr. Leah Jamieson of Purdue University and Dr. David Wormley of Pennsylvania State University.

## Impediments and Suggested Solutions

Approximately 460 engineering and engineering technology deans were invited to participate anonymously in an online survey about barriers and impediments that they either had encountered or anticipated would arise in efforts to implement real-world engineering programs in their institutions. They were also asked to suggest ways to overcome those barriers. Of the 157 deans who responded to the survey, 26 commented on one or more of the programs, yielding observations about 18 of the 29 selected programs. In addition, four deans attended an informal feedback session at the American Society of Engineering Education sponsored Engineering Deans Institute in April 2012.

Three types of impediments were mentioned most frequently and across the program categories mentioned above:

- lack of funding and financial support (12 programs),
- faculty workload concerns (9 programs), and
- challenges encountered with partnerships within and/or outside the institution (9 programs).

Respondents also cited barriers related to intellectual property rights and particular program categories.

**Funding impediments** involved materials and equipment, student stipends, or faculty support. Solutions included charging lab fees or requiring students and their project advisors to secure funding from industry or community partners (e.g., nonprofit agencies in service learning projects) to offset both material/equipment costs and student stipends in co-op programs. Another suggestion was to start with small projects or partner with other institutions to lower initial costs. Most respondents simply suggested raising funds through traditional industry or foundation grants.

**Faculty workload impediments** concerned both teaching load and scalability. As faculty invest their time and energy in new projects, they may have less available for regularly offered classes. As one dean commented:

> *It is not clear how the level of faculty effort in supervising the program is sustainable unless the teaching load is reduced. If the teaching load is reduced, do foundational topics (e.g., engineering sciences) suffer neglect? That is, does the attention given to the [program] compete with the fundamentals needed for lifelong learning? Are graduates well-prepared for success in graduate school?*

Two suggestions for mitigating increased faculty workload were team teaching of courses associated with the programs or providing salary support for industry professionals to either help teach those courses or supervise student projects. In addition, deans at larger institutions commented on the challenges involved in scaling some program activities to larger class sizes and suggested recruiting and training graduate students and/or highly qualified upper-class undergraduate students to lead small group activities. A related issue concerned the additional competition for lab space and other institutional resources that new RWEE programs would generate. One suggestion for reducing this competition was to have graduate students run space-intensive project activities in the summer.

> *"The basic idea is to create an engineer who has deep, strong, up-to-date technical education and the experiences that wrap around that to enable him or her to work in industry, to work across geographical boundaries, to work with people from totally different professional fields."*
>
> ***Dr. Charles M. Vest***
> ***President***
> ***National Academy of Engineering***

**Partnership impediments** involved problems with securing partners in industry, at other academic institutions, and within both the engineering school and the home institution more broadly.

Respondents who cited difficulty in engaging industry partners to participate in projects and/or help provide project or student assessments suggested that working closely with industrial advisory boards to engage partners and fostering partners' program ownership by involving them in early planning conversations were good practices.

One dean commented on the difficulty of finding industry partners for academic institutions that are neither nationally known nor located in large cities where multiple industries are represented. This dean suggested allowing and facilitating student participation in projects within established programs at other institutions or encouraging faculty and administrators to partner with other institutions. Another noted that persistence is important, commenting that "[i]nitially we had trouble finding suitable projects but as we gained experience and the word spread we now find lots of good projects."

Recruiting partners within the institution was also mentioned as a barrier to program implementation. As with industry partners, early conversations and program ownership may be helpful. One dean suggested beginning on a small scale with like-minded people, demonstrating some early success with quality products and outcomes, and promoting cross-campus program awareness as a way to recruit new intra-institutional partners.

For several of the industry partnership programs (e.g., co-op, capstone), **intellectual property rights** were mentioned as a barrier to implementation—specifically, whether the students, the institution, and/or the industry sponsor should retain the rights to any products that result from the partnership. Suggestions to address this challenge included both bringing business or law students to the project team to expand and protect student and institutional intellectual property rights and encouraging universities to recognize the need for companies to protect their products.

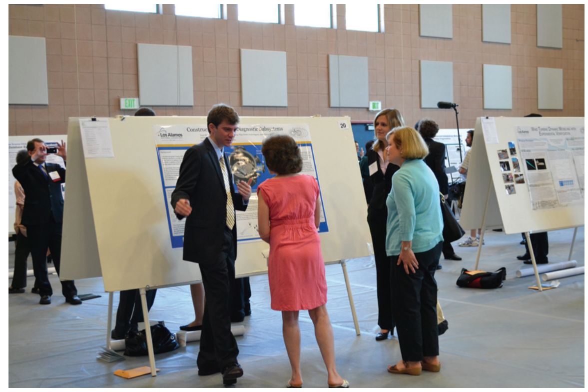
Respondents also described barriers related to **specific program categories**. For example, first-year engineering programs may lack dedicated faculty members or college wide agreement on program goals. Co-op programs may be hampered by the multi-semester commitment often required from students and companies; one suggestion was to develop projects that could be completed in one semester. Capstone courses would benefit from cooperation between chairs and faculty in the scheduling of senior design courses in all departments during the same class periods to enable students on project teams to meet. One dean noted the difficulty of both tracking students' fulfillment of the requirements for the Grand Challenges Scholars Program (p. 15) and finding appropriate student projects related to the program, and suggested the development of a national database of potential Grand Challenges projects for university students.

> *"We are encouraged by the breath of innovative approaches that are exposing engineering students to real world scenarios they will encounter after graduation. We must continue to share best practices, support institutions that are nurturing multidisciplinary education, and provide experiences and contexts that prepare our future engineers to lead and innovate."*
>
> ***Allyson Peerman***
> ***Corp. VP, Global Public Affairs***
> ***AMD***

## List of Real World Engineering Education Selected Exemplars

The program descriptions are organized according to broad categories, including Capstone, Course/Curricular, Co-Op, Extracurricular, First Year, Global, and Service-Learning. Several programs include more than one category but are listed with their primary designation.

## Harvey Mudd College Engineering Clinic Program



**Lead Institution**: Harvey Mudd College, Claremont, CA

**Collaborating Institutions**: Industry, government labs, academic institutions

**Category**: Capstone

**Date Implemented**: 1963

**Website**: http://www.hmc.edu/academicsclinicresearch/academicdepartments/engineering1/clinic.html

**Program Description**: Founded in 1963, the Engineering Clinic is the capstone design experience for all Engineering majors at Harvey Mudd College. Inspired by the medical school model in which young doctors learn to treat patients in a supervised clinical environment, Engineering Clinic helps young engineers learn professional practice on real problems from real companies in a supervised environment and has served as the model for similar capstone experiences at schools around the world. We also run 1-3 Global Clinic projects each year in partnership with multinational corporations and universities. Students work in teams of 4-5 under the guidance of a liaison from the sponsor and a faculty advisor. Seniors participate in a project for the entire academic year, while juniors participate for either the fall or spring semester. Students are entirely responsible for the project and gain experience leading their teams, scheduling the work, and managing a budget. Generally projects work best when the sponsor has a strong business justification for investing in the project and when the liaisons' professional objectives are aligned with those of their organization. About 60-65% of Clinics are run in the Engineering department, 25% in Computer Science, and the remainder in mathematics and physics. 10-15% of the projects are joint between departments. The majority of Engineering Clinics are highly interdisciplinary, which is a good match to HMC's nonspecialized degree in Engineering. Examples of recent Engineering Clinic Projects have included: (1) Los Alamos National Laboratory: instrument a wind turbine to measure vibrational mode shapes and use the measured data to refine a finite element model of the turbine; (2) CareFusion: design, build, and test a novel peristaltic infusion pump; (3) Aerospace Corporation: design, build, test, and fly a spaceborne distress beacon board in a picosat; and (4) SEAmagine Hydrospace Corporation: design, build, and test a sensor system to assist a submarine operator cleaning oil spills.

**Anticipated and Actual Outcomes**: Since 1963, Harvey Mudd College has completed nearly 1400 Clinic projects. Presently, we carry out 23-26 per year in Engineering, about 10 in Computer Science, and 5 between Physics and Math, including several interdisciplinary projects each year. Faculty expect that students will learn how to approach large open-ended problems, teach themselves new technical skills, apply existing technical skills in a professional context, interact with sponsors and suppliers, and sharpen their teamwork, leadership, presentation, and writing skills. Many students report during exit surveys that Clinic was the most influential part of their educational experience. Sponsor satisfaction is excellent, with 95% of sponsors typically rating the outcome at 4 or higher on a 5-point scale and 60-70% sponsoring another project in the next year.

**Assessment Information**: Clinic is assessed against 10 of the 11 ABET criteria and against three internal goals (high-quality projects, good value to sponsor, capital equipment upgrades) using nine assessment instruments involving direct and indirect measurements by students, faculty, sponsors, and staff. The assessment yields 35 items quantified on a 5-point scale, along with four open-ended items related to areas of student interest and technologies and software required. Overall results tend to be well above our targets, and dips on certain metrics from year to year motivate ongoing programmatic improvement. Overall, recent assessment data indicate that students were well prepared for Clinic, apply appropriate tools and techniques, contribute well to multidisciplinary teams, present their results remarkably well, have adequate facilities for their work, and produce highly satisfied sponsors. We would like to see continued improvement in the rigor with which the students state their results, the alignment between stated goals and final deliverables, and the students' ability to articulate the impact of their work on society. Assessment has also led to targeted investments in capital equipment and CAD capabilities to meet the increasing technical needs of the projects.

**Funding/Sustainability**: The program has been run on a self-sustaining basis for nearly 50 years. Clinic raises over $1M of external funding from project sponsors each year. About a third goes to the college overhead, a quarter goes to materials and travel for each project, and a quarter goes for salaries of support staff. The remainder covers programmatic expenses and capital equipment upgrades. Clinic has recently designated an Associate Clinic Director in addition to the Clinic Director, which provides more resources for recruiting projects and strengthening the academic content of the program as well as creating growth opportunities for mid-career faculty. Sponsors pay $47,000 and commit a liaison for weekly teleconferences; in return, they get a hardware prototype and all of the intellectual property rights. Many sponsors also consider Clinic an important part of their recruiting strategy. Clinic sponsors have been approximately 60% established companies, 23% national labs, 10% startups, 5% other academic institutions, and 2% foundations.

## Integrated Product Development and Baker Institute for Entrepreneurship, Creativity and Innovation

**Lead Institution**: Lehigh University, Bethlehem, PA

**Collaborating Institutions**: Industry, local/state government and federal agencies, nonprofit agencies and foundations, academic institutions

**Category**: Capstone/Industry/Entrepreneurship

**Date Implemented**: 1994

**Website**: www.lehigh.edu/ipd, www.lehigh.edu/innovate, www.lehigh.edu/entrepreneurship

**Program Description**: Lehigh's Integrated Product Development (IPD) program started with the three pillars of new product development: engineering, business, and design. We had no industrial design program so we created what we call "design arts." The objectives are: 1) to prepare graduates with the ability to "hit the ground running" at their first real-world job, and for those with an entrepreneurial bent, 2) to create their own jobs by developing products and launching companies. The development of "higher-order" skills and an "entrepreneurial mindset" has become increasingly important. This mindset includes innovation, creativity, diversity, interdisciplinarity, global orientation, ethical behavior, leadership, and teamwork. Lehigh's entrepreneurship ecosystem features 10 entrepreneurship-related campus organizations, 17 educational programs, 34 courses, and 22 labs, shops, and related facilities. Programs are open to all undergraduate and graduate students. Our for-profit partners had a main objective of preparing our students to be successful new employees, while the government agencies supported our entrepreneurship programs to foster economic development. In 2011, 192 students from Engineering, Design Arts (College of Arts & Sciences), and Supply Chain Management (College of Business and Economics) worked in 28 teams on industry-sponsored projects first introduced at our beginning-of-the-semester Industry Project Fair. Funded projects come from alumni working in established companies, local entrepreneurs, and student entrepreneurs. With the 2010 launch of the Baker Institute for Entrepreneurship, Creativity and Innovation, the IPD program was subsumed into a university-wide entrepreneurship initiative that includes the entrepreneurship minor, new programs in technical entrepreneurship, and new courses in social entrepreneurship. The Baker Institute has an external board of advisers and an internal curriculum and program oversight committee. Each fall for the past 10 years the faculty have organized and judged the many dozens of entries annually in our campus-wide entrepreneurship competitions. These competitions and advocacy initiatives include focus areas such as technical innovations, fashion, art, software, alumni, and women entrepreneurs.

**Anticipated and Actual Outcomes**: Students completing the two IPD capstone courses should be able to: identify and define key technical and business components of technical problems; design effective solutions to these problems in a broad global business and social context; demonstrate an understanding of an entrepreneurial mindset; participate in and lead an interdisciplinary product development team; effectively communicate through written, oral, and graphical presentations; address aesthetics and ergonomics issues in product development; develop a value statement for the product/process to be developed; design, create, and evaluate technical and financial feasibility studies; manage people and financial resources; and successfully apply appropriate analytical, numerical, virtual, or physical models at appropriate times throughout the process. We anticipate that students completing this course sequence should reduce the start-up training when they are first employed, which has been reported to take up to two years without IPD.

**Assessment Information**: We measure our programs by assessing student performance, collecting feedback from industry experts, and tracking program growth. Assessment tools have been designed to measure students' performance, output, or artifacts in a given area by observing actual work in real time so the feedback may be used by the students to improve their work. Rubrics have been developed for this purpose as well as to provide consistency across all teams, projects, and advisers. Twenty-one rubrics for each team are completed throughout the semester by faculty, fellow students, and industry experts and another nine for each individual student. At the end of each semester the industry sponsors and entrepreneurs provide indirect, summative program assessment via a comprehensive questionnaire focusing on the programs' infrastructure and work done with/by the student team, and every student provides feedback via a customized course evaluation. Program growth is measured in numbers of students enrolled in courses and number of courses offered.

**Funding/Sustainability**: Three faculty started the IPD program with their own time and resources. In four years the program attracted nine sponsors who provided an average of $2,500 each for 20 student teams. In 1998 Lehigh's president converted an abandoned campus building to use for student projects, with alumni providing over $4.5M. In 1999 the program was funded on the university budget. Its director received a three-year renewable appointment with release time of two courses/year, tuition, and teaching assistant and part-time support staff stipends. Funding sources include: faculty volunteers, university budget, industry sponsors, alumni, congressional earmarks, state agencies, and foundations. To secure a scalable and sustainable program, we built our program and courses into the curriculum as required courses or electives. In the university approval process for courses and programs, the sponsoring departments, colleges, and provost must build faculty and staff support into the university budget. A generous gift from the Baker Foundation launched the Baker Institute in 2010.

## The Enterprise Program

**Lead Institution**: Michigan Technological University, Houghton, MI
**Category**: Capstone, Course/Curricular
**Date Implemented**: September 2000
**Website**: www.enterprise.mtu.edu

**Program Description**: The multidisciplinary Enterprise Program resulted directly from industrial assessment of engineering degree programs across the nation and our belief that all students should have the opportunity to graduate with the confidence, skills, and abilities to start their own company and that topics such as leadership, entrepreneurship, communications, ethics, innovation, and globalization should not be limited to a few courses but integrated throughout the curriculum. Second through senior year students from engineering and non-engineering disciplines participate in teams of 15 to 70 or more that operate like real companies. Team members define problems, develop and design solutions, perform testing and analyses, make recommendations, manufacture parts, stay within budgets and schedules, and manage multiple projects. As students advance through the program, they assume increasing levels of responsibility ranging from project leader to President and CEO of an entire Enterprise team. Real-time interaction with faculty advisors, industrial clients, and peers provides the students with valuable, immediate, and first-hand feedback about the effectiveness of their leadership skills. Enterprise teams are perpetual, and student experiences are long term, typically 2-3 years, with each student having the opportunity to participate in multiple projects. Enterprise has a Governing Board with representatives from five colleges whose charter is to set policy and direction for the program. Several departments have defined a concentration path for each of their majors which allowed for students to fulfill their capstone requirement through participation, and an interdisciplinary Enterprise Minor was created to further facilitate participation across all majors. The primary objectives are to: create an environment for students to facilitate the transition from their undergraduate program to the professional work force, provide opportunities for students and faculty to develop leadership and entrepreneurial skills in a learning setting that closely resembles an industrial or professional environment, give the students ownership of a portion of their academic program that connects strongly to career goals, develop the skills and desire for life-long learning, give the students a taste of the rewards and accountability associated with creating new products and working with paying clients, and utilize the students' fundamental background in science and engineering in the context of a problem when non-technical issues, such as cost or societal impacts, are of equal importance.

Enterprise Program
Michigan Technological University

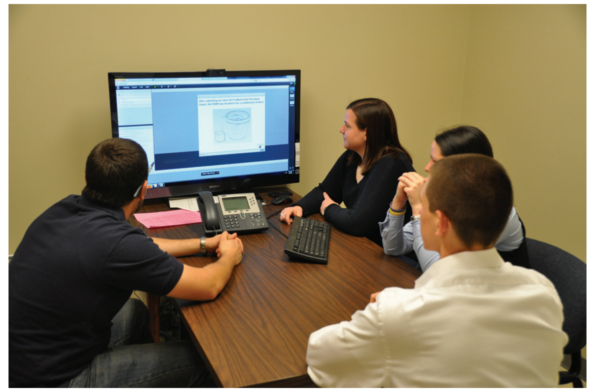
**Anticipated and Actual Outcomes**: Anticipated outcomes included increased retention in the major, improved communication and teamwork skills, participation on projects that facilitate exposure to ABET criteria (a) through (k), as well as increased leadership and entrepreneurship development opportunities. Enterprise has yielded measurable impacts on retention and graduation, with 3-year retention rates of 93-100% for Enterprise students versus 65-85% for non-Enterprise students. Graduation rates are similarly improved. The program has successfully completed two ABET reviews with a documented assessment system incorporating peer-to-peer, faculty advisor and project sponsor feedback on students' teamwork, communication and design skills.

**Assessment Information**: The program undergoes a rigorous annual assessment of graduating seniors' teamwork, communication, and design skills utilizing feedback from peers and faculty advisors. In addition, each completed project is assessed by the external project sponsor who provides feedback on the team's skills. In 2008, Michigan Tech received an NSF IEECI award to assess the impact of Enterprise advising, teaching and mentoring on student outcomes. Results suggest significant positive differences between senior-standing Enterprise students and Senior Design students in terms of the perceived value of the faculty advisor/mentor on a student's career skills, entrepreneurial intentions, time management, and communication ability, and that these differences are attributable to the Enterprise program and the advising students receive. This may be due to the length of time that students participate in Enterprise with a longer and perhaps stronger relationship with the Enterprise advisor. The results also indicate that Enterprise students perceive they have developed stronger teamwork, leadership, communication, innovation, business, and cross-disciplinary skills than their non-Enterprise counterparts. These results may have important implications for the value of long-term, regular, and more focused faculty advising/mentoring, especially in project-based learning, but with potential applicability for all students.

**Funding/Sustainability**: Since implementation, Enterprise has relied on over 100 industry, community and government partners for financial, project and mentoring support. An initial NSF grant of $750,000 was matched with financial and in-kind support from industry partners as well as from Michigan Tech and additional NSF funding has supported development and implementation of a High School Enterprise Program. The program has been self-sustaining since its second year of operation, with a target funding level for each team of $20,000 to $40,000, depending on the scope of the various projects in a given year. Of this, 30% goes toward the administrative expenses of the overall Enterprise program; 10% goes to the faculty advisors for their own professional development; and the remaining 60% goes directly to the Enterprise team for project expenses. Teams may be funded by one or more sponsors each year, depending on the nature of the team project or the number of projects taken on by a team. Enterprise has over 40 industry sponsors each year, many of whom support teams for multiple years and now contribute over $700,000 each year to sustain and expand the program.

## Infusing Capstone Design Projects with Real-World Experiences Using Global and Cross-College Teams

**Lead Institution**: The Pennsylvania State University, University Park, PA
**Collaborating Institutions**: Industry, U.S. and international academic institutions
**Category**: Capstone/Curriculum
**Date Implemented**: 2007
**Website**: http://www.lf.psu.edu/



**Program Description**: The Penn State Learning Factory has two capstone initiatives: (1) teaming with engineers around the globe to mimic the operation of distributed multinational corporate project teams, and (2) teaming with students outside of engineering to mimic the broad, interdisciplinary teaming found in industry. The global project objectives are to: (a) understand the impact of engineering in a global, economic, environmental, and societal context; (b) understand cultural/ethnic differences and develop the ability to work sensitively with them; (c) function effectively in multinational teams; (d) communicate with people whose first language is not English; and (e) organize and deliver communication around the globe. The cross-college project objectives are to: (a) function effectively in teams with members in multiple disciplines; (b) communicate with people who are not engineers; (c) develop innovative solutions by fusing the creativity from multiple disciplines; (d) incorporate design considerations beyond technical engineering issues; and (e) gain an appreciation for other disciplines' perspectives on and approaches to design. The initiatives proceeded in coordinated parallel efforts by first engaging faculty partners at foreign universities and non-engineering colleges at Penn State. Course offerings and academic schedules were adjusted and the logistics for staffing, supervision, and operation of the student teams were developed. Industry partners were recruited to provide the projects as well as participate in weekly video/teleconferences, host site visits, evaluate reports and presentations, and provide team feedback. The global projects have been embraced by multinational corporations, with many closely monitoring the activities to improve their own globally distributed teams. Both initiatives leveraged internal and external research to identify best practices and ensure successful engagements.

**Anticipated and Actual Outcomes**: The anticipated outcomes are that students meet all technical requirements for an engineering capstone design experience, and the global and interdisciplinary teams perform on par with or better than co-located and engineering-only teams. Substantial increases in productivity have been observed from global teams that take advantage of time differences to create a 24-hour work day and from interdisciplinary teams that leverage larger team sizes. Increased awareness of cultural and disciplinary differences and improved communication skills have been observed. Students subsequently entering the workforce noted that the experience helped prepare them to work in a globally distributed, multicultural corporate environment, and many engineering students have shown an increased interest in working for entrepreneurs or local start-up companies. The cross-college partnerships have fueled a five-fold increase in entrepreneurial and start-up firm engagement as industry partners can obtain multiple outcomes from a single capstone project.

**Assessment Information**: An online intercultural assessment instrument assesses pre/post-program student growth. Penn State and Brigham Young University have partnered to capture, compile, and distribute the best practices for organizing and operating internationally diverse student teams. Technical project and professional outcomes are assessed by supervising faculty; industry feedback is used to assess project outcomes. Intercultural and communications aspects are assessed through team observations, interviews, and a specially prepared assessment instrument. Interdisciplinary interactions on cross-college projects are assessed through surveys and team interviews. An assessment expert in the Leonhard Center for the Enhancement of Engineering Education coordinates both evaluations. Program assessment occurs at department and college levels annually and in detail during each ABET cycle. The Learning Factory director reviews the program three times a year with its Industry Advisory Board; solicits feedback from industry sponsors twice a year; meets with capstone instructors and faculty 2-3 times a year to review the program and individual courses; meets regularly with the associate dean of academic affairs to review program outcomes, space needs, administrative support, finances; and reviews finances with department heads semi-annually.

**Funding/Sustainability**: For the global projects, $35,000 was used to (1) support faculty time and travel to identify, visit, and engage international university partners and industry sponsors, and (2) purchase improved video-conferencing equipment. For the interdisciplinary projects, 25% academic release time was provided for one year to help establish partnerships. After each initiative was established, faculty and staff time resumed to what was required for the existing capstone design program coordinated through the Learning Factory. The Leonhard Center and College of Engineering provided initial support and NSF supported interdisciplinary design workshops and ongoing research in global team assessment. Departments provide instructional faculty, and the College of Engineering provides two full-time staff positions and a director. Industry sponsorship covers project costs, TA support, student awards, events, maintenance agreements, and equipment upkeep. A recent $1 million endowment will foster new equipment purchases and engagements with entrepreneurs and start-ups. The initiatives have leveraged the equipment, faculty expertise, and resources of the existing capstone design program to expand, and corporate sponsorship of the program has doubled. The educational and organizational co-development between faculty, administrators, and industry partners was critical to ensure sustainability for these projects.

## A Self-Renewing, Industry-Driven Capstone Design Program

**Lead Institution**: University of Idaho, Moscow, ID

**Collaborating Institutions**: Industry, government, universities

**Category**: Capstone/Industry Partnerships

**Date Implemented**: August 1991

**Website**: http://seniordesign.engr.uidaho.edu/; http://www.webs1.uidaho.edu/mindworks; www.uidaho.edu/expo

**Program Description**: The interdisciplinary senior capstone design program at the University of Idaho (UI) was initially developed in the mechanical engineering department but has continued to expand to all of the engineering departments. The objectives of the UI interdisciplinary senior capstone design program are to introduce students to current "best practices" in industry for design and manufacturing, help students grow professionally by providing a focus for developing teamwork, communication, and project management skills, and increase industry/university collaboration within the context of specific product needs. Results from over 20 capstone design team projects each year are shared with the public, alumni, and industry partners at a signature university event known as the UI Design Expo. The UI commitment to this program has resulted in the construction of a 6000 $ft^2$ design suite that includes a CNC-equipped machine shop, project assembly area, advanced CAD laboratory, 3D printer, conference/study area, design review studio, and graduate student offices. To make this program self-sustaining, a system of knowledge management was developed to manage both explicit and implicit knowledge. Implicit knowledge is transferred through the Idaho Engineering Works (IEW), where a group of graduate students is given specialized training in hardware, software, manufacturing, and leadership with the expectation that they will mentor and support undergraduate students during the senior design course. The mentored undergraduate students then become part of IEW and mentor future students. This program was started by faculty who reviewed publications about Lockheed Skunk Works and research on creativity enhancement and technical leadership, and then sought industrial guidance. This led to finding design problems from industry for students to solve. External project partners donate equipment, provide design problems, provide peer review, and collaborate in resource development. Several campus offices and colleges work together to implement the program.

**Anticipated and Actual Outcomes**: Capstone course outcomes fall into four areas: student learning, program operation, infrastructure development, and community development. Student learning outcomes include: (a) deep immersion in and reflection on self-directed project learning, (b) early prototyping that accelerates and improves the quality of final designs, (c) formal communication (oral and written) that allows clients to easily integrate design project results, and (d) a cadre of graduate student mentors with exceptional technical leadership skills. Program operation outcomes include: (a) annual planning, oversight, and assessment that produces yearly improvements, (b) project results that delight all stakeholders, leading to follow-on projects in subsequent years, and (c) minimal cost to produce results, leading to increased resources for infrastructure. Infrastructure development outcomes include: (a) locally produced, web-based design tools, rubrics, and quick references for just-in-time professional development, (b) innovative learning spaces for virtual and physical prototyping, and (c) diversity of well-maintained hardware and software supporting the creation of circuit board parts. Community development outcomes include: (a) vertical integration of design, engineering science, lab, and graduate courses for better results, (b) contributions to regional economic development, and (c) alliances with other units on and off campus that lead to new and exciting project opportunities.

**Assessment Information**: Program outcomes are measured as part of yearly ABET data collection in areas of design, teamwork, professionalism, communication, and life-long learning. Program outcomes are also regularly reviewed by capstone faculty, Design Expo judges, and by industry advisory boards. Results are recorded in program assessment reports, reviewed by departmental ABET committees, acted upon as appropriate, and maintained in an archive on a shared drive. Capstone faculty regularly review and update a program assessment document that identifies stakeholders, program attributes, and program scope as well as strategic goals and tactical goals under the four program areas—program operations, design education, design/manufacturing infrastructure, and community development.

**Funding/Sustainability**: The program began as an internal bootstrap effort with no more than \$50k funding from engineering departments, external sponsors, and College of Engineering research groups for faculty, staff, and graduate students and less than \$10k for materials. The first projects were done for \$2000/each. The goal is to expand partnerships to include over \$100k/year for graduate student support. Program support will be expanded with hardware/software sponsorships as well as modern manufacturing and metrology equipment that will facilitate a campus-wide expansion to students and faculty working on design projects in multiple disciplines. The program is self-sustaining and continues to operate even as faculty members come and go. One key feature of the program sustainability is a team of graduate student mentors which fosters professional and technical excellence by mentoring undergraduate design teams. Another feature that contributes to sustainability is the UI institutional commitment to providing financial support for the program. While the program has been enhanced with external support, the bulk of the program support is contributed by the University.

## SPIRALed Engineering Education

**Lead Institution**: University of Utah, Salt Lake City, UT

**Collaborating Institutions**: Olin College of Engineering, the University of Texas at Austin, Virginia Tech, community colleges in Utah

**Category**: Capstone, Course/Curricular

**Date Implemented**: August 2008

**Website**: mech.utah.edu


**Program Description**: The purpose of this program is to improve students' abilities to solve practical, open-ended engineering problems by improving their critical thinking skills and their knowledge of engineering hardware, science, and modeling and simulation tools. We are doing this (1) in a manner applicable to large public institutions with inadequate resources, (2) for incoming students with limited knowledge of engineering and declining science and math skills, and (3) in the face of burgeoning enrollments. For place-based educational institutions, now challenged by online education, we have asked three questions concerning how we can maintain the excellence of the education of engineers in the USA. How can we (1) best utilize the revolutionary technological advances affecting education, (2) complement them to improve our students' education, and (3) do so economically in large, public institutions? Our approach is to develop coordinated sequences of courses that involve (1) SPIRALing the students' education (Student-driven Pedagogy of Integrated, Reinforced, Active Learning) by reinforcing and extending their knowledge in a coordinated series of classes (vs. the inoculation approach of isolated lecture classes); (2) teaching by design to motivate learning via open-ended projects that involve modeling, simulation and construction, and competitions with finished devices, while also developing teamwork and communication skills; (3) tailoring projects to each course's technical material; (4) providing laboratory experiences that build towards the students' designs; and (5) using video lectures to complement textbooks so that class time can be better used for active learning. We have begun incorporating these elements into two, two-course sequences. The first-year sequence has a mechatronics and robotics theme and emphasizes engineering spreadsheet calculations, software skills, hardware, manufacturing skills, and programming and controls. The sophomore year sequence has a sustainability theme and emphasizes numerical methods and thermodynamics. Our emphasis is on developing a strong basis for spiraling knowledge into our junior level courses, particularly mechatronics, which has a year-long design project, and into our senior capstone design project course. We plan to have complete documentation of the guidelines needed for an instructor anywhere to self-start our new courses and once developed, these electronic/hardcopy manuals will be continually updated as our courses evolve.

**Anticipated and Actual Outcomes**: We are tracking three outcomes: (a) final exams (pre- and post-introduction of revised classes), (b) retention of knowledge, measured via exams at the start of the junior year, and (c) retention, tracking the names of students receiving upper-division status in the Mechanical Engineering program. The primary goal of the four new courses is to teach students the skills needed to develop, apply, and evaluate engineering models when designing engineering systems. Within each course, students learn and integrate the modeling, mathematical, experimental, programming and manufacturing techniques needed to complete a project. Modeling predictions are compared to the performance of the students' devices during the final competitions. Professional engineering skills to be improved are: (a) design methodology skills, i.e., ability to organize, manage and complete engineering projects, including problem definition, creativity, appropriate analysis, system integration, follow-through to construction and completion, economic considerations, design under uncertainty, testing and evaluation; (b) communication and teamwork skills developed through multiple design projects, which are natural vehicles for proposals, memos, design reviews, final reports and co-operative learning; and c) awareness of social, ethical, and environmental concerns.

**Assessment Information**: These courses are under development so full evaluation is not yet possible. Preliminary evidence from (a) final exam performance, (b) retention of knowledge, and (c) retention of students indicates that the students are learning the material better as measured by their final exam performance, that they are retaining knowledge better as measured at the beginning of their junior year, and that the new classes are helping us with retention of students. It must be emphasized that this information is very preliminary, with lots of confounding variables, and that eventual evaluation of its success can only come after the courses are more fully developed and refined, and evaluations performed using much more sophisticated tools, especially when evaluating our long-term goal of improving higher-level thinking skills.

**Funding/Sustainability**: Development of the first two course sequences was funded by a 3-year NSF CCLI grant of $200,000 ($148,480 in direct costs) used to hire graduate student TAs to help develop the materials. The Mechanical Engineering Department provided an additional TA every semester for development and implementation (~$20,000/year) and allowed reduced teaching/additional instructor time during course development. The Senior Vice-President for Academic Affairs provided $11,000 of flexible funding. We have worked closely with the College of Engineering's CLEAR program (Communication, Leadership, Education and Research), which provides communication instructors who help students with oral presentations, memos and reports, teamwork, and the required end-of-semester self-assessment exercises. CLEAR originated in Mechanical Engineering and spread throughout the college with a William and Flora Hewlett Foundation grant, which led to permanent funding from the University.

## Projects with Industry and Building Energy Use


**Lead Institution**: West Virginia University, Morgantown, WV

**Collaborating Institutions**: Government agencies, non-profits, industry

**Category**: Capstone/School-Government partnerships

**Date Implemented**: 1997

**Website**: [www.mae.cemr.wvu.edu](www.mae.cemr.wvu.edu)

**Program Description**: This program is designed as a capstone design experience for senior mechanical engineering students. The projects are supported by the West Virginia Division of Energy with the purpose of helping West Virginia industries, schools, and institutions to become energy efficient and competitive. It is taught each semester and different projects are developed for each class. The class is divided into teams of 4-7 students that focus on a particular industry, county school system, or other institution. The projects deal with a wide variety of topics including energy efficiency, heat recovery, building energy efficiency, manufacturing efficiency, and robotics. In industry projects, the student team goes to the factory or plant to be acquainted with the problem, take measurements, and meet company officials. They often go through safety training at the plant. More than one visit is conducted at the site as the project develops. They will spend the semester developing designs to resolve the task assigned. At the end of the project, they will write a final report which has been edited and corrected and give a final presentation to plant management and engineers. In the Building Energy Use Projects student teams look at all the schools in a West Virginia County and determine their current energy use using utility bills over a two-year period. The schools are benchmarked and compared to other comparable school in a large database. If the schools are at or above the 75th percentile in comparison, the school may be considered an Energy Star school. The student team must study the building and its operation to ensure compliance. The support of the West Virginia Division of Energy has made it possible to go to every corner of the state to perform these projects. The students get to leave the academic environment and be placed in the actual situation where conditions are not always ideal. Several master's theses have been derived from work on the various projects. These theses have resulted in very beneficial tools being developed for West Virginia schools and industries.

**Anticipated and Actual Outcomes**: Student outcomes are: (1) using teamwork and previously learned material to apply engineering design principles and related techniques to develop energy-efficient, environmentally friendly solutions for enhancing production; (2) enhancing writing, analyzing, and presenting skills; (3) learning new ideas and what engineers and companies do, equipping them to seek employment among industrial corporations; and (4) becoming a lifelong learner. In addition, the companies and school systems receive valuable information to use in manufacturing and energy efficiency efforts. Many students have reported in exit interviews that this program was the highpoint of their college experience and gave them a real sense of accomplishment. Many realized previously unknown leadership abilities and other talents. Alumni surveys show that this team-oriented design project helps with current jobs. Many companies and school systems have realized millions of energy units in savings, and many companies have hired some of the students in the teams. Some of those students who were hired have brought in new student teams from our program because they realize the value of the program. County School Systems have used the results of the student projects to save energy, certify eligible buildings as Energy Star Buildings, and seek funding for energy renovations.

**Assessment Information**: The student projects are continually being upgraded and evolved as new technology enters the workplace. New software for modeling is now in use, making the students more valuable to employers as they seek jobs. We are also developing expert systems for use with plants and school buildings to help administrators make the right energy choices. These will be continually upgraded as the program moves on. We also use the feedback we get from companies and school officials to improve the way we conduct the student projects. Assessment is performed by the state agency in three ways. First, quarterly reports are submitted to the West Virginia Division of Energy giving a full account of current and future projects, the number of students involved and the topics of study. Second, when final presentations are given by the student teams at their respective project sites a member of the agency attends the presentation to review the work. Third, every item spent on the operation of the program is reviewed by the agency officials. We perform a self-assessment based on the project results and the feedback obtained from the industrial partners and the school systems.

**Funding/Sustainability**: Initial funding was approximately $40,000 per year for industrial assistance to West Virginia industries. Some special emphasis was placed on the glass industry in the early years of funding. The project scope has grown to include assistance to buildings and school buildings in particular. The current funding level is $100,000 per year. This money is used for professors' salaries, graduate assistant salaries, student team travel to the project sites, instrumentation, and computers for the design laboratory in the Engineering Sciences Building. The source of this funding is the West Virginia Development Office and the West Virginia Division of Energy.

## The Scaffolded GVSU Co-op to Interdisciplinary Industry-based Capstone Project Program

**Lead Institution**: Grand Valley State University, Allendale, MI

**Collaborating Institutions**: Over 220 partner organizations from 1993 to 2011, including for-profit industry partners, governmental (municipalities, state/federal entities), and educational (primarily other universities)

**Category**: Co-Op

**Date Implemented**: August 1987

**Website**: www.gvsu.edu/engineering

**Program Description**: The objective of this program from its inception has been to prepare graduating engineers who are truly "industry ready" as they move from their undergraduate programs into the industry sector. The major activities of this program include: (1) A cooperative education program that is integrated into the undergraduate experience for all engineering students. Elements of this include: a cooperative education preparation course that provides the students with background regarding the expectations of employers, real-world ethics case studies, and the processes for placement with an employer; three semesters of co-op experience which are supervised by both an industry supervisor and a faculty member, including work experience, reflective journaling, online modules addressing topics such as ethics and engineering economics, and faculty site visits. (2) The industry-sponsored interdisciplinary capstone project program, in which interdisciplinary teams of engineering students are formed into "contract design and build" project teams; all projects are sponsored by industry partners drawn from the co-op employer base who act as customers; engineering faculty guide the student teams and act as additional technical and managerial resources; and the finished products are delivered to the sponsor companies and generally go into immediate use in production, testing, or new product introduction. A project is deemed to be successfully completed when it is accepted not only by the faculty, but also by the industrial sponsor. In addition to academic reporting and design documentation, typical project deliverables include user's guides and troubleshooting manuals. The units involved in this "scaffolded" approach to preparing graduates for engineering practice include all engineering disciplines engaged in the cooperative education program through supervision of co-op students (computer, electrical, interdisciplinary, mechanical, product design & manufacturing) and the Career Services Office and the Career Counseling Center, which partners with the School of Engineering in the preparation, placement, and supervision processes for co-op students. All engineering disciplines engage in the capstone project program through team teaching of the courses and supervision of the projects.

**Anticipated and Actual Outcomes**: Many of the program outcomes outlined by ABET are formally identified and regularly assessed as outcomes for this program. ABET outcomes d, f, g, h, j, and k are formally assessed during the co-op program, including direct feedback on individual students by industry supervisors from the student's workplace. ABET outcomes c, d, i and j are formally assessed during the capstone senior project. Students have achieved levels of 75% or higher for all program outcomes identified. Other outcomes realized through this program include high retention and graduation rates of students in the academic majors, regular interaction with industry partners that have led to several industry-sponsored projects in other courses at the junior and senior level in the curriculum, and a high rate of success among the students sitting for the FE exam each year.

**Assessment Information**: The assessment plan for the co-op experience consists of assessment of students every semester from early in the junior year through the time of graduation by industry supervisors. In addition to ABET outcomes, each student is assessed for their work habits, completion of work products, technical knowledge and competence, and interaction with others inside and outside the organization. In addition, the faculty adviser for each student conducts visits to each worksite and meets with the student and worksite supervisor to review the student's work. Students also complete assessments of their co-op experience. The senior capstone program is assessed yearly for ABET outcomes. In addition, industry partners on the projects provide continuous, real-time feedback to the students and faculty coordinators as the sponsored projects are being completed. This assessment data is reviewed and evaluated at least once per year by each academic program and is used for continuous improvement of each program on an annual basis.

**Funding/Sustainability**: Creation of the cooperative education component was supported by over $300,000 in funding from our industrial partners to support faculty time. Creation of the senior project program is funded by participating companies and ranges from approximately $75,000 for the first year of operation to up to $250,000 in recent years. Support has been continuous since 1987 for the co-op program and 1998 for the capstone project program. Sustainable funding for the cooperative education program has been accomplished through creating an endowed chair to play a primary role in coordinating the engineering co-op program, hiring an Associate Director and Director of Engineering Cooperative Education within the Career Services Office, and integration of the supervision of co-op students within the teaching assignments of engineering faculty, which results in the use of approximately 2 FTE faculty each year. This is an element of the ongoing base budget for the School of Engineering.

## McCormick Office of Career Development

**Lead Institution**: Northwestern University, Evanston, IL

**Collaborating Institutions**: Industry, non-profits, government

**Category**: Co-Op

**Date Implemented**: 1940

**Website**: [http://www.mccormick.northwestern.edu/mcd/](http://www.mccormick.northwestern.edu/mcd/)

**Program Description**: The Office of Career Development is a radical expansion of what was once a renowned co-op program and now serves nearly all engineering undergraduates and graduate students at Northwestern. Its overarching objective is to enable students to set themselves on a path to a professional pursuit of their own making. The McCormick Career Development programs provide opportunities for students to have industry experience (co-op or internships), service learning projects, or employment in research laboratories. These opportunities are built upon the Engineering First® curriculum, including the course sequences, Engineering Analysis and Engineering Design and Communications. Students leverage these team project experiences into real-world positions in industry, government and the non-profit sectors. McCormick students are offered the Introduction to Career Development course (CRDV 301), in their first or second year. The course is taught by adjunct faculty who are working professionals in engineering organizations and the topics addressed in this course equip our students with the tools necessary to acquire their first position as an intern or in co-op and to manage a lifelong career in the professions. Finally, potential employers coming to campus for narrowly defined hiring searches may become partners with this office and may offer placement opportunities to prepared students. External partners aim to provide a high-quality, meaningful and challenging work experience for our students, and to provide timely feedback on performance in each of the ABET criteria for the assessment of student learning outcomes. Undergraduate and graduate students in all academic departments and all major programs of study participate in this office's programs. Faculty provide academic advising that dovetails with the career advising offered by McCormick Office of Career Development.

**Anticipated and Actual Outcomes**: It was predicted that we would expand many programmatic elements and thereby be serving 30% participation in career development programs. The student response was nearly double what we expected, at 55% of undergraduates in an internship, co-op or service-learning arrangement, or paid position in a research lab. The first increase that we experienced was in the enrollments for CRDV 301, which was initiated as a beta test version in the fall quarter of 2007. One section was offered and 15 students enrolled. By the end of the spring quarter of 2008, an additional 85 students had completed the course. Beginning in the fall of 2008, CRDV 301 was established as a prerequisite for students entering the Co-op Program or the Engineering Internship Program and enrollments have averaged 268 students per year since the fall of 2009. The second major development was to add the opportunity for students to work as research assistants in university or government labs, applying the same "work-integrated learning" principles that are present in the co-op and internship experiences. At the same time, in fall 2009, we added a program called Engineering Projects in Service Learning for students whose work would be as volunteers in the non-profit sector, again applying the same principles as the co-op and internship programs. We now serve over 800 undergraduates in the combined programs of co-op, internships, service learning, and research experience. With approximately 1500 students in the baccalaureate engineering programs, 53% of these students are now engaged in the process of gaining experience through career development. Although none of these programs are required of students at McCormick, it is clearly becoming a choice that many students make because they see the value of integrating theoretical and practical knowledge to become whole-brain engineers. As of spring quarter, 2012, engineering students at Northwestern University also have the opportunity to earn co-op or internship recognition through a combination of part-time work and part-time classes. Graduate students have the same opportunities.

**Assessment Information**: All student work is subject to a comprehensive, and penetrating, evaluation process, using input from both the student and their supervisor in industry, labs, or non-governmental organizations. This assessment directly measures student learning outcomes in the competencies that are required for ABET accreditation. These evaluations are discussed first with the student's career advisor and then with the academic advisor. Finally, aggregated data are sent to each department for all of the majors offered by that department for purposes of curriculum review. The McCormick School applies performance metrics that must be met, and the University continuously operates its Program Reviews process. Student learning outcomes are assessed at the end of each work term by the student's workplace supervisor; simultaneously the students evaluate the quality of their experiences at the end of each work term. Students participate in quarterly check-in meetings with their career advisors after each work term, an exit interview at the end of their graduation year, and a survey evaluating the programs and services of McCormick at graduation time.

**Funding/Sustainability**: Current operating budget (non-personnel) is approximately $50,000 per year. The funding sources include $34,000 institutional funds and $16,000 revenue from a career fair. McCormick Office of Career Development receives a full commitment of support from the Dean of the McCormick School of Engineering and Applied Science because of its long history of providing students with opportunities to begin their careers while pursuing their degrees, thereby integrating real-world practice with class-based theory.

## The iProjects Program at ASU Polytechnic

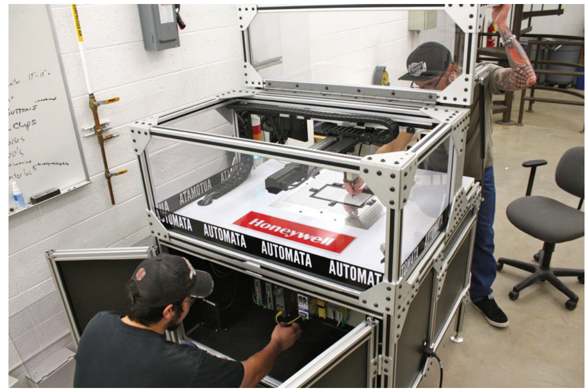
**Lead Institution**: Arizona State University, Tempe, AZ

**Collaborating Institutions**: Industry, government, community

**Category**: Course/Curricular

**Date Implemented**: Pilot in fall 2008, full implementation fall 2011

**Website**: [https://technology.asu.edu/sips](https://technology.asu.edu/sips)




**Program Description**: The iProjects program at the College of Technology and Innovation (CTI) on the Arizona State University Polytechnic campus is designed to be a pervasive college-wide team program that is highly multidisciplinary, practice-based and open to all 35 degree programs in the five primary units within the College. The iProjects program included a number of challenges: a need for large numbers of team-based projects, a recognition that traditional academic degree program structures do not engender pervasive interdisciplinary practice-based work, a space conducive to student teams and project work, mentorship of student teams, and a new financial model. An early phase of the process consisted of benchmarking educational models within engineering used by other colleges and universities, resulting in changes in academic program structure such as establishing a common time for all students in CTI to meet for interdisciplinary projects. Curricula were designed to be project intensive, with project experiences included in multiple years of the curricula, giving students opportunities to develop the skills to work on teams and to manage projects over multiple projects. Strong external engagement was fostered by meeting with dozens of potential external partners. Space was repurposed into studios and laboratories for project realization, as well as a large highly reconfigurable team space called "Start-up Labs" where student teams have space to generate and develop ideas and work on projects. Project mentors were hired who focused on project realization and provided workshops for faculty. The external community (alumni and skilled managers) has been engaged to voluntarily mentor teams. A financial model was developed whereby the program can be scaled based on enrollment. Within this model, sufficient funds are generated not only to maintain projects completion but to improve the infrastructure supporting the programs. Residual funds are allocated to program support staff and non-industry-sponsored student teams. In addition, a new project class has just been launched called "Start Your Enterprise," where we partially fund student teams as they launch their own businesses. The external partners have similar objectives: recruiting students, solving a problem for the company, developing a long-term relationship with the CTI and partnerships with other industries and constituencies with the college as an intermediary, and philanthropy.

**Anticipated and Actual Outcomes**: The College outcomes include the development of meaningful partnerships with external constituencies, professional development of faculty members to enable quality student learning in the context of authentic practice-based projects, placement of students upon graduation with external constituencies, and the development of broader relationships with external constituencies, including training and research partnerships. The student outcomes for the iProjects are linked to the individual program outcomes. The broad outcomes include a mix of technical and professional skills that reflect what is expected of successful practitioners in industry. In terms of design and problem solving, the product realization has been outstanding and has received rave reviews from the industry partners. We have found that students develop a shared appreciation for the value of differences in skills and approaches and are learning how to communicate across disciplines. The reports and presentations being delivered by these teams are more polished and richer in terms of content and the breadth of the project solutions.

**Assessment Information**: Individual projects are assessed, as is the student learning, by faculty and the industry sponsors. This happens at a minimum of one each semester but some projects/sponsors assess project progress as often as every two weeks. The CTI holds meetings with the industrial partners twice a year for assessment of the broader program. There is an internal iProject committee that evaluates the program annually. The engineering education programs have ABET accreditation cycles that include the projects and the overall program as a critical component of the student's demonstrating successful attainment of the attributes included in ABET criteria.

**Funding/Sustainability**: In the first year, two department chairs worked on the implementation along with one external consultant. Faculty were assigned projects as part of their teaching load in the normal mechanism of meeting programmatic obligations, thus no extra cost was associated with their participation in the first year. Project funding was provided by the external sponsors and the typical student project budget was $10,000. For the first year, the staff, chair, and travel budgets were sourced from the department budgets. Since the first year, all funding has come from industrial sponsors and, in a few cases, student program fees for any non-industry-sponsored projects. Industry sponsors fund by the year/project, although several companies have obligated themselves for multiple years. There has been no internal ASU funding allocated since the first year's contribution from the departmental budgets. The iProjects program has become institutionalized and a part of the College strategic plan. The program is configured to be self-supporting in a financial sense, using both the industry sponsorship as well as special program fees assessed of the students.

## Laboratory for Innovative Technology and Engineering Education

**Lead Institution**: Auburn University, Auburn, AL
**Collaborating Institutions**: U.S. and international companies; universities, high schools, camps, industries; Hampton University researches effects of implementation; University of West Georgia provides external evaluation
**Category**: Course/Curricular
**Date Implemented**: August 1996
**Website**: www.litee.org


**Program Description**: LITEE is a collaborative effort between the Samuel Ginn College of Engineering (P.K. Raju, Director) and College of Business (Chetan Sankar, Co-director) that disseminates cutting-edge instructional materials and strategies to undergraduate classrooms. Through case studies and hands-on projects, LITEE works to enhance the skills of engineering students by developing their decision-making, leadership, communication, and holistic problem-solving skills, providing an opportunity to apply technical skills to solve practical problems. LITEE works with industrial partners to identify a problem and bring it alive in the classroom by creating a multimedia case study. Faculty and graduate students from the Departments of Mechanical Engineering, Management, Psychology, and Educational Foundations, Leadership, and Technology collaborate to create case studies, implement them in department courses, and evaluate their effectiveness. Each case study is tested for pedagogy and content with faculty and students at different institutions. Eighteen case studies have been developed and are being used at 60 US colleges and universities as a result of the LITEE Case Study National Dissemination Project, through which instructors are chosen to test case studies in their classrooms and publish their findings. Over 10,000 engineering students have been impacted, and LITEE conducts workshops to give over 1,000 faculty and instructors hands-on experience with cases to help better utilize them. LITEE includes a generic instructional strategy that can be adapted to teach a wide range of courses using case studies. The instructional strategy steps are: develop a course map identifying the required content of a particular course, the capabilities students are expected to develop in it, and how the case study can best be used to teach the content and achieve the expected capabilities; use the course map and new instructional strategy to teach the course, including preparation, application, and assessment; and evaluate the effectiveness of the implementation and refine the strategy as necessary. LITEE also conducts a U.S.-India Research Program, providing students with a rich cultural and research experience working on a problem, with the results transformed into case studies showcasing global engineering issues.

**Anticipated and Actual Outcomes**: The instructional strategy was expected to increase students' engineering self-efficacy, or confidence in their engineering abilities, which would lead to better performance in the classroom and an increase in the retention of engineering students. The team also anticipated an increase in students' perception of their own higher-order cognitive and team working skills. Finally, they hoped for an improvement in students' grades. The results thus far show that students, especially female and minority students, in sections using LITEE case studies tend to consider that their higher-order cognitive skills and team working skills have improved significantly, as has their intention to stay in engineering programs. Longitudinal evaluation has shown that students from these groups also tend to have higher college grade point averages. These results suggest that the LITEE curriculum employed for the engineering students leads to improved student learning and advancement in engineering. Additionally, the undergraduate and graduate students who participated in the development of the LITEE curriculum and are now working in industry overwhelmingly report that their interpersonal skills, written communication skills, presentation skills, leadership skills, teamworking skills, and project management skills had all improved .

**Assessment Information**: The LITEE team embarked on a systematic evaluation of the instructional strategy using an evaluation team composed of statistical and education experts. Several multimedia case studies were developed and used as a primary instructional mode in Auburn freshman engineering classes over a 2-year period. Answers to survey questions provided by students in the comparison and experimental groups were compared to determine whether there were any significant differences in achieving the needed learning outcomes. Students were longitudinally tracked in order to determine the impact, if any, of this innovative teaching approach on their GPA. The longitudinal evaluation revealed markedly higher GPAs for students from the experimental classes, as well as higher acceptance rates into professional programs (mechanical, electrical, etc.) within the College of Engineering. These results suggest that an instructional approach using multimedia case studies is indeed an innovation that leads to improved student learning and advancement in engineering.

**Funding/Sustainability**: The program has been funded by NSF and industry support. Approximately $3.5 million has been used to design, develop, and implement the program. The LITEE team also trains doctoral, master's, and undergraduate students in conducting research on engineering education. To date, the team has trained more than 80 undergraduate, 40 master's, and 8 doctoral students. The program received a five-year $3 million IGERT grant from NSF to expand the curriculum to teach graduate students real-world issues. In addition, LITEE is currently working with a private company, Toolwire, Inc., to develop immersive scenarios based on the multimedia case studies. In order to promote scholarship in STEM education and disseminate research results, LITEE publishes the Journal of STEM Education: Innovations and Research (www.jstem.org). The Journal features high-quality case studies and research articles that showcase the latest in STEM education research.

## NAE Grand Challenge Scholars Program at Duke University

**Lead Institution**: Duke University, Durham, NC

**Collaborating Institutions**: The Franklin W. Olin College of Engineering, University of Southern California's Viterbi School of Engineering

**Category**: Course/Curricular

**Date Implemented**: February 2009

**Website**: [http://www.pratt.duke.edu/grandchallengescholars](http://www.pratt.duke.edu/grandchallengescholars)

**Program Description**: The five components of the National Academy of Engineering (NAE) Grand Challenge Scholars Program are: (1) Project or independent research related to a Grand Challenge. (2) Interdisciplinary curriculum that prepares engineering students to work in domains of public policy, business, law, ethics, human behavior, risk, medicine, and the sciences. (3) Entrepreneurial experience that prepares students to translate invention to innovation. (4) Global dimension that enables students to lead innovation in a global economy. (5) Service learning experience that deepens the students' motivation to bring their technical expertise to bear on societal problems. The Duke program educates engineering undergraduates to have the technical expertise, breadth of knowledge, and the social, ethical, and environmental awareness to successfully pursue leadership positions in addressing the NAE Grand Challenges for Engineering. This is accomplished by requiring each GC Scholar to propose and complete a five-component GC portfolio, and by completing a GC senior thesis. All undergraduate students in the Pratt School of Engineering at Duke are eligible to participate in the NAE GC Scholars Program, and are free to pursue affiliation with a broad array of programs at Duke University as long as it is endorsed by the GC Faculty Advisor and is approved by the GC Scholars Program Steering Committee. However, certain programs are more facile fits to the GC Scholars Program; consequently the majority of our GC scholars have affiliated with the following programs: Duke Engage Program, Pratt Fellows Program, Pratt Smart Home Fellows Program, Pratt Engineering World Health Program, Pratt Engineers Without Borders Program, and the Center for Entrepreneurship and Research Commercialization. Within the Pratt School of Engineering of Duke University, all departments have been represented in the Grand Challenge Scholars Program. These departments are Biomedical, Civil and Environmental, Electrical and Computer, Mechanical, and Materials Science.

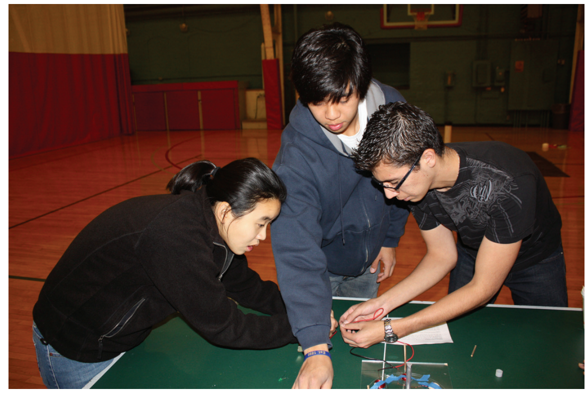
**Anticipated and Actual Outcomes**: The goal of the first two years is to foster the early engagement of engineering undergraduates who may be interested in pursuing a Duke NAE Grand Challenge Scholars designation. It is recommended that interested underclassmen participate in GC-related curricular (course credit) or extra-curricular (no course credit) activities, and engage in organized and informal discussions with faculty and students involved in the GC Scholars Program. Students interested in receiving a Grand Challenge Scholar designation must submit a proposal to the Pratt GC Scholars Committee prior to Thanksgiving Break in the first semester of their junior year. The GC Scholars Steering Committee reviews proposals and successful candidates are notified early in the spring term. The proposed GC portfolio and written GC senior thesis both must be completed by the close of finals period prior to graduation. It is expected that senior GC scholars will present their work in Pratt GC-related activities to network with other scholars and to provide information to interested underclassmen. Senior GC scholars also should plan to attend the national GC Summit to present their work and to network with GC Scholars from other participating engineering schools.

**Assessment Information**: Each Scholar and Faculty Advisor formulate a Portfolio in which the student must show in-depth completion of a (1) research-based or project-based practicum and (2) an interdisciplinary curriculum composed of an engineering major and a series of at least two additional non-engineering courses, both specifically linked to one of the Grand Challenges. "In-depth" is defined as three or more regular semester classes, independent studies, or the equivalent. The student must also show medium or minimum depth completion of (1) an entrepreneurial component on the process of translating invention and innovation into market ventures that is thematically linked to one of the Grand Challenges, (2) completion of a global component that instills awareness of global marketing, economic, ethical, cross-cultural, and/or environmental concerns, and (3) a service-learning component that deepens social awareness and heightens motivation to develop practical solutions for society's problems. "Medium-depth" is defined as at least one of the following: a practicum immersion experience or research activity that spans an 8-week summer or a regular semester, or one regular semester class or independent study. "Minimum-depth" is defined as a semester or less of extra-curricular experience such as a volunteer activity, short course, workshop, seminar series, or conference.

**Funding/Sustainability**: Estimated funding for the first year of the program was $100,000. This includes budgets for the first two classes of Scholars. The Pratt School of Engineering and generous donors sponsored the initiation of the program. An endowment was secured from a generous donor, and additional foundation support has been secured for the program. The program is reviewed annually by the GC Scholars Steering Committee consisting of the directors of undergraduate studies in each of the four academic departments and the directors of Duke Engage Program, Pratt Fellows Program, Pratt Smart Home Fellows Program, Pratt Engineering World Health Program, Pratt Engineers Without Borders Program, and the Center for Entrepreneurship and Research Commercialization.

## Bernard M. Gordon-MIT Engineering Leadership Program

**Lead Institution**: Massachusetts Institute of Technology, Cambridge, MA
**Collaborating Institutions**: Industry, Government, Penn State University, Tufts University, Northeastern University, University of California-San Diego, Rice University, Southern Methodist University, University of Florida, Iowa State University, University of Toronto, U.S. Naval Academy, and U.S. Air Force Academy
**Category**: Course/Curricular
**Date Implemented**: September 2008
**Website**: http://web.mit.edu/gordonelp



**Program Description**: The major objectives are to (1) educate and prepare future engineering leaders of innovation, invention, and implementation efforts, and (2) endeavor to transform engineering leadership in the nation, thereby significantly increasing its product development capability. The Gordon Engineering Leader program (GEL) links (a) immersive experiences on- and off-campus in which students practice, observe, and discuss engineering leadership with (b) courses that provide conceptual and analytical models and frameworks that support engineering leadership with (c) reflection, evaluation and feedback from faculty, peers, program alumni, and experienced engineering industry mentors on lessons learned from activities. Rising juniors and seniors apply for the GEL Year One (GEL1) program consisting of courses in engineering leadership and engineering innovation and design, hands-on engineering leadership labs and projects, mentorships, and a personal leadership development plan. Students who successfully complete GEL1 may apply for the more intensive GEL Year Two (GEL2) program of courses in project engineering and planning and human and organizational contexts, additional engineering leadership labs and projects, a substantial internship, additional mentoring and coaching, increased leadership roles, and a final presentation of their personal leadership development plan. GEL includes experiential learning opportunities for the development of leadership capabilities in weekly two-hour Engineering Leadership Laboratories (ELLs), set in an industry context, that provide practice and feedback on one or more of the capabilities of effective engineering leaders. Sophomores prepare for the program by participating in an introduction to engineering practice, an introductory internship, personalized coaching, reflective activities, and practice in interpersonal and career-enhancing skills. For non-GEL engineering undergraduates, we partner with departments and provide classes, materials, and activities to promote leadership capability development. The Program is also part of a collaboration of like-minded academic institutions that meet to discuss and implement strategies to advance the practical and pedagogical principles of engineering leadership and to share lessons learned and best practices. We also partner with industry to develop the leadership capabilities of early-career engineers by sharing materials and approaches, discussing the creation of workshops and professional courses, and including their engineers in courses, projects and labs, and as mentors.

**Anticipated and Actual Outcomes**: Expected student performance outcomes include increased proficiency in the 30 Capabilities of Effective Engineering Leaders, which are grouped as: Attitudes of leadership; Relating; Making sense of context; Visioning; and Delivering on the vision. Students are assessed weekly in the ELLs. In addition, GELs, through their Personal Leadership Development Plans, self-assess these outcomes, identify areas to improve, and create action plans to improve targeted areas. Although it is too early to judge the careers of our students, GEL students have received employment offers from companies impressed with their internship performance. Also, companies who have sponsored interns, in addition to requesting more interns, have become involved as mentors, ELL observers/evaluators, guest speakers, or contributors of authentic data/information to enhance the ELLs. On a survey of all graduating seniors, GELs had higher confidence in (1) making decisions given uncertainty and (2) recognizing when to stop improving a product and focus on implementation compared to non-GELs in engineering, and higher confidence than graduating seniors in the Sloan School of Management.

**Assessment Information**: Prior research on practice-based learning for development of engineering capabilities and self-efficacy in selection and pursuit of an engineering degree have guided the design of the curriculum and the emphasis that is placed on the experiential and real-world nature of the ELLs. Program success is noted by 90% of applicants citing strong recommendations from current students as the primary reason for applying. ELLs student leaders are evaluated, GELs perform self-assessments, self-reflections, and create plans for improvement of leadership capabilities, and GEL2s are required to create and present a portfolio of evidence of their capability development. Assessment of leadership self-efficacy included a pre-/post-test survey in 2010-2011; GELs rated their self-confidence that they could "Persuade a team to give up on an approach that at the moment only you see why it cannot succeed," and "Help team members arguing for very different strategies arrive at a choice they can all support." Confidence increased significantly for most statements, except the statement "Raise critical questions that reveal both strengths and weaknesses of a team member's new idea," resulting in revising the ELL on inquiry/dialoguing/advocacy.

**Funding/Sustainability**: Initial program funding was from the Bernard M. Gordon Foundation, with an overall pledge of $20M over 10 years and a requirement of matching funds to be raised by 2020. The matching and additional funds are being raised through fundraising, industrial grants, contracts and gifts, and a start-up contribution from the Dean of Engineering. It is anticipated that as the Program grows and achieves increased notice, it will receive additional donations from alums and companies who have hired graduates and will become self-sustaining from those donations and from endowment earnings.

## Beyond Traditional Borders

**Lead Institution**: Rice University, Houston, TX

**Collaborating Institutions**: Academic institutions, healthcare organizations, non-governmental organizations, and government agencies

**Category**: Course/Curricular

**Date Implemented**: 2005

**Website**: www.btb.rice.edu

**Program Description**: The Beyond Traditional Borders (BTB) design curriculum teaches undergraduates from all majors to use the engineering design process as a framework to formulate solutions to complex health challenges identified by a global network of clinical partners delivering healthcare in low-resource settings. Students work in interdisciplinary teams to develop and implement technologies in response to the challenges, and clinical partners mentor teams as they use the engineering design process to develop their technologies. Students identify design criteria; design solutions; build, test, and refine prototypes; and present work to multidisciplinary teams of mentors, working on increasingly complex design challenges as they progress through the curriculum and invest in their designs because they want to produce a useful intervention to improve global health, not simply to earn a good grade. Exceptional students undertake extended summer internships to implement their technologies in hospitals and clinics in the developing world. Under the guidance of trained healthcare providers, interns are expected to: demonstrate technologies and gather feedback; develop and implement a solution to another barrier to health care identified by the host site; and pinpoint a new challenge for which a solution can be developed and implemented. U.S. academic institutions collaborated to develop the original curriculum and continue to provide design challenges and mentorship. Healthcare organizations in low-resource areas in the developing world and U.S. help identify design challenges, mentor students, give feedback, and host interns. Foreign academic institutions provide formal research opportunities. One technology was licensed to industry, students have filed 8 provisional patents with 3 converted to utility patents or patents pending, and students have developed 58 designs used in 21 countries to care for 45,000 patients.

**Anticipated and Actual Outcomes**: BTB was designed to: (1) create an interdisciplinary cadre of graduates that would become the next generation of leaders in global health and (2) teach a diverse group of students how to use science and engineering for humanitarian benefit. Another objective was to develop new technologies to implement in resource-poor settings to improve health outcomes and reduce global health inequities. In addition to learning the engineering design process, it was anticipated that students would learn cross-disciplinary and cross-cultural problem-solving and leadership skills, preparing them for careers and graduate education in global health technology. Students participating in either BTB design courses or other Rice courses with a civic research component were surveyed. More BTB students reported the course project enhanced skills in: creativity (60% BTB; 28% other); leadership (78% BTB; 44% other); ability to effect social change (60% BTB; 40% other); and ability to solve real-world problems (94% BTB; 76% other). A survey showed that 95% of international interns intend to include global heath in their careers.

**Assessment Information**: The program is assessed according to the following questions: (1) How is the program valuable or not for students in the short or long term? What are student, faculty, and international partner perspectives on the students' experiences? Indicators include number of students who pursue higher education or careers related to science/global health technologies and number of technologies developed and disseminated that improve global health. Surveys, student career paths, mentor feedback, student focus groups, student outcomes, and the impact of current and future designs are used for assessment. (2) In student achievement and future career directions of undergraduate students, what is the relative value of project-based courses, local research experiences, international research experiences, international internships, and programs integrating all approaches? Indicators include student value of experiences; persistence in related research and development activities; participation rates in multiple programs; and publications resulting from participation. Course-instructor evaluations, student team evaluations, exit questionnaires, alumni surveys, student and faculty vitas, publication searches, citation impact, and peer review through an external evaluation committee are used for assessment. Alumni are just entering their careers, but four student-authored papers have been published in peer-reviewed journals and student teams have won 18 competition awards.

**Funding/Sustainability**: The program was implemented with \$2.2 million over 4 years. Students work on their technologies in the Oshman Engineering Design Kitchen, a 12,000 sq. ft. space for undergraduate students with ready access to design tools, prototyping equipment, computational facilities, meeting rooms, and ample space for prototype design and development. In addition to global health technologies, the OEDK supports design projects across a wide variety of topics. Funding was provided by the Howard Hughes Medical Institute through its Undergraduate Science Education Program. Rice provided support for staff salaries and philanthropic funding for internships and design teams was also received. BTB has been institutionalized as a minor in global health technologies, which has engaged more than 10% of undergraduates since 2006. Women represent 65% of students in the minor's core courses; underrepresented minorities represent 18%. The design courses in the program and the facilities to support the efforts of the design teams are operated primarily with institutional support. Currently, the international internship is primarily supported with grant funds; however, the program is steadily expanding through philanthropic support for internships and design teams.

## A Field Robotics Program for Real World Undergraduate Education

**Lead Institution**: Santa Clara University, Santa Clara, CA
**Collaborating Institutions**: Government agencies, commercial partners, non-profit entities, academic partners
**Category**: Course/Curricular/Interdisciplinary
**Date Implemented**: 1999
**Website**: rsl.engr.scu.edu

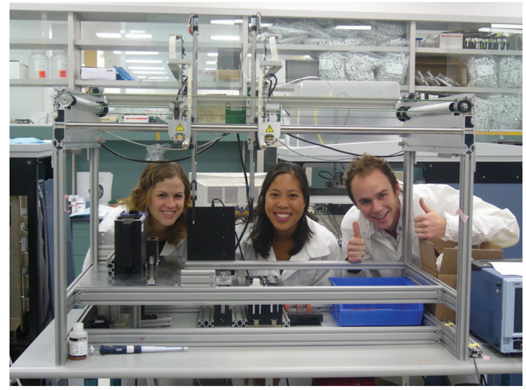
**Program Description**: This interdisciplinary field robotics program run by the Santa Clara University (SCU) Robotic Systems Laboratory (RSL) is an integrative education program in which teams of students design/fabricate/test/demonstrate high-quality robotic systems that operate on land/sea/air/space and meet the specific needs of external clients. The nature of the program was influenced by the robotics-oriented interests of the lead faculty member and the need to simultaneously serve the teaching and research demands on faculty. Once a field-oriented robotics program was identified as the objective, financial demands naturally led to the pursuit of development projects with paying clients. These projects have included a wide range of partners from government, industry, academia, and the non-profit sector. Over the past decade, interdisciplinary projects have involved faculty and students in a variety of academic departments, including mechanical, electrical, computer, civil, and bio-engineering, math/computer science, physics, archeology, and business. Specific objectives are to: (a) provide real-world, hands-on, interdisciplinary engineering education experiences, (b) provide project-based learning initiatives spanning cradle-to-grave product lifecycle, specifically including the challenges of producing, maintaining, and operating a robust field-capable system, (c) require students to plan, organize, and manage a team, development process, and operational activities in a fiscally and logistically sustainable manner, (d) work with customers to identify and solve problems cost-effectively, (e) provide engineering challenges that require research-oriented technology advancements, and (f) engage in compelling activities that inspire students. Projects engage students differently: junior/senior students target design challenges, cutting-edge capabilities motivate graduate researchers, and freshmen/sophomores are introduced to relevant technologies and practices by learning how to operate and maintain systems. Through the Kern Entrepreneurship Education Network (KEEN), we are working with other universities to provide students with opportunities that expose them to deep interactions with customers and demand the application of business acumen to the development and operation of advanced technical systems. Through the IEEE Real World Engineering Projects program, we will share curricular elements with universities throughout the world.

**Anticipated and Actual Outcomes**: Anticipated outcomes included: (1) learn advanced concepts and practices; (2) apply science, math and engineering principles to the design of advanced systems; (3) work with clients to understand needs, translate needs to requirements, manage implementation of requirements through a development process, and verify the achievement of requirements and needs upon completion; (4) manage development and operational activities to include creating fiscally and logistically sustainability strategies for long-term program viability; (5) engineer complete systems with the quality required to meet the demands of real-world operation and a client-oriented program; and (6) develop technical innovations that improve client value through increased performance, faster response, and improved cost-efficiency. We routinely reach capacity, and feedback from students, graduates, industry mentors, and department industrial advisory boards consistently supports the notion that we are providing exciting and novel opportunities for undergraduate engineering students. Evidence shows improved senior capstone project performance for robotics-oriented projects, and long-term client relationships and funding continuity showcase RSL's value. Several publications include student authors and serve as a strong record of the level of technical innovation.

**Assessment Information**: Student learning is assessed based on the educational mechanisms used to support their participation, which may be different within a project given that students may be involved in different ways. Students participating in a project as part of a senior capstone program are assessed based on the established norms of the capstone program (designed to meet ABET requirements). Younger students may be involved in the same project as part of a 1-unit course in either marine operations or satellite operations. These courses teach students basic concepts relating to marine/space systems, how these systems are built and function, and how to safely and efficiently maintain and operate these systems. Students participating through such courses are evaluated based on the approved assessments for those classes. Students active on a project through other mechanisms (e.g., independent study, graduate research, internship) are assessed in a manner consistent with those educational activities. Through KEEN, we assess student learning at a programmatic level through detailed inventories assessing the maturation of student competencies and characteristics over their four-year program.

**Funding/Sustainability**: Although this program has been supplemented by education-oriented financial support, much of the funding results from customers who provide financial support for the system to be developed. Support is priced commensurate with the work and value provided, not based on a pre-set nominal fee. Systems are maintained and operated over subsequent years, and new students are trained to manage, maintain, and operate the systems in order to provide long-term services. Funding, at an average level of several hundreds of thousands of dollars each year, has been consistently secured through a variety of clients throughout the past decade. We will continue developing systems that specifically address the needs of clients that can afford to pay for our services and systems.

## Team Internship Program (TIP)



**Lead Institution**: University of California San Diego, San Diego, CA

**Category**: Course/Curricular/ Industry/Internship

**Date Implemented**: Summer 2003

**Website**: www.jacobsschool.ucsd.edu/TIP

**Program Description**: Through UC San Diego Jacobs School of Engineering's Summer Team Internship Program (TIP), students receive real-world industry experience in a multi-disciplinary team environment. This experience builds their leadership skills while developing critical systems engineering understanding. During the program, students work on-site with industry partners as a multi-disciplinary team focused on a significant engineering project. Students work as paid full-time employees over a 10-12 week period during the summer. Teams consist of 2-5 members, each with distinct engineering experience and training. Participants can be at the undergraduate, master's, or Ph.D. level. The program is available to all engineering majors and in some cases teams will include MBA, cognitive science, visual arts, or other majors from UCSD or other universities. The majority of the internship projects are located in San Diego or Silicon Valley but also include opportunities for students to work internationally. Past international teams included projects in China, Germany, India, Israel, Japan, Korea, and Liechtenstein, among others. TIP staff advertises the project, pre-screens student candidates, expedites the selection of teams, and provides team engineering training before students depart campus for their summer internships. In addition to the team approach, TIP is unique in that sponsors are required to pre-define a significant project for the students. As a result, students achieve innovative, high-quality outputs in a shorter period of time with noteworthy results, which in turn drive the return on investment (ROI) for the project sponsor. The added benefit is that the company sponsor is able to spend more time mentoring the team on the larger objectives rather than minute details, which reduces the effort required to supervise a single intern. The majority of the teams are multi-disciplinary, and by combining multiple majors and grade-levels on one project, the students are able to consult with one another to leverage their individual expertise and learn new skills across traditional engineering disciplines, thus building a systems approach to innovative thinking and problem solving. Starting with one team in 2003, TIP has placed 717 students on 248 teams with 66 different companies. Each year the program grows, involving more students and companies while retaining past sponsors.

UCSD Jacobs School of Engineering
Team Internship Program

**Anticipated and Actual Outcomes**: For the Jacobs School's students, TIP provides opportunities to embed themselves in real-world, hands-on, interdisciplinary industry engineering experience. Students enhance their communication and leadership skills while also developing critical team-oriented and systems engineering understanding. Students contribute to tangible outcomes including prototypes; product or process plans and evaluations; product re-design; technical documents; and patent applications. Our corporate partners' objectives are to hire top talent and get innovative ideas that they would not otherwise have through internal R&D efforts. Industry and government sponsors get: a targeted and streamlined recruitment campaign; exposure to future employees; competitive insights, fresh perspectives, and a unique valuation of a project; high potential in proofs, prototypes, products, and patents; and optimized cost efficiency along with maximized quality output. The majority of interns are offered continued part-time employment during school or full-time employment after graduation. In some cases, the company sponsors have completely shifted their intern strategy to the TIP model.

**Assessment Information**: The program is assessed both through final presentations by the students and through a survey of the students and the corporate sponsors. Students give a formal presentation on their project results to company managers and UCSD faculty and staff. This final presentation promotes TIP across the company and gives the interns the opportunity to present their ideas to a senior audience. At the conclusion of the internship each summer, students and company sponsors are asked to assess the program. Amongst the students surveyed in summer 2011, 63% were extended offers to continue their internships or for full-time employment; 67% of students stated that TIP influenced the focus of their studies and/or career aspirations; and 96% of student participants would recommend TIP to a friend. Amongst the companies surveyed in summer 2011, 100% said they would host a TIP team again. Sponsors value the following benefits of TIP (ranked in order): pre-screening of resumes, training in leadership, on-campus exposure, and on-campus interviews. On average, at least 2 patents result from TIP team work each summer.

**Funding/Sustainability**: The program has a budget of $6,000 plus the salary of 1 full-time staff member. The program's budget is re-evaluated each year based on metrics that involve industry value, student experience and innovation opportunities as well as program efficiency. The program sustains itself by converting Team Internship Program company sponsors into Corporate Affiliates Program members who pay a yearly fee ranging from $3,000 to $25,000. We are also considering a fee for access to the program from companies that are not members of our Corporate Affiliates Program. In addition, the sponsor companies pay salaries directly to the students. The corporations continually find value in the team internship format. For example, in the first year of the program, there was 1 team with 3 interns, and it cost the company less than $25k to support the team while the CEO remarked it would have cost him at least $150k to implement the project the students completed inside the company.

## Amherst Incorporating Diversity Education into the Engineering Curriculum: How Do We Train Students to Work in Diverse Teams?

**Lead Institution**: University of Massachusetts, Amherst, MA

**Category**: Course/Curricular/Diversity

**Date Implemented**: June 2006

**Website**: http://www.umass.edu/ice/igert/curriculum.html


**Program Description**: The initial goal of this project was to incorporate diversity education into the required undergraduate Chemical Engineering curriculum at UMass Amherst. Since the project's inception, the curriculum has been modified to include undergraduate Research Experience for Undergraduates (REU) students and two interdisciplinary graduate programs (Graduate Certificate in Cellular Engineering and NIH PREP). The objectives of the new curriculum were to (1) raise awareness about diversity in the engineering workplace among engineering students, including the current percentages of women and minorities at different professional levels and challenges faced by underrepresented individuals in these environments; and (2) educate students about the institutional policies and personal skills, including communication styles, negotiation styles, and management styles, that facilitate diversity in the engineering workplace. The activities included (i) developing lectures to formally discuss diversity issues such as the state of underrepresented groups in the engineering workforce, historical trends, and institutional policies that promote diversity; (ii) developing scenarios involving conflict resolution and diversity that students could role-play and discuss; and (iii) inviting female and minority guest speakers to discuss their personal career paths and experiences. Discussions included examining institutions listed as encouraging for women and minorities and their guidelines for promoting diversity, including strategies for recruiting and hiring, policies for family leave, on-site child care, spousal hiring, part-time work arrangements, and mentoring of women and minorities in the workplace. Guest speakers expose students to individuals who can serve as role models for underrepresented engineering students, raise awareness among the general student body about the challenges faced by women and minorities in engineering, and help to change misperceptions among the general student body regarding "who does engineering." Other topics discussed include academic career paths, differences in communication and negotiation styles among women and men in the workplace, and strategies for managing and effectively communicating with individuals who have different communication styles.

**Anticipated and Actual Outcomes**: The anticipated outcomes were that students would have (1) a higher awareness about diversity in the engineering workplace among engineering students, including the current percentages of women and minorities at different professional levels and challenges faced by underrepresented individuals in these environments; and (2) a greater understanding of institutional policies and personal skills, including communication styles, negotiation styles, and management styles, that facilitate diversity in the engineering workplace. Post-graduation, an anticipated outcome was that students receiving this training would work more effectively in diverse teams. Among undergraduate chemical engineering students during 2007-2011, almost all agreed the activities were effective in achieving the stated outcomes. Several students expressed an interest in taking a full three-credit course on diversity and broader impacts in engineering, which was piloted in 2008. Among REU (2006-2011), Graduate Certificate students (2007-2011), and NIH PREP graduate interns (2009-2011), the average student response to course materials has been positive and is increasing over time. The less positive response from earlier years likely reflected the need to adapt certain course materials and case studies for graduate populations.

**Assessment Information**: The undergraduate chemical engineering component of the program is regularly assessed with student surveys, student interviews, faculty assessment, and alumni surveys as a part of our ongoing ABET assessment. The REU and graduate components of the program are assessed as a part of the external evaluations of these programs, which include student surveys and student focus groups. The initial course materials were developed for undergraduate chemical engineering students, students completed surveys to assess achievement of the program objectives, and the results were shared in an on-campus workshop on diversity education. With the initial positive results from that assessment, our department formally changed the course objectives for our Chemical Engineering Professional Development course.

**Funding/Sustainability**: Implementation funding was $6,000 from an internal competition for diversity education. These funds went towards purchasing relevant texts, faculty and staff time for assessment, and travel costs for invited guest lecturers. Expansion of the program to REU students and graduate students was supported by grants from the NSF and NIH. The undergraduate Chemical Engineering component materials have been institutionalized and formally integrated into our curriculum. For the components involving REU and graduate students, we continue to apply for federal training grants to offset the costs of assessment and guest speakers. The UMass Graduate School, UMass Provost's Office, UMass Vice Chancellor for Research and Engagement, College of Engineering, and College of Natural Sciences have provided some matching funds. At the graduate level, the program has been semi-institutionalized, with some discussions of long-term support to develop a curriculum for all graduate students at UMass Amherst. Although the materials have already been developed for both undergraduate and graduate audiences, and the lecture and role-playing aspects of the curriculum can be continued even if no additional funding is obtained, ongoing funding is needed for program evaluation and guest speakers.

## Austin PROCEED: Project-Centered Education in Mechanical Engineering

**Lead Institution**: University of Texas at Austin, Austin, TX
**Category**: Course/Curricular
**Date Implemented**: September 2000
**Website**: http://www.me.utexas.edu/proceed/

**Program Description**: PROCEED (Project-Centered Education) is a department-wide curriculum reform program with the overarching goal of producing BS graduates who are exceptionally industry- and graduate study-ready. The central themes are (1) better connection of theory with practice, (2) restoration of the "hands-on" element of engineering education, (3) building teamwork and organizational skills, (4) enhancing communication skills, and (5) developing competence in dealing with complex open-ended problems. Specific activities include collaboration with corporate engineers to develop case studies, videoconferencing with corporate engineers to demonstrate applications of related theory, use of reverse engineering of real products and systems in many courses to teach analysis and design, development of hands-on labs and integration of lab work with theory in core courses, introduction of new computer simulation projects in several theory courses, development of an online portfolio system to showcase student project work, development and application of comprehensive assessment methods, opening of a senior elective sequence to a broad variety of career path options, and creation of Bridges to the Future certificate programs which encourage high-performing undergraduates to participate in research as a jump-start to graduate study. Faculty met in informal seminars to discuss how to prepare mechanical engineers for the 21st century with no budget, space, or faculty constraints. Workshops, some with corporate advisors, then defined 15 pilot projects. Components are often provided by sponsors, who also provide detailed product information and send engineers to talk about them. Faculty and students regard project-centered education as worth the extra effort, although some students try to keep their GPAs up by taking fewer semester hours in PROCEED, thus lengthening time to graduation. We are exploring ways to alleviate concerns by carefully eliminating low value-added content and possibly expanding summer offerings of time-intensive courses.

**Anticipated and Actual Outcomes**: Our specific desired outcomes are: ability to (1) know and apply engineering and science fundamentals; (2) solve open-ended problems; (3) design mechanical components, systems, and processes; (4) set up, conduct, and interpret experiments and present results in a professional manner; (5) use modern computer tools; (6) communicate in written, oral, and graphical forms; (7) work in teams; (8) lay a foundation for learning beyond the degree; and awareness of (9) professional practice issues, including ethical responsibility, creative enterprise, and loyalty and commitment to the profession; and (10) contemporary issues in engineering, including economic, social, political, and environmental issues and global impact. Student evaluations, particularly related to Outcomes 1 through 7, show PROCEED sections consistently rate higher in quantity of work, quality of assignments, and improvement of student skill level than conventional courses. Course instructor and graduate surveys reflect high student satisfaction despite high workloads. ABET accreditation reviews cited the hands-on philosophy as a major strength and gave high marks to courses employing reverse engineering. Outcomes 8, 9, and 10 depend on general education courses and extracurricular experiences.

**Assessment Information**: The QQI (Quantity, Quality, and Improvement) instrument was developed to assess student perceptions of the effectiveness of project-based courses by measuring the quantity and quality of learning opportunities and student achievements with respect to specified learning outcomes. It was piloted in 2002, incorporated in an online survey, and subsequently implemented in a representative sample of newly implemented project-centered courses. QQI provided valuable feedback to instructors at the formative stage, as well as confirming which outcomes received the highest positive student response as a result of the implementation of project-centered learning. Other methods include exit interviews with graduating seniors, feedback from recruiters and departmental advisory committees, and ABET reviews. A doctoral student from the College of Education with 10 years of mechanical engineering experience developed metrics for assessing the effectiveness of project-based methods. Detailed formative and summative evaluations of several PROCEED classes against control sections were carried out in the early stage of implementation. As the program transitioned to mainstream implementation, less formal qualitative evaluations were carried out on a regular annual basis for our ABET documentation process.

THE UNIVERSITY OF TEXAS AT AUSTIN
Cockrell School of Engineering

**Funding/Sustainability**: External support has been provided by corporate and private donors, who contribute financially and in-kind with equipment and components. Corporate partners compete aggressively for graduates and have articulated three primary objectives: (1) achieve a high level of visibility and name recognition, (2) motivate students toward consideration of careers in their respective industries by exposing them to projects illustrative of the type of work they might do after graduation, and (3) raise the overall quality of the undergraduate educational experience, thereby enhancing their professional competence and leadership potential. Initial startup costs for the program totaled approximately $900K over a 4-year period, 70% funded by corporate grants and 30% by internal matching. The approximate breakdown was: lab equipment and renovation, 60%; salaries and wages (developmental), 30%; administrative support, 7%; miscellaneous, 3%. Since its inception, a total of over $1.5 million has been contributed by corporate sources. We have been able to absorb the added costs into our regular operating budget, and have been able to maintain a modest level of new curriculum and lab development through continuing support from loyal donors.

## The VCU da Vinci Center for Product Innovation

**Lead Institution**: Virginia Commonwealth University, Richmond, VA

**Category**: Course/Curricular

**Date Implemented**: 2007

**Website**: www.davincicenter.vcu.edu

**Program Description**: An initial collaboration of Virginia Commonwealth University's (VCU) Schools of the Arts, Business, and Engineering, the da Vinci Center for Innovation's aims are to (1) prepare students to enter a product innovation career; (2) catalyze innovation through interdisciplinary collaboration among the disciplines of the Arts, Business, Engineering, Humanities, and Sciences; and (3) serve as a resource for advancing interdisciplinary innovation and entrepreneurship. Center offerings include an undergraduate Certificate in Product Innovation, continuing education programs, and a Master of Product Innovation. The primary purpose is to develop analytical, creative, and team skills in students and prepare them to achieve leadership roles in companies and agencies. These skills come from intensive engagement with real problems in real settings, working with students and faculty from complementary disciplines as well as representatives of corporate affiliates and other partners. All da Vinci Center programs embrace innovation from an interdisciplinary perspective and do so by bringing in learning from multiple disciplines. This corresponds to a focus on creating "T-shaped people," which is advocated by Tim Brown, CEO and president of IDEO. The "T-shaped people" model portrays students as deep in one disciplinary area (e.g., arts, business, or engineering) and augmented with broad knowledge of all aspects of innovation activity. Solidifying the product innovation experience for undergraduates is a capstone project, which synthesizes learning in the program and gives students product innovation experience. Projects have been company-sponsored, although there is the possibility of student-initiated projects that reflect an entrepreneurship element by focusing on business creation upon project completion. The sponsor provides the project context and is engaged with the student team through the semester. Faculty mentors guide the students through the semester to ensure project organization, task understanding, and the meeting of project milestones. Sponsors designate a representative to serve as project liaison. Depending upon the needs and expectations of the sponsor and the team, the project liaison may attend some team meetings. On occasion the team may meet with the team liaison via video conference or travel to the sponsor's site. Formal meetings with the sponsor occur at mid-semester and the end of the semester, honing students' communication skills.

**Anticipated and Actual Outcomes**: Learning objectives for students are to (1) Gain an understanding of and appreciation for interdisciplinary innovation – students are surveyed at various points in the program with pre- and post-scores compared to assess understanding and appreciation for interdisciplinary innovation; (2) Develop product innovation skills – company sponsors evaluate student teams during the capstone course on their abilities to perform product innovation skills while engaging in the capstone project. The criteria of novelty/aesthetics, fit/synergy, and technical capability/feasibility are employed; these criteria correspond to Arts, Business, Engineering, Humanities, and Science dimensions, respectively; and (3) Hone teamwork skills – faculty mentors evaluate students during the capstone course on their abilities to work collaboratively as team members. Students also conduct a 360 evaluation that includes themselves and their team members. Since 2009, student participation in the da Vinci Center has grown exponentially. A significant reason is the offering of a Seminar in Product Innovation, a speaker series open to all students. Student feedback consistently mentions how the capstone experience broadens their thinking about innovation and working across disciplines. Our company sponsors are satisfied with student deliverables and continue to serve as sponsors.

**Assessment Information**: Regular meetings with the deans from the Schools of the Arts, Business, and Engineering are held to review Center programs. An annual report is produced. Student appraisals are collected. Alumni of the program are just now beginning their careers and stay connected to the Center and with each other largely because of their positive experiences. They will be followed and asked periodically to relate their experiences in the program with the requirements of their jobs and their progress in their careers. Corporate managers who work with the Center also provide feedback on usefulness of the work product of the teams after the projects are completed.

**Funding/Sustainability**: Project sponsors have included a number of companies and State of Virginia departments. The Center also has worked with a local entrepreneur to prove a business/technology concept. The deans of VCU's Schools of the Arts, Business, and Engineering formally established the Center with a $150K commitment by the three schools towards the Center's operation. An interim Director oversaw the Center until fall 2009 when a full-time Director was hired, and a program coordinator was hired in June 2010. Current annual operational expenses are approximately $280,000, covering 75% of the Director's salary, 100% of the program coordinator's salary, faculty mentor stipends, project expenses, design lab equipment, and other expenses necessary to enable successful operations. Since 2007, the only sources of funding have been company sponsorships. MWV Foundation has graciously renewed their support of the Center since its inception. Assuming the Master of Product Innovation meets enrollment goals, the Center will have sufficient funds to support ongoing operations. The Office of Provost has also indicated a willingness to provide the funding to support the Undergraduate Certificate in Product Innovation. Additionally, the Center hosts an executive training program in January; all proceeds of this program go to the da Vinci Center.

## The Vertically Integrated Projects (VIP) Program

**Lead Institution**: Georgia Institute of Technology, Atlanta, GA
**Collaborating Institutions**: Morehouse College, Purdue University, University of Strathclyde
**Category**: Curricular
**Date Implemented**: January 2009
**Website**: http://vip.gatech.edu, https://engineering.purdue.edu/vip, http://www.strath.ac.uk/viprojects

**Program Description**: The Vertically Integrated Projects (VIP) program is an undergraduate design program that operates in a research and development context. Undergraduates on VIP teams earn academic credit for their participation in design teams that create products based on ideas from faculty research. The teams are: Large – 10-20 students per team; Multidisciplinary – drawing students from around campus; Vertically Integrated – a mix of sophomores through seniors each semester; and Long Term – undergraduates may participate for up to 3 years. The products and systems the teams design and develop are of sufficient scale and complexity to be of significant benefit to the faculty mentors' research effort. The size and vertically integrated nature of VIP teams function like a small engineering design firm. Students progress from "entry-level" positions at the sophomore year, during which they learn about the projects and technology from the more senior students. As juniors they apply what they learn in their courses and as new team members to the design of the project. As seniors they generally lead some aspect of the project and are mentored in technical and project management tasks by the graduate students and faculty. The program works well in any discipline and is especially well-suited to multi-disciplinary efforts. The VIP program traces its origin to the Engineering Projects in Community Service (EPICS) Program. We observed some weaknesses in EPICS that led to the creation of VIP. EPICS has insufficient recognition of faculty effort as team advisors in the evaluation processes leading to pay increases and promotions, which can be overcome in part by focusing the teams on projects of benefit to faculty research efforts. In EPICS, some projects drawn from the community lack sufficient technical depth to challenge the students, which can be addressed by focusing the teams on design problems embedded in faculty research efforts. Finally, projects were limited to disciplines closely associated with community issues, which can be overcome by focusing on faculty-initiated projects. Companies support VIP with donations of funds or equipment. Partners/customers of VIP teams are typically the same as those associated with each faculty advisor's research effort. Every discipline involved contributes its own expertise to the overall collaborative effort of each VIP team.

**Anticipated and Actual Outcomes**: We anticipated the formation of sophisticated collaborative networks within and between VIP teams and various groups of students and tracked and characterized the networks within and between the teams at Purdue and Georgia Tech. Results show students actively interact regarding both technical and managerial advice. The number of individuals with whom students interact has increased slightly as the program has grown. The E-I index (# of contacts outside group − # of contacts inside group)/(total contacts) shows increasing integration across gender, years, and teams. Students at Purdue were slightly more interactive across graduate and undergraduate student ranks. Students tended to develop 2-3 sources of advice. Graduate students are knowledge leaders and serve as the primary resources for the range of advice and assistance, but there is important peer exchange among undergraduates. The data show not only that advice-based ties flow across undergraduate and graduate students, but that the undergraduate students are also engaging across rank regarding technical and project management information and assistance. While it is expected that information should flow within each team, results showed that significant ties exist across teams at both institutions.

**Assessment Information**: The critical benchmarks are the number of faculty, graduate students and undergraduates involved, the number of disciplines involved, and the total number of teams. At GT, the ultimate goals include: at least 100 teams and a total enrollment each semester of 1500 or more students; at least one VIP team in each discipline; and full integration into the curriculum. Current goals include a uniform strategy across all engineering and computing disciplines for integrating senior design/capstone courses with VIP so that VIP is both the first true vehicle for multidisciplinary senior design and students can remain members of their VIP team while satisfying senior design requirements. We are currently proposing further research to correlate student performance, as measured by design notebook grades and peer evaluations, with centrality to the collaborative network within a student's team.

**Funding/Sustainability**: At both Purdue and Georgia Tech, the start-up costs were roughly: 25% release time for the lead faculty member; support for a research staff member; a TA to help with course management, oversight of the VIP lab, administration of the design notebook process and the peer evaluation process; a room large enough for a meeting of 20 or more people; projector; a few desktop and laptop machines; and access to virtual servers. Funding was raised via NSF grants, the endowment income for Prof. Coyle's Chair and Center, ECE and the College of Computing, and gifts from several companies and donors. At Georgia Tech, all funding is recurring. The College of Engineering recently approved a request for recurring funds for a Program Manager to assist with the administration and growth of the VIP Program. VIP is thus already sustainable over the long term. To assist with the continued expansion of the program, the VIP leadership of all schools will continue to collaborate on proposals to the National Science Foundation, foundations, corporations, and potential donors.

## The Distinctive Education Program at IIT

**Lead Institution**: Illinois Institute of Technology, Chicago, IL
**Collaborating Institutions**: corporations, entrepreneurial ventures, non-profit organizations, government agencies
**Category**: Curricular
**Date Implemented**: January 2010
**Website**: http://www.iit.edu/undergrad_ed/

**Program Description**: The Distinctive Education Program at Illinois Institute of Technology (IIT) was created to: create a shift in the engineering educational model from one-to-many (lecture/lab format) to many-to-many (multiple faculty interacting collaboratively with students) to enhance learning; create a catalyst for innovation and creation of solutions to problems, by providing students with collaborative space, supplies, equipment, and materials; and cultivate teamwork and improve communication and faculty/student interaction. The program is composed of three interconnected components serving all undergraduates: (1) an interdisciplinary curriculum that integrates industry experts and problem solving (IPRO 2.0) with a network of faculty and professionals spanning all of our colleges; (2) a 13,000 sq. ft. dedicated space equipped with a rapid prototyping lab available to all students (The Idea Shop) that brings people from different backgrounds and areas of expertise together and provides materials, human resources, technology, and equipment; and (3) a strategic commitment to providing and integrating technology (iPad initiative), in which the university provides Apple iPads to all first-year students. To support this technology, IIT enhanced its campus-wide wireless infrastructure, provided training, and changed the way it does business, communicates and learns. The IPRO curriculum was integrated into the normal faculty-teaching load and is fully supported by university leadership. All undergraduates must complete two 3-credit-hour semester-long IPRO projects.

**Anticipated and Actual Outcomes**: We anticipated the program would: (1) foster a collaborative learning environment serving interdisciplinary project teams with state-of-the-art workspace and prototyping tools, (2) provide students more time and resources to work on projects, (3) create more community engagement and outreach projects, (4) increase corporate sponsorship, (5) increase enrollment, (6) provide access and equal opportunity to a diverse student body, (7) allow faculty to develop iPad-based curricula, (8) encourage sustainability and paperless initiatives, (9) increase student-faculty interaction, (10) encourage student ownership of research, ideation, fabrication, and professional development, (11) bridge social interactions of faculty, staff, facilitators, practitioners and industry experts, and (12) provide understanding of the project/product development cycle and give students the means to bring their ideas to market. Our actual outcomes also included: (1) resources for faculty members to offer supplemental programs, lectures, and workshops, (2) increased use of educational apps, (3) analysis of real-time, continuous feedback, (4) projects driven by students' passion and interest, (5) user-centered design methodology, (6) interprofessional foundation based on principles of teamwork, communication, project management, and ethical decision-making, (7) integration of concepts and faculty from psychology, design, business, architecture, and law into engineering education, and (8) increased public awareness of IIT.

**Assessment Information**: Assessment involves students, faculty, sponsors, alumni, employers and administrators. Data is collected throughout the course about learning objectives and performance of individuals, teams and program resources. Students must function on multidisciplinary and cross-functional teams, organize and manage complex projects, communicate effectively in a variety of ways, and engage in problem solving including complex non-technical considerations. Assessment includes evaluation of deliverables (project plan, midterm review, presentations, exhibit/poster, final report), evaluation of IPRO Day performance by Chicago-area professionals, student satisfaction and team climate surveys, academic committee reviews, team member peer evaluation, and instructor and sponsor feedback. Since 2010, we have been reinventing IPRO via IPRO 2.0: The Next Generation of IPRO Experience, to further align our interprofessional, project-centered learning goals with IIT's vision and strategic plan. This is accomplished by: (a) integrating our Institute of Design's user-centered design principles, core problem solving, and collaborative innovation methodology, (b) fostering high-performance teamwork that encompasses team building, leadership, project management, communication, and ethical decision making, and (c) delivering a discovery and ideation process that inspires students to conceive new ideas.

**Funding/Sustainability**: First-time implementation: staff salaries (5.5 FTE), \$380,000/yr; faculty salaries, \$250,000/yr; expendable materials and supplies, \$80,000/yr; major equipment purchased, \$212,000; iPad initiative, \$250,000/yr; wireless improvements, \$100,000; and rent, \$300,000/yr. The costs for prototyping the original IPRO program were borne by the university through its operating budget from 1995 to 1998 and then augmented through fulfillment of its business plan. From 1995 to 2010, IPRO has a record of receiving sustaining funding over several years in one-semester increments from corporations. As part of the strategic plan, the university has guaranteed the long-term sustainability of the Program by implementing the Responsibility Centered Management model. Sustainability is a result of strong commitment from the university's upper administration and a clear funding model. The annual funding for the program comes from net tuition revenue (\$1,000,000), IPRO corporate sponsorships and foundation grants (\$500,000), the Provost's Office (iPad initiative; \$250,000.00), workshops, rapid-prototyping services, Idea Shop Store (\$5,000), and partnerships with programs sharing space like Exelon Summer Institute and Boeing Scholars Academy.

## Engineering Career Awareness Program

**Lead Institution**: University of Arkansas, Fayetteville, AR

**Collaborating Institutions**: Dual degree programs: Fort Valley State University (Fort Valley, GA), Philander Smith College (Little Rock, AR), University of Arkansas at Pine Bluff (Pine Bluff, AR), Pulaski Technical College (Little Rock, AR), Crowder College (Neosho, MO), and Northwest Arkansas Community College (Bentonville, AR). Other universities provide sites for REU experiences, and corporations provide support and internships.

**Category**: Extracurricular/Retention

**Date Implemented**: Fall 2007

**Website**: ecap.uark.edu

**Program Description**: The goal of the Engineering Career Awareness Program (ECAP) is to increase the number of underrepresented students, especially those who are capable but financially challenged, who obtain engineering degrees and enter engineering graduate studies or the engineering workforce. ECAP recruitment strategies include: informational outreach efforts with large populations of underrepresented students, making presentations, educating counselors and talking individually to students; involving current minority engineering students who can relate well to future ECAP students; disseminating scholarships and financial aid information to underrepresented students to assist them in navigating the complicated scholarship and financial aid system; and forming partnerships with HBCUs. ECAP includes six retention elements: a three-week summer in-residence engineering bridge program to allow students to engage in engineering/teambuilding activities, make friends, and transition to campus life; renewable scholarships, which supplement other scholarships and grants to make each student's total award equal to the cost of attendance; yearly paid summer co-op/internship, research, or study abroad opportunities; mentoring by junior and senior ECAP students; a living-learning community; and a Freshman Engineering Program designed to increase retention of all freshman students through block scheduling and specialized services. The Biological, Chemical, Civil, Computer Science & Engineering, Electrical, Industrial, and Mechanical Engineering departments all support ECAP students financially through departmental scholarships and provide additional faculty mentoring, while the Freshman Engineering Program facilitates specialized tutoring and peer mentoring by other ECAP students. The Honors College provides competitive study abroad and undergraduate research grants as well as scholarships for high-achieving entering students. The Enrollment Management Office, which includes the Scholarship Office, assists in identifying potential ECAP students and awarding the Silas Hunt Scholarship. The Office of Diversity Affairs, which includes the Multicultural Center and Pre-College Programs, provides support for the ECAP Summer Bridge Program as well as additional mentoring support for ECAP students. University Housing, Development and the Career Development Center also play integral roles.

**Anticipated and Actual Outcomes**: Since ECAP's implementation, the number of new freshmen ethnic minority students has increased 190% to 20% of the class in 2011. The University competitively awards a Silas Hunt Scholarship to underrepresented students, and ECAP has raised its acceptance rate from 60% to 79% and increased the number of engineering recipients. The retention and graduation rates of ECAP students are significantly higher than those of non-ECAP students. ECAP students completed internships with at least 24 companies and participated in REU programs at 8 other universities. Of the 2011 graduates, 27% pursued engineering graduate degrees and the rest obtained placement with corporations with an average starting salary of $62,000. In addition, ECAP students are highly sought after by numerous corporations looking for diverse engineering talent. Several companies have hired ECAP students for internships or full-time employment and have participated in the ECAP Executive Speaker Dinner Series.

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**Assessment Information**: ECAP is part of a formal research program started in 2008 as part of work funded by NSF to determine quantitative and qualitative factors that impact and predict student success beyond grades, financial need, social integration, and student satisfaction. This longitudinal research study integrates demographic, academic, and financial data with data from an annual survey asking engineering students about their satisfaction with the college retention and degree programs, integration and comfort level with people from diverse populations and with majority populations, alcohol and substance use, physical and mental health, religion, sexual orientation, and other factors rarely assessed. In addition, the project hired an external evaluator to collect data from independent sources to determine whether stated quantitative benchmark objectives are met and to implement systematic qualitative evaluation techniques to support the quantitative information. The seven evaluated program elements are: 1) recruitment, 2) the Freshman Engineering Program, 3) peer mentoring, 4) co-ops, internships, or summer research experience, 5) summer bridge program, 6) scholarships, and 7) the living-learning community. This approach helped determine which program elements require incremental improvement, while still supporting the ongoing overall project assessment.

**Funding/Sustainability**: In Fall 2006, the College of Engineering committed $100,000 for the startup of ECAP, including a $51,000 marketing plan, $24,000 in targeted recruitment costs, and $25,000 for the inaugural three-week summer program. In 2007, the College renovated and furnished 5,500 square feet of space in Engineering Hall at a total cost of $300,000. Current annual costs are: recruitment, $15,000; summer residency program, $30,000; average annual need-based scholarships, $364,630; recruitment/retention personnel, $74,500; ECAP Dinner Series, $8,000. The College is working to secure an endowment to ensure that this program continues long into the future.

# FUSE (First Undergraduate Service learning Experience): Real-World Adaptive Engineering Design

**Lead Institution**: Boise State University, Boise, ID

**Collaborating Institutions**: Non-profit and community organizations

**Category**: First Year/Service Learning

**Date Implemented**: Spring 2009

**Website**: http://coen.boisestate.edu/fuse

**Program Description**: The Introduction to Engineering course is a project-based lab course designed to provide students greater insights into the activities and challenges that engineers in all disciplines encounter in their jobs. A service learning option, FUSE (First Undergraduate Service learning Experience): Real-World Adaptive Engineering Design, was added to the course during the spring 2009 semester and focuses on adaptive technology design where students modify or adapt equipment for a person with a disability. Students have disability awareness training before arranging their first client meeting and spend the last half of the semester working in teams to understand the problem and develop a solution. Clients work closely with students throughout the project to help them fully understand the problem, evaluate design options and prototypes, and ensure a successful solution. Students are required to brainstorm multiple design options and evaluate them as to which is most likely to meet the project requirements, cost, and schedule goals. They are encouraged to develop prototypes using inexpensive, readily available materials and use them to conduct functionality testing to further verify the design. The results of these tests allow students to refine their product plans and increase the chances of success with their final product. Projects are carefully screened for scope and scale to ensure students have the time and ability to successfully complete them. Consultants and mentors from the university and community are available to students. Over 60 projects have been completed, and students experience tremendous satisfaction when they are able to see tangible results of their efforts, solve a "real" problem, understand the impact they have had on their client's quality of life, and see a project through to completion. Several students have offered support to their client long after the class has ended. For each non-profit and community organization, there is a personal point of contact serving as liaison. Relationships with people at these organizations, coupled with successful completion of projects, are key to building the program.

**Anticipated and Actual Outcomes**: The objectives are for students to: (1) discover the creativity, challenge, and rewards in solving an engineering problem; (2) apply critical thinking and problem-solving skills using the engineering design process, to identify, analyze, and solve a problem from the community; (3) practice the skills necessary to be a successful engineer, including project management skills, working on a multi-disciplinary team, and communicating within a project team, with instructors, with clients, with community partners, and with industry experts; (4) contribute to the community; and (5) better understand themselves, including their strengths and weaknesses, by reflecting upon these experiences. FUSE is assessed using self-reflections, team member evaluations, self-evaluation, client evaluations, consultant/instructor design reviews, and evaluation of project deliverables required at each milestone in the design process. Most students develop a strong rapport with clients and design a customized solution to meet their needs. Understanding the benefit of their work for the client often motivates students to put forth more effort than for a normal class project.

**Assessment Information**: We investigated the effectiveness of using service-learning (SL) compared to non-service-learning (NSL) on influencing introductory engineering students' (1) motivational attitudes toward collaborative project-based learning and (2) self-assessment of engineering abilities measured against ABET outcomes. The motivational attitudes investigated were interest in learning, relevance of learning, confidence in engineering knowledge, confidence in collaborative learning, and satisfaction in learning. Significant changes in student engagement in class activities and ability to work with team members were noted in several students as they worked with their client in solving a problem. Results showed that the SL method was significantly more effective than the NSL method in terms of positively influencing students' motivational attitudes toward collaborative project-based learning and improving self-assessment of abilities. Follow-on research showed that SL students' motivation, interest in learning, relevance of learning, and satisfaction in learning scores were significantly higher than NSL students' scores. SL students' confidence levels in their engineering knowledge and collaborative learning were higher than NSL students', but the differences were not statistically significant. SL students' self-assessed engineering abilities were higher than the NSL students' in c, e, and k ABET outcomes.

**Funding/Sustainability**: Because the instructor was already a full-time employee, there was only incremental additional cost, approximately \$50/student, associated with adding the SL program to the existing course. Funds for the first semester pilot program were provided by an internal university grant for approximately \$1200. Existing laboratory space, fabrication equipment, and resources were shared with other programs with no costs incurred. The College's long-term goal is to solicit funds from alumni and private individuals to help sustain and grow the program. In the near term, the program will be funded at the current rate with general funds and donations of goods and services from the community. FUSE has its own course name, number, and an extra credit hour so students receive credit for the extra work. This allows our college to pay adjuncts who sponsor a section and makes it easier to schedule as it increases the visibility as a distinct course offering.

## Nephrotex: A Professional Practice Simulation for Engaging, Educating, and Assessing Undergraduate Engineers

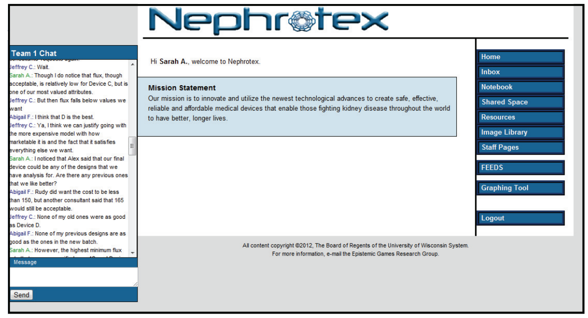
**Lead Institution**: University of Wisconsin-Madison, Madison, WI

**Collaborating Institutions**: University of Pennsylvania

**Category**: First Year

**Date Implemented**: August 2010

**Website**: epistemicgames.org




**Program Description**: The Nephrotex virtual internship can be classified as an epistemic game—a computer simulation of a professional practice. The primary objectives of Nephrotex are (1) to offer an alternative first year program that models authentic engineering practices, (2) to give students an opportunity to engage in engineering design and complex problem solving, and thus (3) to motivate students, especially women and underrepresented minorities, to continue in the field of engineering. First year students play the role of interns at a fictitious medical device company and participate in complex problem solving. The instructors and teaching assistants role play as employees of the company. Students are also prompted to learn more about the company, its employees, mission, vision, and history through short assignments that require students to explore the Nephrotex website including creating staff pages. Students go through two complete engineering design-build-test cycles and must select a final optimum prototype at the end of their internship and justify their design decisions by writing reports in their digital engineering notebooks. Students must also try to satisfy stakeholders within the company who have conflicting values, which adds additional complexity to the design problem. In fact, the design of the simulation does not allow for students to create a device that satisfies all the stakeholders' requests. Thus, each student individually justifies their design selection and explains why he/she chose to meet certain stakeholders' requests and not others. In addition to the structure of the design exercise and the simulated professional environment, the fact that the simulation is entirely online means that it is broadly accessible to large and small classes, in non-traditional or extension classes, at a broad range of institution types. Faculty, graduate students, and undergraduate students from the College of Engineering and the College of Education were involved in the development, building, and testing of this project. The co-PIs on this project were a professor from the biomedical engineering department and a professor from the educational psychology department (learning sciences area). Two undergraduate students in engineering physics, two undergraduate students in biomedical engineering, and two graduate students in learning sciences were involved in the development and implementation of this program. A mechanical engineering professor, the instructor for the course, also assisted with original implementation.

**Anticipated and Actual Outcomes**: We implemented Nephrotex in a first year course in which students choose two half-semester modules to study a single topic in engineering in depth; Nephrotex was offered as one possible module, and the other modules involved students working in teams to read and discuss research addressing engineering problems, but did not engage in engineering design. We anticipated the Nephrotex students would learn engineering content, be more motivated to persist in engineering, view engineering more positively, and have a better understanding of what an engineer does compared to students in other modules. We expected that this increase would be more significant for women and that students would be engaging in complex discourse surrounding engineering design and problem solving. The data from fall 2010 support these three claims about the experience of students in Nephrotex. All students in Nephrotex had statistically significant gains in engineering content knowledge related to the design task posed in Nephrotex. Women in Nephrotex had a statistically significant increase in positively viewing engineering careers compared to women in the control group. The more that a student participated in complex engineering design discourse in Nephrotex, the more likely they were to report that they viewed engineering more positively.

**Assessment Information**: There were two sources of data collected for this analysis: (1) students' pre- and post-survey responses about perceptions of engineering careers and motivation to persist in engineering and (2) students' discourse through participation in the chat program. All data was recorded and collected digitally. The discourse data was coded using a set of codes developed from ABET criteria for undergraduate engineering program outcomes and using epistemic frame theory as a guide for professional practices. We used Epistemic network analysis (ENA), which allows measurement of the development of connections students make between skills, knowledge, identity, values, and epistemology of engineering professional practice. This quantification helps us determine if students are engaging in engineering design and solving problems similar to the ways that professional engineers solve problems. We then analyzed these data to investigate whether students were more motivated to pursue engineering after participating in a virtual internship and how students were discussing engineering design problem-solving in the context of the virtual internship. Our research questions for the first implementation of the virtual internship were focused on engineering content learning gains, engagement with the virtual internship, attitudes towards engineering, especially among women, and motivation to continue in engineering.

**Funding/Sustainability**: Initial funding was provided by an NSF grant of $500,000. The program costs included salaries for PIs, undergraduate students, and graduate students, travel, materials and supplies, and publication costs. We are exploring the idea of pairing with other academic institutions as well as potential industry partners.

## Great Problems Seminars

**Lead Institution**: Worcester Polytechnic Institute, Worcester, MA

**Collaborating Institutions**: University research center; cultural & educational institutions; non-profit; community programs

**Category**: First Year

**Date Implemented**: Fall 2007

**Website**: http://www.wpi.edu/academics/Undergraduate/FirstYear/gps.html

**Program Description**: Great Problems Seminars (GPS) engage first year students with current events, societal problems, and human need; require critical thinking, information literacy, and evidence-based writing; develop effective teamwork, time management, organization, and personal responsibility; and provide first year students with a project experience that prepares them for more substantial required projects. Current GPS offerings have either a singular focus problem (energy, food, healthcare) or analyze the NAE Grand Challenges. Courses are team-taught by faculty from Engineering, Arts and Sciences, and Business. The instructors are present concurrently, demonstrating mutual respect and modeling intellectual discourse and learning. Grades are largely based on written work and projects, not quizzes and tests. In the first half of the course, faculty and students explore the depth and breadth of the problem, developing an appreciation of the complexity and inter-relatedness of the technical, social, economic, cultural, political, and historical issues using selected readings from a variety of sources like news media, books, scholarly writings, or historical texts. The faculty's role is that of facilitator and tutor in leading class discussions. Students respond to and further explore the issues through writing, discussion, and open-ended problem solving, both as individuals and in teams. Invited speakers and experiential learning provide further opportunities to cement knowledge and expand understanding. Teams of 3-5 students work on a project for the final half of the course, either developing a solution for a sponsor's problem or solving some aspect of the course's big problem. With substantial guidance, students research the problem, identify possible solutions, select effective solutions taking into consideration real-world constraints, and design an implementation process and mechanisms to assess effectiveness. During the process, the students are expected to communicate with sponsors, advisors, external experts, and other teams, seeking feedback and advice. The team produces a report and promotional literature targeted to the audience from whom action is required as well as a poster presented to the WPI community in a joint GPS poster session. GPS was informed by pedagogical literature, and faculty have been engaged in pedagogical research projects and have used their background and expertise to inform course activities.

**Anticipated and Actual Outcomes**: Anticipated outcomes were increased disciplinary engagement, big picture thinking, appreciation for social context, self-exploration, teamwork, and improved oral, written, and public communications. Actual outcomes included: (1) leadership in international Interactive Qualifying Projects (IQP) for graduation, which are interactive projects between social sciences and technical issues; (2) high level of interest in Grand Challenges graduates in Global Perspectives Program and seamless transition to IQP and Major Qualifying Projects (MQP) in the student's major carried out in the senior year; (3) increased awareness of the impacts of engineering interventions and solutions on environment and culture; (4) big picture thinking about one's professional development; (5) appreciation of complexity of real life issues and embracing humanities and social science offerings on campus; (6) self-exploration via increased critical thinking, questioning canon, defining professional interests earlier; (7) teamwork; (8) improved oral, written and public communications; and (9) improved success at attaining internships and summer employment post-GPS.

**Assessment Information**: GPS is assessed externally each year to explore student attitudes towards attaining global learning outcomes, student and faculty perceptions of the program, and student performance on a project required for graduation. Methods include pre/post surveys of students, student and faculty focus groups, and surveys of project advisors. A survey revealed that GPS students reported statistically significantly higher levels of engagement than non-GPS students in working effectively in teams, developing a greater understanding of contemporary and global issues, solving complex problems, and presenting and defending opinions by making judgments about information, validity of ideas, or quality of work based on a set of criteria. GPS alumni indicated they developed skills in project management, teamwork, time management, presentation skills, critical thinking, team leadership, accepting critical feedback, and having confidence to speak with individuals in positions of power.

**Funding/Sustainability**: Prior to initiation, WPI made a commitment to reinvigorating first year programs by investing in a 50% new position, the Associate Dean for the First Year. Costs specific to GPS are: summer support/course development, $35,000; instructor compensation, $65,000; and course costs, $10,000. An alumnus made a substantial donation each of the first two years and the difference was funded from the university's operating budget; the University operating budget now provides full support for the program. We continue to hire faculty who have designated responsibility for teaching in the GPS. Departments have an expectation to contribute by allowing faculty participation. The program has funding to help cover faculty time if necessary. We solicit philanthropic contributions to support the program, but the program is not contingent upon receiving external funding. WPI has fully committed to the program as part of its academic operation. Other key contributors are technology professionals, reference librarians, and the offices of Undergraduate Admissions and Academic Advising, which make incoming students aware of these courses when they register prior to their first semester.

## AguaClara

**Lead Institution**: Cornell University, Ithaca, NY

**Collaborating Institutions**: Non-profit sector, international water organizations, national and local government

**Category**: Global/Humanitarian

**Date Implemented**: Spring 2005

**Website**: aguaclara.cee.cornell.edu

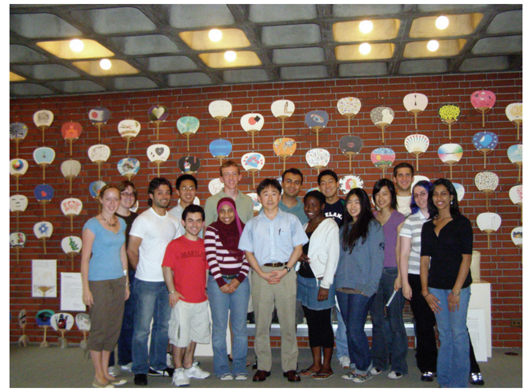
**Program Description**: The AguaClara program at Cornell University is a group of faculty and students working together with the goal of researching, inventing, and designing sustainable municipal-scale drinking water treatment plants to empower resource-poor communities around the world. Through our partnership with a local non-profit organization, water treatment plants designed by Cornell students are being built in Honduras on an ongoing basis. There are currently six plants providing safe drinking water to 32,300 people every day. The AguaClara water treatment plant technology addresses the global challenge of providing a sustainable method for surface water treatment for human consumption. The AguaClara Program designs treatment systems that function at the community scale rather than at point of use, and the ensuing economies of scale make the cost of safe drinking water sustainable even to communities with very limited recourses. The AguaClara technology seeks to rectify the shortcomings of the available community drinking water treatment plant technologies by offering a design based on the real water quality, economic, operational, and governance needs of small and mid-sized developing communities. AguaClara technology is being used by community-based water service organizations in small and mid-size towns in Honduras. The local Water Board is trained in the administration of the treatment plant. One or more local residents become plant operators, responsible for the daily operation of the treatment plant as paid employees of the Water Board. As the purveyor of the technology, Agua Para el Pueblo (APP) directs the construction and training programs, but the end owner and beneficiary of the project is the community through its Water Board. The Water Board independently administers the completed project exclusively with the water fees it collects from users and without subsidy. It is not uncommon for an AguaClara research team to take an idea for an improvement to a plant component, research the constraints, design and build a prototype and send the design to Honduras to be built into a plant within a year. This fast turnaround time allows students to see the direct impact of their work before graduating from Cornell. The direct link to the real world also motivates students to do high-quality work with externally imposed deadlines.

**Anticipated and Actual Outcomes**: When the AguaClara program began, the students and faculty involved with the program expected to develop a solution that fit the context of resource-poor communities in Honduras, to allow users in real-world conditions evaluate this solution, and to use this feedback to improve the designs. The students who participate in the AguaClara program have taken advantage of the opportunity to engage with a global problem, as evidenced by the number of students and the duration of their participation in the project (approximately 3 semesters). Many graduate and undergraduate students have made the decision to attend Cornell because of the experience offered by the AguaClara program. Over one hundred students have traveled to Honduras during the January intercession for an educational exchange trip. Students engage with the plant operators, community members, and local engineers to gain a more complete understanding of the problem and context for which they are designing. AguaClara technology has reached over 32,300 people.

**Assessment Information**: The AguaClara program can be evaluated by the amount of student interest it has generated and sustained since 2005. The quality of the students' work can be seen in the performance of the water treatment plants they designed -- over 32,000 people are now served by AguaClara technology in Honduras. The fiscal sustainability of the plants can be assessed based on their financial viability in the long run. All seven of the plants built since the program's inception in 2005 remain in service, and the water boards that control them have successfully managed tariffs to keep the plants well maintained. The pride community members take in taking charge of their water supply is evident in the words of Antonia Lira, the president of the water board in Alauca, Honduras: "We have time to overcome the errors that our grandfathers made. They have passed the bill on to us, and it's our turn to pay it. Now, thanks to God, man has given us this technology, this plant. I feel very proud that I've given something good to my children. They will have clean water, treated water."

**Funding/Sustainability**: Typically, local government funds 15-20% of the project and international organizations contribute the remainder through APP. After construction, the low operational costs of AguaClara plants facilitate full support by local communities. Although APP has been the primary purveyor of AguaClara to date, the delivery process could be replicated by other institutions with engineering and governance expertise in community water supply. The initial costs are difficult to estimate, including program founder Monroe Weber-Shirk's salary, laboratory space donated by the department, laboratory supplies, and preliminary trips to Honduras. Approximately $175,000 would be estimated for these costs. The San Juan Foundation provided much of the initial funding. Funding from a $200,000 National Science Foundation grant provided some salary support. The EPA's P3 competition provided $85,000 for chemical dosing research (2009-2011). The undergraduate and graduate students associated with the project apply for funding on an ongoing basis.

## NanoJapan: Connecting U.S. Undergraduates with the Best of Nanotechnology Research in Japan



**Lead Institution**: Rice University, Houston, TX
**Collaborating Institutions**: University of Tulsa, SUNY-Buffalo, University of Florida, Texas A&M University, and Southern Illinois University, Carbondale; University of Tokyo, Tokyo Institute of Technology, Keio University, RIKEN, the National Institute of Materials Science, Chiba University, Osaka University, Osaka Institute of Technology, Kyoto University, Tohoku University, Shinshu University, Hokkaido University
**Category**: Global/Summer Program
**Date Implemented**: May 2006
**Website**: http://nanojapan.rice.edu

**Program Description**: The NanoJapan: International Research Experience for Undergraduates (IREU) program focuses on cultivating interest in nanotechnology among students, especially those from underrepresented groups, and encouraging them to pursue graduate study and research in the physical sciences. This twelve-week summer program involves first and second year undergraduate science and engineering students from universities nationwide in research internships with Japanese nanoscience laboratories. While the heart of the program is the summer research experience, NanoJapan places strong emphasis on preparing students to work effectively in cross-cultural laboratory settings. Before beginning work in their research labs, students complete a three-week orientation program based in Tokyo that combines 45-hours of Japanese language instruction, an orientation to Japanese life and culture, and an introduction to nanoscale science in Japan. At the completion of the orientation, the students depart for their research labs, working for eight weeks at universities throughout Japan. At the end of the summer, the students return to Rice University to participate in a re-entry seminar and present their summer research as part of the Rice Quantum Institute (RQI) Annual Research Colloquium. Obstacles exist for U.S.-Japan collaboration, primarily linguistic and cultural barriers, and our project aims to break down these barriers by providing future generations of researchers with understanding of both the culture and the state-of-the-art technology in each country. NanoJapan also strives to foster the development of intercultural communication skills and understanding among participants and host research labs.

**Anticipated and Actual Outcomes**: The objectives are: a) to cultivate an interest in nanotechnology as a field of study among first and second-year students; b) to cultivate the next generation of graduate students in nanotechnology; c) to add to the skill set of active nanoscience researchers; d) to create students who are internationally savvy and have a specific interest in and knowledge of Japan; and e) to simultaneously educate students in culture, language and technology, in order that they may be more effective when addressing global scientific problems. Since 2006, 106 freshman and sophomore students representing 37 different U.S. institutions, including three community colleges, have participated. Among participants, 35% are women and 15.1% represent diverse ethnic groups. Alumni have gone on to pursue a wide range of other international opportunities including additional summer research, semester study abroad, international development and entrepreneurship programs, and graduate study. Among alumni who have graduated, 39 are pursuing STEM graduate study, one received a Hertz Fellowship, one received a Churchill Scholarship, one received an NSF East Asia Pacific Summer Fellowship to return to Japan for graduate research, and six have received NSF Graduate Research Fellowships.

**Assessment Information**: To assess students' attitudes towards the engineering profession, we administer the Pittsburgh Freshman Engineering Student Attitude Assessment (PFESAA), designed to measure four facets : 1) definition of engineering; 2) attitude about engineering; 3) self-assessed confidence; and 4) self-assessed skills including working in groups. Language proficiency is assessed by the OPI (Oral Proficiency Interview), an American Council on the Teaching of Foreign Languages instrument that stresses students' oral communication skills and rates students on a scale ranging from Novice-Low to Superior. The OPI is administered as a post-program test to all students; students with prior language study also complete a pre-test. Research has correlated gains in oral proficiency with intercultural effectiveness. Gains in intercultural learning are assessed by the Intercultural Developmental Inventory (IDI), which is taken prior to participation in the international experience, shortly after return, and within six months of return from Japan. We maintain alumni records regarding participants' additional research or international activities, graduate school, success with scholarships and fellowships, and employment; program alumni will be required to submit an updated CV annually.

**Funding/Sustainability**: The annual cost for 12 students is $265,250, including staff salaries, travel, and approximately $13,795 per student. salary costs: manager: $57,500; assessment: $9,700; int'l travel expenses for faculty & staff: $32,500; student costs ($165,550): student international airfare: $22,300; airport shuttles: $500; pre-departure orientation (2 days lodging & meals): $1,850; orientation in Tokyo (3 wks): lodging: $16,500, organization & administration: $18,500, beginning language classes (45 hours): $10,500, intermediate language classes (45 hours): $9,500, intro to nanoscience seminar speakers: (20 hours): $1,500, JP Society seminar speakers (9 hours): $1,200, classroom rental fee: $2,500, cultural excursions & programming: $10,000; research internship - student housing/living stipends (8 weeks): $54,500; mid-program mtg. in Kyoto: student lodging & traditional Japanese arts workshop: $8,700; re-entry program at Rice (lodging & meals for 3 days): $4,500; assessment: language: $1,500, intercultural: $1,500.

## International Engineering Program

**Lead Institution**: University of Rhode Island, Kingston, RI

**Collaborating Institutions**: Technical University of Braunschweig, academic institutions in Germany, France, China, Spain and Mexico; industry

**Category**: Global/Curricular

**Date Implemented**: September 1987

**Website**: http://www.uri.edu/iep/;
Online Journal for Global Engineering Education
http://digitalcommons.uri.edu/ojgee/

**Program Description**: The University of Rhode Island International Engineering Program (IEP) leads simultaneously to a Bachelor of Science in engineering and a Bachelor of Arts in German, French, Spanish, or Chinese. Students study the language and related culture(s) each semester along with their engineering curriculum, and spend the entire fourth year abroad completing one semester of study and research experience at a partner university and a six-month professional internship with a company where the target language is the primary source of communication. The goal is to graduate engineering students with a high level of competency in a second language as well as significant practical engineering experience in a different cultural setting. The IEP has also impacted graduate engineering education with the introduction of dual degree master's and doctoral programs in partnership with the Technical University of Braunschweig in Germany. The IEP is a totally integrated experience, beginning on day one of the first year, and maintains high standards from both the engineering and language points of view, requiring students to function as engineers in a cross-national setting. The University sends more engineering students abroad for a full-year experience and graduates more engineers with newly acquired languages than any other school in the country. An additional outcome of the IEP which had not been foreseen originally is its appeal to women, minorities, and bright high school graduates who are initially reluctant to study engineering. The faculty involved have been very conscious of the experimental nature and the challenges in bringing together two disparate disciplines for a common goal. Language faculty are heavily involved in offering specialized courses for the IEP students and in preparing them for experiences abroad as exchange students and interns. Several partner companies provide pre-internships for students at U.S. facilities, followed by six-month internships at their facilities abroad. Many students find employment with our corporate partners and our placement rate for graduates is very close to 100%. For the last 15 years IEP has sponsored the annual Colloquium on International Engineering Education, attracting people from around the world.

**Anticipated and Actual Outcomes**: Outcomes include: (1) strong technical education measured through classroom assessment and evaluation of research work at university and internship; (2) second (or third) language competency measured by national foreign language proficiency standards; (3) cross-cultural communication skills evidenced through long-term program evaluation; (4) exposure to engineering as practiced in other cultural environments; (5) foundations of a global professional network through experiences abroad; (6) newfound mobility and love of travel as a necessary skill for the global workplace; (7) success in applications for the best graduate schools and other unique opportunities. An investigation of the long-term impact as seen by students now in the workplace showed the extent to which the overall program positively affects both personal and professional development. Graduates tell us that their time spent abroad, in addition to the outcomes above, dramatically increased their problem-solving, confidence, self-reliance, communication, leadership, and courage to take calculated risks. It furthermore enabled them to elevate personal goals and reach for standards and achievements which had seemed unattainable.

**Assessment Information**: Assessment is ongoing and multifaceted, including traditional classroom work assessment; assessment of internships and study abroad via evaluation of student journals, written reports, student debriefing, collection of feedback from faculty and internship mentors abroad, and longitudinal case studies of graduates; language assessment through classroom work, demonstration of success on the job, and American Council on the Teaching of Foreign Languages proficiency examinations. Evaluation also includes data collection regarding program recruitment and growth, student retention, success in the job market, and corporate interest in the program. Assessment of the program has also come in the form of recognition by external awards. The IEP has graduated over 350 students, many of whom have put their global skills to work. Twenty five percent of all engineering undergrads are currently enrolled; approximately 35 students go abroad each year.

**Funding/Sustainability**: The program was funded initially for three years with a FIPSE grant ($155,000), which supported release time for development, the creation of special German language sections for engineering students, and travel to develop internship opportunities with companies in Germany. Funding has come from the U.S. Department of Education, NSF, the National Security Education Program, German and Chinese governments, corporations, and private foundations and donors. Total funding support to date is over $10,000,000. The full-time directorship and coordinator are funded by the university as are salaries of key faculty in the program. There are IEP line items in the budgets of both the College of Engineering and Arts & Sciences that cover all personnel. The operating costs of the Living and Learning Community are part of the student room and board costs. Yearly donations from foundations, corporations, and individuals that have been consistent over the last 15 years continue to provide operating expenses and steady increases to the IEP endowment. The yield from this endowment supports student scholarships and travel. Most IEP students are supported at least partially by honors scholarships.

## EPICS (Engineering Projects in Community Service) Program

**Lead Institution**: Purdue University, West Lafayette, IN

**Collaborating Institutions**: Industry and community partners (non-profit, government)

**Category**: Service Learning

**Date Implemented**: August 1995

**Website**: [www.purdue.edu/epics](http://www.purdue.edu/epics)

**Program Description**: Engineering Projects in Community Service (EPICS) is an engineering-based design program operating in a service-learning context. Students earn credit participating in multidisciplinary design teams that solve technology-based problems for local and global not-for-profit organizations. Students experience the entire design process to create products that work and are durable, easy to maintain, and accompanied by appropriate manuals and documentation. The curricular structure supports designs over several semesters and students may register for multiple semesters or years. Faculty, instructors, and industry volunteers are advisors while students lead large design teams and create and manage project plans, budgets, the design and development process, and the relationship with their community partner. Designs are reviewed through formal industrial design reviews and students must communicate frequently with a wide range of audiences. Vertical integration (first-year through senior students teamed together), provides built-in mentoring and continuity for projects spanning semesters. EPICS also has a lecture and workshop component with topics such as the design process, project management, leadership, ethics, and social context. Workshops offer students active learning experiences to develop skills to hone on the project team. Another EPICS objective was to share technical knowledge of the university with the community, which has been accomplished with over 300 diverse projects. The community context both offers opportunities for students to explore ethical and social context issues related to their designs and helps attract and retain students who are underrepresented in engineering. EPICS integrates cultural, disciplinary, and community perspectives in a way that illustrates the value of diversity. It was initiated based on industry feedback that real-life design projects with real users would produce better learning and professional preparation; since then, educational research has supported the principles and practices on which EPICS is based. EPICS disseminated the model to 20 universities and 50 high schools in the U.S. and 27 abroad and was awarded the NAE's Gordon Prize in 2005.

**Anticipated and Actual Outcomes**: A multidisciplinary curriculum committee oversees the academic aspects of EPICS. The original intent was to provide the broad education needed for the practice of engineering, but with increasing participation of students from outside engineering, outcomes were adapted and adjusted to be inclusive. The current outcomes are: ability to apply disciplinary material to the design of community-based projects, understanding of design as a start-to-finish process, ability to identify and acquire new knowledge as part of the problem-solving/design process, awareness of the customer, ability to function on multidisciplinary teams and appreciate contributions from individuals from other disciplines, ability to communicate effectively with varying audiences, awareness of ethics and professional responsibility, and appreciation of social contexts. Over 5000 student self-reported evaluations indicate that more than 80% advanced in design process, communication skills, teamwork, and community awareness; more than 70% developed technical skills, resourcefulness, and organizational skills; and 68% developed ethical awareness. The most valuable skills learned were: teamwork (86%), communication (49%), organization (39%), technical (36%), and leadership (26%). Another analysis shows early participation increases engineering retention and 70% of students report increased motivation to stay in engineering.

**Assessment Information**: Students develop a portfolio of artifacts, including design notebooks, reports, and reflections, which are used to both determine grades and assess learning. Other analyses focus on understanding design, ethics, and communication and have shown that EPICS is developing these desired attributes. EPICS attracts more women than are represented in their respective majors. A qualitative research study included interviews with women in EPICS and found that, while the students thought the community context was important, the main reason they enrolled in EPICS was to gain engineering experience. Industry panels assess the design teams across an entire day and include comparisons across teams, which serves as an informal external evaluation of the overall program. Evaluations are also done by the community partners. Research efforts, including six PhD theses, have included fundamental research into the development of human-centered design skills, retention and motivation among diverse students, development of professional skills, ethical reasoning, and cross-disciplinary learning and communication. Research continues to inform the curriculum, principles, and practices and is used to develop and enhance EPICS.

**Funding/Sustainability**: Cost is approximately $1700 per student/year. The original 2-year FIPSE grant was $70,658 with a Purdue match of $210,936 for faculty release and TA support. In 1997, a three-year grant from Learn and Serve America was secured for $100,000/year with a one-for-one match. Cost sharing was used to leverage faculty time and TAs, but as EPICS proved its value all departments moved to direct support. The directors negotiated models of faculty teaching credit and TA allotments based on enrollments from their respective majors. Purdue contributes funds for administrative staff, and a staff person works with other universities to build a network of educators who collaborate and learn from experiences and research findings. The provost provides annual support. EPICS is in the College of Engineering and University budgets with instructional support proportional to enrollment. Corporate partnerships provide materials and supplies to provide designs at no cost to the community. Grants are solicited for large projects, special initiatives, and research activities, and a partnership with IEEE supported global expansion.

## Infusing Real World Experiences into Engineering Education—List of Nominated Programs

Quality programs that infuse real world experience into engineering education can be found throughout the United States. Following are the programs nominated but not selected as models for this report, and who provided permission to be listed.

***Lead Institution: Project Name, Website (if available)***

**Baylor University**: A Multi-Faceted Strategy at Baylor University to Produce Entrepreneurial Engineers

**Boston University**: Societal Engineer, http://www.bu.edu/eng/about-us/societalengineer/education/

**Brigham Young University**: Integrated Product and Process Design, http://capstone.byu.edu

**California State University, Los Angeles**: Professional Practice Program, http://www.calstatela.edu/academic/ecst/professional_practice/

**California State University, Sacramento**: The California Smart Grid Center – Helping make Smart Grid a reality, www.ecs.csus.edu/CASmartGrid

**Colorado School of Mines**: YouTube Fridays, http://rheology.mines.edu/Teaching.html

**Columbia University**: Senior Design Course in Biomedical Engineering, http://www.bme.columbia.edu/pages/academics/undergrad/senior_design.html

**Columbia University**: Engineering Better Human Health in Africa, http://www.cuewb.org/projects/ghana/about

**Cornell University**: Integration of Simulation Technology into Engineering Curricula, http://confluence.cornell.edu/display/simulation

**Dartmouth College**: ENGS 89/90 Engineering Design Methodology and Project Initiation/Completion, http://engineering.dartmouth.edu/academics/courses/engs89/

**Drexel University**: weServe Program, www.drexel.edu/weServe

**Drexel University**: PIRE: A 3-tier Infrastructure to Advance Humanoid Research, http://dasl.mem.drexel.edu/pire/

**Duke University**: Engineers for International Development and the Duke Chapter of Engineers Without Borders, http://ewb.pratt.duke.edu/ and http://deid.pratt.duke.edu/

**Duke University**: Devices for People with Disabilities, http://bme260.pratt.duke.edu/

**Duke University**: Engineering World Health Summer Institute, http://ewh.org/index.php/programs/institutes

**Franklin W. Olin College of Engineering**: SCOPE (Senior Capstone Program in Engineering), http://scope.olin.edu

**Gannon University**: Scholars of Excellence in Engineering and Computer Science (SEECS), www.gannon.edu/seecs

**Georgia Institute of Technology**: The InVenture Prize, https://inventureprize.gatech.edu/

**Georgia Institute of Technology**: Industry Focused Senior Design at Georgia Tech ISyE, www.isye.gatech.edu/seniordesign

**Johns Hopkins University**: Longitudinal Design Teams, http://eng.jhu.edu/wse/cbid/page/cbid_undergraduate

**Louisiana Tech University**: Living with the Lab, www.livingwiththelab.com

**Michigan State University**: Cornerstone Engineering / Residential Experience (CoRe), http://www.egr.msu.edu/residential

**Middle Tennessee State University**: Industry projects to facilitate classroom learning, http://www.mtsu.edu/et/

**Massachusetts Institute of Technology**: The Beaverworks Program – Collaboration and Innovation in Real World Design–Build Capstone Projects

**New Jersey Institute of Technology**: Concrete Industry Management (CIM), http://engineeringtech.njit.edu/academics/cim/

**New York Institute of Technology**: NYIT-Intrepid Design Competition, http://www.nyit.edu/intrepid

**Northeastern University**: The Gordon Undergraduate Engineering Leadership Program, www.northeastern.edu/gordonleadership

**Northwestern University**: Global Health Technologies, http://www.cight.northwestern.edu/education/index.html

**Ohio Northern University**: Incorporation of Poverty Alleviation in Third World Countries in a First-Year Engineering Capstone Course, http://www2.onu.edu/~k-reid/

**Ohio University**: Designing to Make a Difference, http://www.ohio.edu/mechanical/design/

**Ohio University**: Global Consulting Project-Argentina, http://cob.ohio.edu/gcp

**Penn State University - Wilkes-Barre Campus**: Developing a High Altitude Balloon program at Penn State Wilkes-Barre, http://www.personal.psu.edu/axl17/HAB.htm

**South Dakota School of Mines and Technology**: Back in Black: Multifaceted Curriculum Development, http://sdmines.sdsmt.edu/sdsmt

**St. Ambrose University**: Program for Assistive Technologies for the Underprivileged, www.engineeringpatu.blogspot.com

**Temple University**: Senior Project I and II, http://vader.eng.temple.edu/wp-content/uploads/2011/10/ENGR-4296-Syllabus-.pdf

**The Ohio State University**: Multidisciplinary Engineering Capstone Design Program, http://eeic.osu.edu/capstone


**The Ohio State University**: Social Innovation and Commercialization, http://socialinnovationinitiative.org/what-we-do/social-innovation-and-commercialization/

**The University of Texas at Austin**: Graduates Linked with Undergraduates in Engineering (GLUE), http://www.engr.utexas.edu/wep/career/glue

**Union College**: Engineering and Liberal Arts Entrepreneurship Seminar, http://www.union.edu/academic/majors-minors/mechanical-engineering/

**University of Arizona**: Interdisciplinary Senior Capstone Design Program with Industry Participation, http://design.engr.arizona.edu

**University of California, Irvine**: MAE188 - Engineering Design in Industry, https://eee.uci.edu/programs/edi/

**University of California, Davis**: Collaborative Interdisciplinary Design Experience, http://www.bme.ucdavis.edu/louie/

**University of Illinois Urbana-Champaign**: ME470- Senior Design, https://www-s.mechse.uiuc.edu/courses/me470/

**University of Illinois Urbana-Champaign**: Global Leaders in Construction Management, http://glcm.cee.illinois.edu/

**University of Massachusetts Amherst**: Authentic Engineering Design Challenges for First-Year Chemical Engineering Students, http://che.umass.edu/faculty/surita-bhatia

**University of Michigan**: Multidisciplinary Design Program, http://www.engin.umich.edu/multidisciplinarydesign/

**University of Michigan-Dearborn**: Henry W. Patton Center for Engineering Education and Practice, www.engin.umd.umich.edu/ceep/

**University of North Carolina, Charlotte**: Industrial Senior Design Program, www.srdesign.uncc.edu

**University of Notre Dame**: Department of Civil Engineering and Geological Sciences Annual Junior Class Field Trip, http://www.nd.edu/~jjwteach/final_fieldtrip2010.html

**University of Notre Dame and Georgetown University**: Student-Enacted Simulation of Real-World Software Engineering Processes, http://www.cs.miami.edu/~blake/RWSoftEng.html

**University of Oklahoma**: Structured Industry Sponsored Capstone Program to Enhance Experiential Learning, http://www.ou.edu/coe/ame/audience/current_students/capstone_programs/mechcapstone.html

**University of Pittsburgh**: Freshmen Engineering Academic Program, http://www.engineering.pitt.edu/Freshman/Conference/Annual_Freshman_Conference/

**University of Puerto Rico at Mayaguez**: Manufacturing Automation Room

**University of Utah**: Professional Practice and Design Course, www.civil.utah.edu

**University of Virginia**: Jet Engine Manufacturing, http://www.mae.virginia.edu/NewMAE/?p=984

**University of Wisconsin – Madison**: First-year Students as Interviewers: Uncovering What It Means to Be an Engineer, http://www.tinyurl.com/hplengr

**University of Wisconsin-Platteville**: Introduction to Infrastructure, http://www.uwplatt.edu/ce/

**University of Texas at Dallas**: UTDesign, http://www.utdallas.edu/dept/eecs/utdesign/index.html

**Virginia Tech**: The Land Development Design Initiative, http://www.lddi.cee.vt.edu

**Western Kentucky University**: Project-Based Learning Throughout Three Curricula, http://www.wku.edu/engineering/