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Experiential Learning Opportunities Exploring the Impact of Engineering Solutions- A Collaborative GenEd-Engineering Effort

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Abstract

At the Illinois Institute of Technology (IIT), General Education (GenEd) requirements for Bachelor Degrees include six credit hours dedicated to project work that brings students from all across the university to work in teams that resemble a professional work setting. These inter-professional student teams work with faculty and/or industry mentors on a wide range of projects. Students assume different roles in the team and are encouraged to approach the project from their own perspective and to contribute their respective discipline-specific knowledge while performing within their professional role in the team. Engineering students in these inter-professional teams are often addressing (and leading) the technical aspects of the project using engineering approaches to problem solving.

To take best advantage of this GenEd requirement and its potential impact in engineering education, our college of engineering has been working to create projects that provide opportunities for students to address significant contemporary challenges that can benefit from engineering solutions. This paper describes an "Urban Systems" inter-professional project course that (in the context of the themes of energy, heath, security and water) examines challenges posed by urban systems, proposes creative solutions, and forms innovation teams focused on the research and development of prototype solutions. Developed to specifically target local issues in Chicago, IL where IIT is located, the intent of the course is to foster the use of engineering approaches to problem solving, creativity, innovation and entrepreneurship among students. Ideas that have emerged from this course range from new apps to better serve the community on healthy food needs to a new concept of a cooling tent for hot summers. In addition to the opportunity to apply their respective discipline-specific knowledge, theme-centered, engineering-led, inter-professional projects provide our students with team work, leadership, and project management skills while contributing to the broad education necessary to understand the impact of engineering solutions in global, economic, environmental, and societal context.

Interdisciplinary project courses

Project-based learning opportunities can help students develop better communication and team cooperation skills, gain experience with divergent and convergent thinking modes that foster engineering intuition, and enhance student ability to apply experiences and skills form one context to another[6]. According to Howe and Wilbarger[9], engineering capstone design courses that included interdepartmental or multidisciplinary teams increased from 21% in 1994 to about 35% in 2005. Lattuca et al.[10] examined 40 engineering schools, collecting data from graduates, faculty members, program chairs, deans, and employers, and concluded that relative to students of a decade earlier, the graduates of 2004 were better prepared. The greatest improvements occurred in student understanding of social and global issues, the ability to apply engineering skills, teamwork, and the appreciation of ethics and professional issues. Based on their review of project-based learning efforts at several schools, Esterman et al.[7] provided the following list of characteristics common to successful programs:

- Projects should be developed so they can be completed and provide a positive experience for the students.
- Sponsored projects should not be on the critical path of the sponsor, but having stakeholders interact with the team makes the project more meaningful.
- Project objectives must be clearly defined from the start.
- Relative to analysis problems, design problems are much more effective.
- Students need to be aware that they will manage the project and have the freedom to fail.
- Complex and diverse projects are essential if the multidisciplinary team is to be engaged.

Recent studies about these kinds of team courses suggest that the terms "interdisciplinary" and "multidisciplinary" can have different interpretations. For example, in describing their work with teams of architecture, construction, and engineering students, Chiocchio et al.[3] cite the work of D'Amour et al.[5] and make the following distinction: Multidisciplinary describes professionals from different disciplines working in parallel on the same project, and interdisciplinary describes professionals from different disciplines collaborate and share knowledge required to solve complex problems. Bhandari et al.[2] use the term "multidisciplinary" to describe a course that included about nine engineering disciplines; apparently there were no students from non-engineering disciplines. Hotaling et al.[8] use the concept of "multidisciplinary" for a course that included mechanical and biomedical engineers. Smith and Cole[14] describe their experience with a project design course that involves undergraduate students from civil, mechanical, and electronic and computer engineering.

The Urban Systems Interprofessional Projects

IIT began an institute-wide formal interdisciplinary program in 1995. The new general education requirement was comprised of six credit hours of Interprofessional Projects (IPRO) designed to be satisfied within two, three-credit hour courses in a two-semester time period. The IPRO program involves teams of students learning about design-centered methodology and innovative thinking, and applying those techniques to develop solutions to real-world problems. Because the requirement applies to all undergraduates, an IPRO course might include students from engineering, architecture, human sciences, physical sciences, applied technology, and business. In 2012, the National Academy of Engineering (NAE) recognized IIT as having one of 29 programs in the nation that have successfully infused real world experiences into engineering undergraduate education[11].

Two years ago the College of Engineering Distinctive Education committee designed a new IPRO course around the theme of urban systems. We define an urban system as any collection of independent parts that interact to make cities work better. Examples of urban systems include those that provide energy, communications, education, healthcare, water supply, transportation, solid waste management, recreation, and transportation. Urban systems are a great vehicle for project-based learning because they involve tangible, real-world issues, the problems are global (nearly 30% of undergraduates at our institution are international students), and comprehensive solutions to these problems require a multidisciplinary approach. In addition, urban systems need maintenance and repair, and it will be expensive. Based on an assessment of conventional civil engineering infrastructure[1], the costs for infrastructure repair in the U.S. will exceed $3 trillion by 2020. Above and beyond conventional repair, urban systems need redesign to move forward toward the intelligent, integrated systems that will make future cities work.

IIT is in a unique position to address these needs because we are in an urban environment; we are a multidisciplinary institution (programs in engineering, architecture, sciences, law, business, and design are well-suited to urban problems); and we have a history of collaborative interactions with various city departments that play a vital role in maintaining and improving urban infrastructure.

In fall 2014, the urban systems IPRO had 35 students, representing several engineering disciplines, architecture, psychology, business, and the sciences. The sequence of major tasks for the semester (Figure 1) guided students through a multistep process including problem definition, exploratory prototyping, and project execution, all culminating in a final presentation at a campus-wide IPRO exposition.

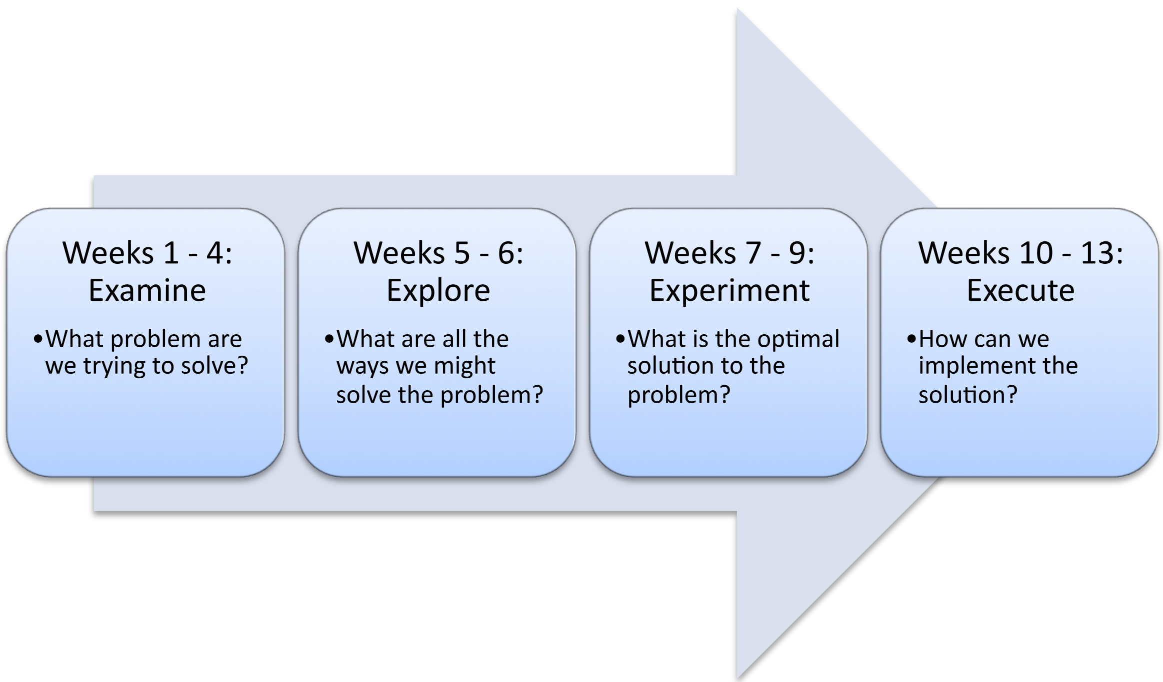

Figure 1. Timing and sequence of major tasks in the Urban Systems IPRO course[13].

In the first week of the course, students receive a copy of *Sustainable Chicago 2015 Action Plan*[4]. This document describes seven categories that are vital to the sustainability of Chicago:

- Economic Development and Job Creation
- Energy Efficiency and Clean Energy
- Transportation Options
- Water and Wastewater
- Parks, Open Space, and Healthy Food
- Waste and Recycling
- Climate Change

Sustainable Chicago provides important background information on urban issues and encourages students to start to identify topics relevant to their majors. Examples of some of the issues students focused on last year include:

- Providing clean energy options for underserved communities.
- Increasing the choices for healthy food options in urban food deserts
- Harvesting stormwater for nonpotable applications
- Options to improve recycling services for small businesses
- Connecting students living in urban areas to the right opportunities so they will have the skills necessary to get an internship and move up in their career
- Approaches for reducing bike theft in the city

Students were asked to consider potential solutions that might involve creation of a new service, a new product, or some combination of service and product. Their proposed solutions should be innovative and implementable, to the point that prototypes can be presented during the IPRO exposition day regardless of whether the solution is a product or a new business model. Examples of their solutions include:

- Water turbines for urban rivers
- A fresh fruit vending machine
- Alternative business model for recycling
- Flexible car designs for commuter rail services to adjust the amount of standing room during peak travel times
- A smart bicycle pedal to help prevent bike theft
- Helicopter commuting as an option for addressing traffic jams

We find that student solutions often take either of two approaches, large-scale transformations targeting large-scale urban solutions, or small-scale transformation targeting small-scale urban solution. The following paragraphs include more details about the last two projects from the above list, to provide an example of the range in scales and help clarify the class structure and process.

One transportation team focused on the question: "How can we put more bike riders on the streets of Chicago". Team members learned that many urban bike riders were frustrated about stolen bikes. They developed statistics suggesting that relative to cell phone theft, the police are much less concerned about bike theft. The team's brainstorming effort helped them realize that most bike locks failed to protect the cyclist's personal property. Their proposed solution was a smart pedal that can be produced using a 3-D printer, assembled with a few additional purchased parts, and used to replace conventional pedals on a bike. The smart pedal has an alarm and a GPS chip to locate the bike. The team presented a prototype of their design at the IPRO exposition.

Another transportation team focused on the question: "How can we reduce the frustration of car passengers during rush hour traffic". After several brainstorming sessions, they generated two wildly different solutions: Create an elevated bike highway or assess helicopter commuting between city and suburbs. Focusing on the helicopter approach, they began a comparative analysis to ensure their idea did not overlap some similar solution. The team also began collecting supporting data and developing a cost analysis for their project, including the potential for new business opportunities in the area around the helicopter landing pad. Interestingly, since that project ended, UBER proposed helicopters as a means of transportation in congested areas, such as sports events[15].

Assessments

Student grades for the course are based on the status of the project and the quality of the teamwork. During the term student teams are required to complete self-assessments surveys. That information, complemented by faculty observations, helps to identify students whose contribution to the teams is lacking. Because those surveys take place during the term, there is time to remind students that part of their grade hinges on teamwork.

Near the end of the term students complete a self-assessment about the effects of their IPRO experience, rating their agreement from 1 (strongly disagree) to 5 (strongly agree). Overall the responses were very favorable (Table 1); the mean score from the ten questions was about 4.3. The assessment helped us understand that students consistently agreed they acquired problem-framing skills, but that there was considerable variance and less agreement about their ability to analyze a potential ethical dilemma.

Table 1. Summary results from the end-of-term assessment including responses from 21 students.

Concept	Mean	S.D.
I have a much better understanding of complex urban problems.	4.19	0.51
I learned a lot about the important characteristics of successful team work.	4.29	0.78
I understand what is meant by project-based research in contrast to other forms of research.	4.14	0.73
I know how primary and secondary research differ from one another and the importance of each.	4.57	0.93
I know how to locate data that relate specifically to my work and how to cite that information.	4.05	0.50
I understand how to organize a productive brainstorming session.	4.29	0.78
I know how to organize an analysis of a potential ethical dilemma.	3.48	1.08
I know what it means to frame a problem, and I can explain what a proof of problem calls for.	4.67	0.48
I have a greater appreciation of the need for good communication skills.	4.62	0.59
I understand the difference between a prototype and a solution.	4.57	0.68

We also have information from an external assessment. The end-of-term IPRO exposition day includes teams of judges who interview each team, view team presentations, and rate each team's performance based on ten criteria:

- Team members actively engage the visitor in conversation about the project and are enthusiastic, passionate, and focused.
- Exhibit area is eye-catching with attractive posters, brochures, videos, prototypes, and other materials. Dynamic and interactive elements are used.
- Describes the work of the team: tasks completed, information/data collected, analyses performed, conclusions/recommendations reached. (Includes recognition of the contributions of any consulting experts, resource providers, previous teams, and other organizations.)
- Highlights benefits and added value of the team's work compared to contemporary practice.
- Describes major impacts, risks and challenges associated with the project: technical performance, need for enabling technology, social, competitive, environmental, safety, regulatory, financial.
- Applied appropriate methods associated with professional practice (e.g., brainstorming, experiment design/testing, scientific method, user-centered design, iterative prototyping, survey research, business planning.)
- Devised innovative approaches to overcome obstacles or achieve breakthroughs.
- Describes major accomplishments of the team.
- Conveys a deep understanding of the impact the project has or can have on a community, market, sponsor, industry or profession.
- Several team members are engaged, with questions answered clearly and confidently in a way that complements the entire exhibit experience. Team members are able to effectively reflect on the professional experience they have gained.

Although there is some duplication of the in-class assessment, the judges' criteria provides a slightly different perspective, with less emphasis on the process and a greater focus on the final product and each team's presentation skills. The average IPRO exposition score in our IPRO was 8.4 (ranging from 7.8 to 8.9), not significantly different from the overall average IPRO exposition score of 8.3.

Through a couple of iterations of this interprofessional projects cluster course, we have observed that:

- Relative to assigned team structures, self-selected teams are more likely to result in students that are fully engaged in their projects.
- Because the IPRO cluster could involve up to 40 students, it is important to have a skilled facilitator who can coordinate the various student teams and organize the course, and an appropriate range of mentors who can provide domain knowledge for the wide variety of topics.
- We have benefitted from a dedicated, flexible meeting space and ready access to a comprehensive machine shop that makes it possible to explore various prototype designs.
- It is important to identify faculty mentors who value the interdisciplinary approach so that they are able to make room in their schedules to champion the cause.
- Students and faculty mentors can struggle to find a balance between focusing on the process or on the product. The process versus product dilemma can play a major role in

student and faculty satisfaction levels in the course, and lead to questions about assigning and accepting final grades for the course.
- The most creative solutions come from the most diverse interdisciplinary teams. Interestingly, many engineering students struggle with the approach at the beginning of the term. Their comfort zones are built on experience with prescribed problem solving; asking them to justify and explain the existence of a problem and come up with a novel solution is different, but we believe it is an essential skill for success.

Elements we plan to include in future iterations of the course include:

- Pre- and post-assessments to measure changes in student comprehension
- A diversity index to assess how diversity affects team functions
- Shared assessments with other IPRO groups to compare different approaches

In their final assessment, students had an opportunity to provide written responses to specific questions about the course. We conclude with a sampling of their comments:

- The most important urban challenges are:
    - "…community involvement and education."

- The most important characteristics of successful team work are:
    - Communication, mutual respect, collaboration

- To organize an effective brainstorming session it's important to:
    - "Don't discount any idea right away, think outside the box. Look at the problem from multiple angles, don't get all your ideas running in one direction, you will miss out on a lot."

- To organize the implementation of a solution:
    - "…to implement a solution, you have to take into consideration who will be affected by your solution, and the greater implications of that. The process may be repetitive - it may not work the way you wanted it to the first time, so you might have to try again or you might have to try differently."

- The steps to organize analysis of a potential ethical dilemma include:
    - "Find out who the problem effects [sic] currently. Find out who the problem effects [sic] later on. Find out with your design, who it effects. Finding out who the problem and design effects [sic] now and in the future is the method to go about whether it is direct or indirect...it is best to know how it effects [sic] all parties."

- What does it mean to "frame a problem"? What does it mean to provide "proof of a problem"?

    - "Framing a problem … means to describe an issue using logic to express facts about it. Framing a problem starts with formulating a question. Proof of a problem means to use more detail, information, statistics, or research to express facts about this problem."

- How have your communication skills improved and what skills do you want to improve?
    - "One of the teammates in our group is an architect. I thought it was interesting and useful that she was able to communicate her ideas through brief, rough sketches. This is something that I tried to improve because at times I found it difficult to explain a design idea without actually drawing it out."

- What is a prototype valuable; how might a prototype relate to a solution?
    - "Having a prototype allows you to view your solution come to life. It lets you see the flaws your solution has and how you can improve upon them. Your solution can change because of this."

In summary, the interprofessional projects course provides a multidisciplinary experience where students have the opportunity to apply discipline-specific knowledge to very tangible topics that are relevant to urban problems. Structured as engineering-led efforts, in these projects our students gain from teamwork, leadership, and project management experience, while they benefit from the broad education necessary to understand the impact of engineering solutions in global, economic, environmental, and societal context. We want students to develop the critical thinking skills they will need to solve the challenging problems of urban systems, and encourage students to develop solutions within reach the reach of current technology.

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Bibliography

1. ASCE (2013) 2013 Report Card for America's Infrastructure. American Society of Civil Engineers. Information from the ASCE web site (http://www.infrastructurereportcard.org/) accessed January 2015.
2. Bhandari, A.; Ong, S.K.; Steward, B.L. (2011) "Student learning in a multidisciplinary sustainable engineering course" ASCE Journal of Professional Issues in Engineering Education and Practice Vol. 137, No. 2:86-91.
3. Chiocchio, F.; Forgues, D.; Paradis, D.; Iordanova, I. (2011) "Teamwork in integrated design projects: Understanding the effects of trust, conflict, and collaboration on performance" *Project Management Journal*, Vol. 42, No. 6:78–91.
4. City of Chicago (2012) *Sustainable Chicago 2015 Action Plan*. The plan can be obtained at the City of Chicago website, cityofchicago.org. Accessed June, 2013.
5. D'Amour, D., Ferrada-Videla, M., San Martin Rodriguez, L., & Beaulieu, M.-D. (2005). The conceptual basis for interprofessional collaboration: Core concepts and theoretical frameworks. Journal of Interprofessional Care, 19, 116–131.
6. Dym, C., et al. (2005) "Engineering Design Thinking, Teaching, and Learning," Journal of Engineering Education, Vol.94, No.1:103-119.

7. Esterman, M.; Patru, D.; Amuso, V.; and Hensel, E. (2007) "Development of integrated project tracks for a college-wide multidisciplinary engineering design program at RIT". Presented at the American Society for Engineering Education Conference. Accessed from http://scholarworks.rit.edu/other/647.
8. Hotaling, N.; Burks Fasse, B.; Bost, L.F. Hermann, C.D.; Forest, C.R. (2012) "A quantitative analysis of the effects of a multidisciplinary engineering capstone design course" *Journal of Engineering Education* Vol. 101, No. 4:630-656.
9. Howe, S., and Wilbarger, J.,(2006) "2005 National Survey of Engineering Capstone Design Courses," Proceedings of the 2006 ASEE Annual Conference & Exposition, #1781.
10. Lattuca, L.R.; Terenzini, P.T.; Fredericks Volkwein, J.; Peterson, G.D. (2006) "The changing face of engineering education" The Bridge Vol. 36, No. 2:5-13.
11. National Academy of Engineering (2012) "The Distinctive Education Program at IIT" in *Infusing Real World Experiences into Engineering Education* National Academy of Engineering Real World Engineering Education Committee Report. The National Academy Press, Washington, DC.
12. Ollis, D.F. (2004) "Basic elements of multidisciplinary design courses and projects" Int. J. Engng, Ed. Vol. 20, No. 3:391-397.
13. Alexis, J. (2014) The Interprofessional-by-Design process was created by the IPRO lead office at the Illinois Institute of Technology, Chicago, IL.
14. Smith, D.R.; Cole, J. (2012) "Development and evaluation of an undergraduate multidisciplinary project activity in engineering and design" American Journal of Engineering Education, Vol. 3, No. 1:41-52.
15. UBER (2013) YOUR #UBERCHOPPER IS ARRIVING NOW...Posted July, 2013 at the UBER blog http://blog.uber.com/2013/07/02/uberchopper/.