USING REAL-WORLD MULTIDISCIPLINARY DESIGN EXPERIENCES TO PREPARE YOUNG ENGINEERS TO ENTER TODAY'S WORKFORCE

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ABSTRACT
As educators we must ask ourselves whether we are truly meeting the needs of today's young people to become engineers. Are we showing students what it means to be an engineer and how engineers help people and contribute to society? Are our young engineers prepared to successfully integrate knowledge from diverse areas of the sciences, mathematics, arts and humanities, and social sciences, to solve the complex multidisciplinary problems that the world is facing? The mission of Rensselaer's O.T. Swanson Multidisciplinary Design Laboratory (MDL) is to provide clinical real-world experiences for students that build confidence and teaches them to integrate discipline specific knowledge with practice on challenging design projects. The MDL provides a culminating experience intended to prepare students to enter the workforce. The projects are open-ended, technically challenging design problems that encompass a broad array of important contemporary issues. In addition to defining an important problem, sponsors provide a significant grant and their direct participation with the students, faculty and staff who work to provide design solutions. Lessons learned over the past three years have opened our eyes to some of the major changes needed in how to educate engineers and prepare them to enter the workforce. These lessons are expected to influence changes affecting our entire curriculum.

Keywords: multidisciplinary, design, engineering, education

1 INTRODUCTION

The engineering profession is at a crossroads. The world is becoming increasingly more complex and connected, the advance of science is accelerating, and socio-technical problems are abundant. Engineering has always been viewed as a problem-solving profession, but today's problems require us to take a fresh look at how we solve problems in the context of this new world. In the United States, the engineering workforce is aging and a new breed of young engineers will be entering the workforce. As educators we must ask ourselves whether we are truly meeting the needs of today's young people to become engineers. Are we showing students what it really means to be an engineer? Are we inspiring them with the potential benefits they offer to the world? Are our young engineers prepared to successfully integrate knowledge from diverse areas of the sciences, mathematics, arts and humanities, and social sciences, to solve the complex problems that the world is facing?

In the United States, people in government, industry, and academia are asking these questions. Many of the answers indicate an urgent need for change. A new generation of young people, with diverse backgrounds, interests, skills, and needs, must be enthused about the profession of engineering and be prepared, in both technical and non-technical areas, to solve the problems that the 21st century will present. People are starting to refer to this new breed of young professionals as "renaissance engineers" (Jackson, Splitt); young men and women who get involved in society, stand for practical and cooperative solutions, and work to change the world to make it a better place to live. To create this new breed of renaissance engineers requires a new approach to engineering education.

This paper describes Rensselaer's multidisciplinary design experience and how we have used sponsored real-world design projects to better prepare young engineers to enter today's workforce. The paper will highlight programmatic strategies and approaches, and share successes and failures associated with implementing the program. It will attempt to describe (to the extent possible) some of the complex interactions between students, sponsors, and faculty. It will conclude with thoughts on some of the major lessons learned and what the future may hold for clinical real world design experiences in engineering education.

2 THE CURRENT SITUATION

Engineering is an increasingly difficult profession to define. We broadly consider ourselves problem solvers. We are responsible for many of the technological marvels that people use everyday, yet many people do not understand or appreciate the engineering profession. In fact, even prospective engineering students are often at a loss when asked about what engineers do. Earlier, during their secondary education, they may have been enthused by what technology has to offer, but upon entering a university to study and ultimately learn how to practice engineering they are often unsure of what it means to be an engineer. Engineering curricula at many U.S. universities place a heavy emphasis on the introduction of a "fundamental body of knowledge" during the first years of study. This has not changed in decades. Unfortunately, by the time students are ready to graduate, many are not yet ready to actually practice engineering. In the past, the assumption was that the analytical skills practiced in solving well-defined physics and math problems would provide a basis for application at their place of employment where they are charged with solving open-ended and often ill-defined problems.

Organizations today that employ engineers are faced with complex business issues that require quick response from technical professionals who understand and value multidisciplinary perspectives. The learning curve for entry-level engineers is getting steeper. Engineering graduates are being asked to "hit the ground running" and be adaptive to an ever-changing world. Not only must our young engineers be technically competent, but they must also have teamwork and communication skills that allow them to effectively work with others who may not have a technical background. They must be able to effectively integrate knowledge and information from diverse technical and non-technical areas. They must exhibit leadership skills with confidence, and command respect from other working professionals. They must have the sensitivity, integrity, and ethical understanding to appropriately put the work they do and the solutions they come up with into a broader social context.

3 EXPERIENCES WITH REAL WORLD MULTIDISCIPLINARY DESIGN PROBLEMS

The mission of Rensselaer's O.T. Swanson Multidisciplinary Design Laboratory (MDL) is to provide clinical real-world experiences that build confidence in and teach students to integrate discipline-specific knowledge with practice on challenging design projects.

The MDL provides a culminating experience intended to prepare engineering students to enter the workforce. In the past three years, since the MDL first opened, we have secured and delivered results on 25 industry-sponsored projects from global companies including Albany International, Barclay Capital, General Electric, Harris Corporation, International Business Machines, General Motors, Pitney-Bowes, Lockheed-Martin, Northrop-Grumman, and United Technologies Corporation. In addition to industry-sponsored projects, individual entrepreneurs, and public and private foundations have also sponsored projects, which serve to enhance and broaden the mix of possible project options for students.

The projects are open-ended, technically challenging design problems that encompass a broad array of important contemporary issues such as technology innovation and entrepreneurship, manufacturing productivity and quality, environmental conservation and alternative energy, and aids for people who are physically and/or mentally challenged. To date, MDL experiences have predominantly involved mechanical, materials, electrical, computer systems, biomedical, and industrial engineering majors. In addition to defining an important problem, sponsors provide a significant grant as well as their direct participation with the students, faculty, and staff who work to provide design solutions.

Past projects have included a wide variety of problem areas such as the following:

- Market research and feature development for a new car options package to appeal to young (so called Gen Y) buyers.
- Design and development of a steam test facility for evaluating new energy efficient steam turbine system design concepts.
- Concept development and evaluation of new energy efficient in-door air quality technologies.
- Design of systems that can be used to help seniors live safely and comfortably in their own home.
- Exploration of information technologies and system layout for a new investment trading facility.
- Design and prototype development of thin film sensors for corrosion prediction.
- Prototype development of smart adaptive control systems for factory automation utilizing CAD/CAM process knowledge.
- Development of lead-free soldering materials and joining methods.
- Design of a prosthetic device to help a young boy with no hands to eat independently for the first time.
- Concept development and engineering test of a wind turbine powered catamaran.

Provided with a list of possible project descriptions from which to choose, students submit an introductory memo and resume to express their interest in a specific project along with their qualifications. They are typically quite anxious to have a real world engineering design experience to help them prepare for the workforce. We have found that many students favor projects that have social impacts or deal with familiar subject areas for which they have had some prior exposure. They prefer design problems with few constraints and would rather approach design from a “clean sheet” perspective. It is often more difficult to motivate students to work on projects that involve the application of existing technology to complex systems for which they may have had little or no prior background or exposure. And, it can be difficult to keep students motivated on projects for which the best approach to design is to use off-the-shelf hardware and time tested methods.

Problem descriptions are usually very broadly stated with sufficient difficulty to challenge a team of experienced engineers, yet if left without guidance, students will often attempt complete solutions in a single semester. Sponsors are asked to identify projects that are important to them, but not on their critical path. Since we ask sponsors for their direct involvement, we want projects that will not only serve as a great learning experience, but will also promote enthusiastic participation from the practicing engineers that serve as technical liaisons and mentors to the student teams. Some of the best projects involve problems that may be more speculative and risky from a business standpoint and for which the sponsor may have tried and failed to find a solution in the past. Problems that benefit from fresh, creative, "out-of-the-box" thinking, are a good fit. Meanwhile, as part of the learning experience, student teams are expected to properly scope the level of effort and seriously consider the resources and time they have available to successfully accomplish a more focused set of team proposed project objectives.

The complicated challenge for instructors and sponsors becomes calibrating the high expectations and idealistic aspirations of students with a realistic set of objectives and plans. A multidisciplinary team of faculty works together with sponsor mentors to help students develop a clear understanding of design objectives, constraints, and risks. Faculty members who work with the MDL typically have prior experience actually working as engineers. Many have "clinical" appointments. Clinical appointments are special positions at Rensselaer. A clinical professor has significant professional experience and is expected to focus on teaching, not research. Research faculty who have no obligation to teach also get involved with projects, but often as expert consultants or as reviewers during final project design presentations.

As a multidisciplinary team, faculty members will offer differing perspectives and approaches on how to solve problems and advise students. Over time, we have become more sensitive to the fact that each of us have different teaching styles and experience, and there is often a fine line between "telling-teaching" and allowing time for students to "discover-fail-succeed". Similar to the famous story about the blind men and the elephant, each faculty member brings different perspectives and approaches for helping students solve problems. This sometimes creates some consternation and/or amusement on the part of students seeking our help, but we also explain to them that "this is real world", and they can expect such differing viewpoints when seeking advice from consultants, experts, and stakeholders about problems they will face in the real world. In fact, we believe, such diversified perspectives, while sometimes frustrating for students and faculty alike, is an integral part of teaching students about the importance of broadly considering alternative solution paths when solving complex problems.

During the early stages of a project, students are instructed to broadly and thoroughly explore the background to a problem, perform competitive benchmarks, and research prior art. Students are encouraged to make frequent and direct contact with sponsor mentors and to develop a productive working relationship. Ultimately, a major part of their grade will depend upon their working relationship with their sponsor mentor(s). Project success often appears to be directly correlated with this vital relationship. To cultivate teamwork, students partake in interactive group exercises that teach about customer requirements definition, engineering specifications, project planning, concept generation and selection, risk assessment, problem decomposition, engineering analysis, design for manufacture, prototype development, experimental methods, and testing. Faculty members take on multiple roles of coach, consultant, referee, advisor, manager, and ultimate assessor. The use of traditional lecture is minimal. Impromptu and informal presentations by or to students are a more frequent occurrence.

The multidisciplinary aspects of a project present themselves as a natural occurrence of the design process. Most, if not all, real design projects are inherently multidisciplinary. Working with sponsors, faculty will configure teams based upon the expected disciplinary content in a project. As a culminating experience for students, faculty are interested in having students exercise and, often for the first time, tie together or integrate knowledge from earlier coursework in their particular disciplinary specialty as well as from general engineering or the basic sciences and mathematics. It is not our interest to make electrical engineers do mechanical engineering, or industrial engineers become materials engineers, etc. Instead, each student is expected to participate in a design project that is suitable and appropriate for his or her background and area of interest. Meanwhile, we are also interested in exposing students to different thinking patterns and making them more receptive to alternative problem solving approaches. We want each student to actively participate, so each student is expected to develop an appreciation and in-depth awareness of all the critical technical aspects of their project and be able to provide impromptu project status reports at any time.

While at the beginning stages of a project all team members will work to develop a common set of team objectives and plans, after a project moves into the concept development stage, role definition becomes more clearly defined. For example, electrical engineers will work on control circuits or signal processing, mechanical engineers will work on machine design, heat transfer, or fluids dynamics, industrial engineers will work on manufacturing systems integration or workspace planning, and materials engineers will provide consultation on material properties and selection, or work on the application and/or processing of new advanced materials. We have found that it is best to allow teams to be “self-directed”, and to allow leadership and team organization to emerge naturally. This approach instills project ownership and initiative on the part of the students. In preparation for their MDL experience, students will have already taken an introductory engineering design course in their sophomore year and a sequence of professional development courses. These courses help prepare students for the challenging MDL environment. For a well-orchestrated team, the dynamic interplay between students becomes an exciting and gratifying performance for faculty and sponsor to observe. For dysfunctional teams, faculty and sponsor intervention, when properly administered in a timely fashion, can help save a team, if the students are willing to listen and accept help.

Many factors contribute to team success. These include many of the same “best practices” that are often cited for high performing product and process development teams in business and industry. For example, successful design teams will:

- Develop a common understanding of project requirements
- Properly identify the end user and obtain their direct input on design requirements
- Interpret and prioritize customer requirements
- Establish quantifiable engineering specifications
- Consider a broad range of concept solution alternatives
- Converge on a concept solution using a rationale team decision making process
- Perform a detailed risk assessment of potential design and project issues

- Maintain an on-going action items list and use it to help keep the team on track
- Create a realistic project plan and properly scope the level of effort
- Conduct regular effective and efficient project team meetings
- Provide appropriate status reports to stakeholders and get help if necessary
- Use engineering analysis to predict performance and evaluate design trade-offs.
- Develop realistic cost estimates
- Understand manufacturing processes and use design for manufacturing guidelines
- Provide complete and unambiguous design documentation
- Meet or exceed applicable regulatory standards and codes
- Set design specifications that are consistent with process capability

Ultimate assessment is culminated in the form of a final team oral presentation, project demonstration, and written technical report that is delivered to the sponsor. The project demonstration is crucial to making it real! Concepts and analytical evaluations alone are not enough. Teams are required to show a proof of concept in the form of a physical model, working prototype, or testable artifact.

After participating on an MDL project, students will inevitably express a new awareness of the complexity associated with a real-world problem. Depending upon project dynamics, different students will learn different things on different projects. Learning points often expressed and documented by students in their final semester memos include:

1. Improved teamwork, leadership, and communication skills
2. Understanding of how the design process really works
3. Development of an appreciation for the importance of "attention to detail"
4. Understanding of the role of test and measurement in design
5. Application of analytical knowledge and skills from prior coursework
6. Understanding about a new and different technical or non-technical area
7. Exposure to the business aspects of engineering

The MDL provides a very customized form of learning for our students. Students are exposed to and develop a new awareness for a broad array of subject areas. At the same time, they also become deeply immersed in the application of specific knowledge content. Since there is little formally delivered content, students are forced to engage in a more active style of learning. The experience serves to exercise phases of the learning process often missed in more traditional courses and thus serves to cement prior learning, as a culminating experience is intended to do.

In addition to a successful learning experience for students, we have also seen benefits to our sponsors that are, increasingly, resulting in repeat sponsorship of new projects each year. This is extremely important to us, since continued success with this form of educational experience depends upon a continuous stream of new project ideas and a source of funding that goes well beyond the typical resources provided for more traditional teaching methods. These additional resources include administrative support, project material and/or equipment purchases, facilities and equipment support services, and the extra faculty time and effort associated with a very dynamic and ever changing learning environment. By far, the largest resource component is for the people (i.e., faculty and staff) who support the students and facilitate their success.

While our sponsors are sometimes unclear about if and how they may have implemented specific project results, we suspect that their participation is not purely philanthropic. In general, sponsors will cite benefits that involve helping them to think in new and creative ways about solving a problem that is important to them. The projects also offer an opportunity for sponsors and students to become better acquainted for potential job recruitment. Some projects have provided the impetus for the sponsor to pursue the project in greater depth internal to their own organization. Although project results are generally for the sponsor, we will also pursue intellectual property opportunities for ideas that have been sponsored through entrepreneurial and foundation funding.

4 LESSONS LEARNED AND CONCLUSIONS

Lessons learned over the past three years have opened our eyes to some of the changes needed to better educate and prepare young engineers to enter the workforce. The biggest lesson is that challenging real-world design experiences help students integrate knowledge and there is a growing consensus that such experiences should be used throughout the engineering curriculum starting in the first year [3]. There are two dimensions to this knowledge integration. One involves the horizontal breadth of knowledge integration associated with the humanities and social sciences into the engineering curriculum. The other dimension involves the vertical depth of knowledge integration associated with scientific fundamentals and engineering application.

An emerging group of students from our new interdisciplinary Product Design and Innovation (PDI) program offers a glimpse into how to integrate the humanities and social sciences (H&SS) into an engineering curriculum. PDI offers a dual degree program built around a studio design class each semester, which is integrated into a core-engineering curriculum leading to bachelor degrees in both mechanical engineering and H&SS. The program is administered through our Science and Technology Studies department, which resides in the School of Humanities and Social Sciences. The studio design courses expose students to a broad range of open-ended design experiences, where they learn how to combine cultural, aesthetic, and technical skills and knowledge with the insight and context of social concerns and issues. As these students make their way through the PDI program, they ultimately have culminating experiences with the MDL, which serve as senior capstone design studios. We have found that compared to the typical engineering senior, PDI students clearly differentiate themselves, since they are comfortable and competent with multidisciplinary thinking and at odds with the conventional mindset that tends to focus on disciplinary specialization. They represent the kind of student that industry is asking for to be cultivated as our next generation of engineers.

On the technical side, we find that integration of analysis, test and measurement is one of the most challenging aspects of doing real world design projects. By the time students become seniors, many have difficulty recalling some of the “fundamental” principles they learned in physics. Many students have also not yet grasped the concept that much of engineering is about meshing abstract mathematical models with physical test and measurement. Laboratory experiences help, but do not totally provide a solution, because many complex real-world engineering problems do not present themselves in a fashion where the “fundamentals” can be easily applied. Introducing real world problems sooner in engineering curricula would expose students to this situation and help them to become more comfortable and gain confidence with unstructured problems where parameters may have ill-defined relationships and considerable variation.

While it is clear that we still have much more to learn from our MDL experiences, preliminary results indicate that we are moving in the right direction and are at the threshold of something very exciting! At the heart of this excitement is how a diversity of perspectives and viewpoints can lead to creative and practical solutions to real-world design problems at the undergraduate level. We are also showing how it is possible to cooperatively blend the objectives of education and business. Lessons learned in the MDL are also being used to help shape future curriculum changes and optimize the learning experience for our students. Most exciting is that we are showing that it is possible to actually create "renaissance" engineers who are capable of blending technical competence and leadership with social awareness and responsibility.

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REFERENCES

[1] Splitt, Frank G., "The Challenge to Change: On Realizing the New Paradigm for Engineering Education," Journal of Engineering Education, April 2003, Vol. 92, No. 2, Pages 181-187.

[2] Jackson, Shirley Ann, "Changes and Challenges in Engineering Education," Main Plenary Speech, ASEE, June 23, 2003.

[3] Core Engineering Renaissance at Rensselaer: A Common First-Year Integrated and Connected Curriculum, National Science Foundation Proposal # 0343110, July 7, 2003.

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