Experiences in Integrative Research and Education Projects with Undergraduate Engineers

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Introduction

Academic careers offer engineering faculty an array of activities that they are expected to participate in - these include teaching, research and publications, laboratory development, student advisement, accreditation documentation, committee work, and service to professional organizations, to mention a few areas of involvement. Time constraints, the diversity in the set of responsibilities, and promotion/tenure expectations cause faculty to be very selective in the energy concentrated on these tasks. The general trend has been to focus on either teaching or research as the major activity - a choice that is, in many cases, determined by the mission of the university. Traditional paradigms have further dictated the separation of teaching and research activities - a separation that is keenly felt in predominantly undergraduate institutions.

However, a lot of engineering faculty have started merging their teaching and research activities creating a synergy that benefits all participants in the process. In recent times, undergraduate research and the integration of research into educational activities has been scrutinized by various institutions nationwide and has been a topic of funding interest to several agencies. According to the National Science Foundation, undergraduate research allows students to experience first-hand how basic research is carried out, and to make contributions of consequence to various fields(1). The development of models that successfully integrate teaching and research involves the investment of significant time, resources, and skill. It is therefore important to review the successes and failures of efforts at various sites. One such site for integrative research and education at the undergraduate level is Kettering University.

Overview of the University and Selected Laboratory Facilities

Kettering University is a fully cooperative private engineering college which offers various ABET-accredited Bachelor of Science degrees in engineering of which Manufacturing Systems Engineering is one. The Kettering system of education is unique with its five-year, fully cooperative program featuring alternating 12-week academic terms and cooperative assignments in industry. Although in its early days the Institute had only one sponsor, today the university has over 550 cooperative employers with over 700 locations nationwide. During the final phase of the program, each student undertakes a thesis on a significant problem faced by the cooperative employer, under the joint supervision of a faculty member and an industrial advisor.

Education at Kettering University has always featured a heavy emphasis on hands-on experiences using industrial grade equipment - this is attributed to the heritage of the university and the intentions of its founders. Laboratory facilities include Computer Integrated Manufacturing (CIM), Metallurgy, Materials Testing, Basic & Advanced Machining, Foundry, Ceramics, Metrology, Polymer Processing, Rapid Prototyping, Manual & Machine Welding, Sheet Metal Forming, and NC Systems. This paper addresses work done in the CIM and Metrology laboratories.

The CIM facility provides undergraduate students with a sophisticated environment in which they can learn about, experiment with, and conduct projects and research activities in CIM. The laboratory supports classes in NC Systems, Robotics, and CIM and features an AS/RS, an AGV, twelve robots, machine vision, Auto ID equipment, five CNC machines, Allen Bradley Programmable Logic Controllers, conveyor systems, high end personal computers and workstations. The equipment is configured into cells for material storage, material handling, machining, and assembly, and uses supervisory computer control techniques to integrate the various cells. The laboratory has been funded by the National Science foundation (NSF), the Society of Manufacturing Engineers (SME), various corporations, and internal university funds.

The Metrology laboratory has in the past four years experienced a huge influx of funds that are a result of the renewed interest in integrating various aspects of metrology back into the curriculum. The laboratory features CMS's, vision-based inspection equipment, contour measuring and roundness measuring machines, height gages, and assorted calipers and micrometers and other instrumentation for manual measurements. Software includes a recent addition for reverse engineering. The laboratory has been funded by the Mitutoyo Corporation, the National Science Foundation (NSF), the Society of Manufacturing Engineers (SME), and internal university funds. Both facilities have offered students an opportunity to participate in some very significant efforts that will now be discussed.

Integrating Undergraduate Research and Education

A December 1997 article in the ASEE Prism cites various methods for integrating teaching and research (2). They may be abbreviated as follows:

1. Encouraging students to pursue independent research work
2. Bringing research into the classroom
3. Sharing research with communities outside the university
4. Encouraging greater emphasis on teaching among research faculty

There exists strong case for the synergy between research and education in manufacturing and other engineering disciplines at the undergraduate level. For starters, the introduction of research examples and advances into courseware ensures that faculty and students stay abreast of the latest developments in the field. Furthermore, engineering curricula are constantly engaged in the battle to balance the amount of information presented to students versus the depth of coverage in these areas. It is therefore not uncommon for the educational experience to be reduced to a breadth-focused overview of a variety of topics presented in disjointed fashion.

The introduction of research experiences into the curriculum allow universities to move away from this state of affairs and pull together different areas of the curriculum with a deeper interest in a selected research topic of interest. This approach has long been advocated by educational psychologists such as Benjamin Bloom in his taxonomy of Educational Objectives(3). In this publications he advocates the mastery of subject matter by deep studies in the area - a methodology that is supported by undergraduate research.

Another benefit of the synergistic approach is the conversion of "free" electives by undergraduates to focused work in an area of interest to them. In some cases, as in the case at Kettering University, the increased exposure through various experiences has led them to significant work for the baccalaureate thesis. Finally, it may be argued that undergraduate research whets the appetite of potential master's and doctoral researchers and may offer interesting possibilities in bolstering declining enrollments of US citizens and residents in graduate schools. The list that was developed and presented by Ms. Coppula is now presented once again rank ordered by the time invested by students in various research activities:

Bringing Research into the Classroom

Methods suggested in this area by various experts include the usage of examples, problems, and data from actual research projects. At Kettering University, the author has relied on student research in the form of literature/Internet searches, field trips to selected sites, interviews with industry personnel, and the preparation/presentation of technical reports as a part of courses on CIM, Robotics, and Material Removal Processes. The approach has been instrumental in giving students a deeper understanding of what technology and methods are state-of-the-art and those are currently state-of-the-industry.

In 1997, the author was involved in contract research in the area of robotic polishing or die cast aluminum parts with simple and complex surfaces that had to be finished using an abrasive process. Students were involved in early literature surveys and also researched, in small groups, specific topics such as media selection, equipment specification and selection, reach studies and cell design, supervisory control, force/torque sensors, off-line programming, cycle time optimization, and environmental/safety issues. In this way several students were members, albeit for twelve weeks, of the larger research group that was involved with this year-long project in the CIM Laboratory.

In a recent case students enrolled in a course on Quality Assurance successfully integrated three separate areas - SPC, numerically controlled machining, and metrology for a class project. Parts machined on a CNC machining center (with parametric changes) were measured using a vision-based inspection system, and the results obtained were statistically analyzed for QA purposes and the class project. In all of these cases the students spend only part of the semester working on their research projects. There has been a recent emphasis at the university to increase the interaction between diverse topical areas as described above. Another method of bringing research into the classroom is the conversion of traditional courses into educational research experiences. This will be discussed in the following section.

Independent Research

Independent research projects that span an entire semester have been a long time favorite of faculty members seeking to involve various constituents in a focused study of a specified topic. At Kettering University, the author has been involved with individual students and small groups of 2-3 students in a variety of independent research projects. These include the design of a flexible assembly cell using a SCARA robot, the design of a serial interface monitor between an assembly robot and a host computer, the design of a robotic workcell to sort parts, cycle time optimization in robotic processing operations, process monitoring and control, and systems integration.

The selection of the topic and the overall process has been initiated in some cases by the author publishing an RFP for interested students or by students approaching the author with requests that have been triggered by a past course, tours through the facility, or a stated interest in the area under study. The author has treated independent research programs have been treated as independent study projects at Kettering University. Assigned a designation of IMSE-499, each of these courses has had a published syllabus with goals/objectives, guidelines, and reporting/assessment/evaluation procedures. These and other managerial issues will be addressed from a global perspective in a subsequent section. Students spend several hours each week at scheduled times and on their won time working on the problem. At the end of the semester students are required to make a presentation to an audience of other students, technicians, faculty, and even industrial sponsors - this enhances the overall quality of the project and its perceived importance in the eyes of all of the constituents.

Another semester long approach is the conversion of traditionally taught courses into intense research experiences. In the spring of 1999, IMSE-490: Robotics will be taught in a project form as opposed to the traditional lecture-laboratory-term project format. The problem that students will be expected to solve is the automation of the material handling and finishing operations associated with the injection molding process. Students will be integrating two robots into an injection molding cell for unloading parts and degating them. To complete this project they will be required to work in teams in the areas of cell design, reach studies, end effector design, cell safety, interfacing of robot and molding machine, robot programming, fixture design for automated degating of parts, integration of the automated cell with an AGV, inspection, and overall systems integration. While several of these would be traditionally addressed in lecture and laboratory sessions this intensive 12-week experience will replace all other course requirements and present all of the traditional courseware in an integrated format. While the project has not even been begun at the time of this writing, it is interesting to contemplate a discussion on kinematics and the determination of singularities within the context of this robotics project.

The Baccalaureate Thesis

Earlier in the course of the paper, the author discussed the undergraduate fifth-year thesis program. In the traditional sense this is handled at the student's co-operative employer's site.

Here students spend up to a year researching and working on a topic that is of significant importance to their co-op employer. Topics range from systems integration and automation on manufacturing lines to the development of a manufacturing process for a component. Some of the topics that the author has co-advised with industrial advisors appear below:

- Optimization of Prototype Build shop Tooling and Procedures
- Process Certification of Coverlay Tack and Press
- The Development and Implementation of High Speed Machining on 6AL-4V Titanium
- The Application of Automated Riveting in Building Frames
- Automatic Loading of Body Side Subassemblies to a Lay-Down Body Side Framing System
- Control Systems Design for an Automatic Plasma Tab Weld Station
- Design and Implementation of a Transformer Pacing and Labeling System
- Design and Development of the Sparcmate 225 Arc Welding Workcell
- Analysis and Application of Lean Manufacturing to the Existing Facility
- Automated Mold Polishing Machine
- Best Practices for Development & Optimization of Paint Robot Path Teaching
- Implementation of Process Monitoring and Control Systems in the Manufacture of Flat Plate Headed Sensors
- Design & Implementation of CAM Models for Part Programming CNC Lathes Utilizing Group Technology Concepts
- Computerized Quoting System for the Design & Build of Special Machinery

In each of the above-mentioned projects the students are responsible for implementing a scope of work that is developed by the student, the employer, and the university. This intensive experience has led to many developments that remain proprietary in nature due to the competitive advantage that the company gains through the research efforts of its co-op students.

In a few cases the work and the preparation for baccalaureate theses have been carried out on site at Kettering University. In these cases students have through various circumstances separated from their co-op employer, chosen to do the work at the university due to an intense interest in the topic, or even participated in the program as international students from a partner university. The author has served as the advisor to projects in the CIM and Metrology facilities to students from Kettering University as well as FHTE-Esslingen, Germany.

These include the integration of a bar coding system into a flexible assembly cell, the robotic polishing of aluminum parts, the design and implementation of an automated screwdriver, and the evaluation, assessment, and implementation of an automatic inspection system. Most theses demands full time work from the students involved in the project - many of the co-op employers significantly reduce the workload placed on the students at this time of their academic careers allowing them to focus all of their time and energy on the research topic. This was also the case for the theses developed at the university.

Management of Research Activities

In all of the above cases a common framework has been used for the management of these research activities. However for the projects of shorter duration some of the formalistic procedures have been incorporated on an informal basis. The author is responsible for the initial development of the RFP and the project description. In some cases such as student-proposed independent research projects or thesis projects proposed by co-op employers, the student or the employer advisor has a major role in the development of the project description. This is then subject to review by the faculty member advising the student in this endeavor. Clarity in project description is imperative to the success of credible and innovative research and development projects. Some of these issues have been recently addressed in an article by Barbara Olds and Ron Miller in the ASEE Prism. Building on a foundation of NSF-recommended evaluation/assessment procedures and ABET's EC2000 criteria, the paper addresses critical issues in project evaluation and assessment using the project evaluation matrix that addresses research questions, performance criteria, implementation strategies, assessment/evaluation methods, timelines, and audience dissemination (4).

Once the project description has been developed a plan of attack and a timeline are essential for good project management. Regular communication on a weekly or other pre-determined time interval must be conducted using a variety of media. This is needed and involves all constituents for purposes of project updates, periodic reports, exception handling, and focus/re-direction if necessary. Formative and summative assessments must be conducted to assess the impact of the project over its lifecycle. The final stage involves the preparation of a written technical report and the presentation to the audience that was specified in an earlier section of this paper.

Conclusions

The integration of undergraduate research into education process is an achievable goal with a significant impact on the overall process and system. The approach has been quite successful at Kettering University and has resulted in several satisfactory experiences and value-added developments for various groups of students, several corporations, and the author. Several students have also benefited through publications and presentations and career development through networking with other professionals in the field.

Some of the obstacles to the approach have been the additional workload placed on the faculty member, effective project evaluation and grading in some cases, effects of the workload carried by the students as part of their academic requirements on their research, and problems associated with the lack of adherence to the scope/extent of the project or loss of focus. On occasion, projects are affected by financial issues such as the loss of income faced by students working on their thesis at the university as opposed to working on a problem at the co-op employer. It is here that the university or an external sponsor must be of assistance to alleviate this concern in the interests of the intrinsic value of the project. The author plans to continue the integration of research and education using these and other developing methods - the next step is an increased

focus on the project evaluation matrix for better documentation. Another area to be developed is the growth of the faculty research team to offer research experiences in more areas beyond the CIM and Metrology laboratories and additional work on the integration of these and other areas.

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