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Active Learning in Manufacturing Engineering Programs

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Abstract

This study presents various activities to engage students more actively in their manufacturing engineering education. Active learning is an important approach to prepare engineers, especially manufacturing engineers. Competitions, projects sponsored by industry, capstone projects, laboratory exercises or projects simulating real-life scenarios, and service or research projects are all discussed here as possible components within manufacturing engineering curricula, whereas engagement outside the classroom through the Learning Factory concept is offered as the main alternative. Even though internship and co-op programs can be effective in the growth of prospective manufacturing engineers, this study primarily focuses on the student while he or she is at school, yet engaged with the real-world. Sample activities are detailed with a specific focus on their outcomes. Cases covered here are a mix of the product of an engineering education literature review and actual examples from the first-hand experiences of the author and his students. A wide range of areas are reviewed, including the diverse fields of manufacturing processes, reverse engineering and rapid prototyping, automated identification systems, industrial device control, robotics and automation, and safety engineering. The study concludes with a comparison of the pros and cons between the components presented in this paper and internship and co-op programs. Prospective project and laboratory ideas are also included in the paper.

Introduction to Active Learning

In traditional formal education, students mostly learn within a classroom setting where they are lectured as they follow a set of notes or their textbook pages. Contemporary educational research indicates that such a passive environment is not effective, resulting in limited knowledge retention by students [1]. Active learning is about finding ways of actively engaging students in the learning process to improve the results of the process [2]. Active learning is a multi-faceted and directional approach where various interactions are welcomed in the form of teacher-to-student, student-to-teacher, and student-to-student [3]. This approach was included within, “The Seven Principles of Good Practice in Undergraduate Education” [4]. “In the Seven Principles in Action” the authors state that active learning is not solely a set of learning activities but more of an attitude altering approach on both students and faculty. According to them, it is to channel the students to think about how and what they are learning, as well as asking them to take responsibility for their own education. The students take a greater role in their education, while self-management and self-

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motivation become critical parts of the learning process [5, 6]. In active learning, knowledge is directly experienced, constructed, acted upon, tested, or revised by the learner [7]. The following resources cite important components of active learning, including the use of multiple senses, high-level thinking, and stress-relief:

- Involving the use of multiple senses of the body, such as hearing, seeing, and feeling, the processes of interacting with other people and materials and producing responses or solutions to a problem are all critical components of active learning. Students involved in successful active learning activities within team environments develop communication, higher-level thinking skills, teamwork skills, positive attitudes towards the subject, and motivation to learn. Being in teams that continue to work, as opposed to individuals that quit while working problems, generates an environment with less pressure and fear of failure [3].
- Chickering and Gamson suggest that students must do more than simply listening by reading, writing, discussing, or being engaged in problem solving. To be actively involved, students must engage in such higher-order thinking tasks as analysis, synthesis, and evaluation [4].
- According to Silberman students should do most of the work. They use their brains by studying ideas, solving problems, and applying what they learn. It should be fast-paced, fun, supportive, and engaging. Hearing, seeing, questioning, and discussing it with others allows students to learn well. Students need to do it, figure things out by themselves, come up with examples, try out skills, and do assignments that depend on the information they already acquired or will acquire [8].
- Four major components of active learning are [3]:
    - Dialogue with self is about a learner thinking reflectively about their topic of interest or work. Students write about what they are learning, how they are learning, what role this knowledge or learning plays in their own life, and how this makes them feel. Tools of this type may include keeping journals and developing a learning portfolio.
    - Dialogue with others is more than listening to an instructor. A much more active form of dialogue occurs when a teacher creates a small group discussion on a topic. Sometimes teachers can also involve students in dialogue situations with practitioners and experts in class or outside of class. Other proposed activities include pair-shares, collaborative learning groups, student debates, and student-led review sessions.
    - Observing occurs whenever one watches or listens to someone else doing something related to them. This might be a student observing a teacher do something or observing the natural, social, or cultural phenomena being studied.
    - Doing refers to any learning activity where the learner actually does something, such as writing a research proposal, and sees it through happening. For example, this includes completing a project such as designing, building, and engineering a structure; designing and conducting a science experiment; critiquing an argument or piece of writing; or making an oral presentation.

Case studies analysis and role-playing in simulation activities indirectly engage students in the doing process.

Problem-based, experiential, and inquiry-based learning are the most often cited forms of active learning [9]. Other similar concepts, such as discovery learning and cooperative learning, where students working in teams on problem solving under project management practices, leads to self-confident students who feel accountable and are good team members [3].

Adopting active learning does not mean replacing the highly structured methods or even eliminating the lecture format [9, 10, 11]. Kirschner, Sweller, and Clark suggest that 50 years of empirical data does not support those using active learning methods early in the learning process [12]. This can be interpreted that formal and structured methods are still needed early to establish a strong basis or background within any given area, only to be strengthened by the active learning activities.

Active Learning in Manufacturing Engineering Education

Active learning is an important approach to prepare engineers, especially manufacturing engineers. Internship and co-op programs can be effective active learning tools and are typically the two main options. However, they are not the only options. Thus, this study explores the student while he or she is at school, yet actively engaged, sometimes with real-world or real-world like activities. These activities can be listed as:

- Competitions
- Case study reviews
- Film reviews and videos
- Projects sponsored by industry
- Capstone projects
- Laboratory exercises or projects simulating real-life scenarios
- Service projects
- Research projects

These activities are all discussed here as possible components within manufacturing engineering curricula, whereas engagement outside the classroom through the Learning Factory concept is offered as the main alternative. Sample activities are detailed with a specific focus on their outcomes. Cases covered here are a mix of the product of an engineering education literature review and actual examples from the first-hand experiences of the author and his students. A wide range of areas will be reviewed, including the diverse fields of manufacturing processes and systems, reverse engineering and rapid prototyping, automated identification systems, industrial device control, robotics and automation, and safety engineering.

For engineering students, taking part in national or international engineering competitions provides an opportunity for being involved in well-planned and organized educational activities [13]. Competitions, such as the ASME (American Society of Mechanical Engineers) Human Powered Vehicle, ASCE (American Society of Civil Engineers) Concrete Canoe, and SAE (Society of Automotive Engineers) Mini Baja, bring engagement through an activity that simulates real life. In all of these competitions, students need to design and develop a system that has to perform within certain expectations. Other competitions, such as SME Rapid (Prototyping) Conference DDM (Direct Digital Manufacturing) Competition or NISH (National Institute of Severly Handicapped) National Scholars Award, are based on manufacturability of the design and originality and functionality, respectively. The author will give brief examples on two competitions: SAE Mini Baja and NISH National Scholars Award.

The SAE Mini Baja competition requires engineering students to design and build a single-seat all terrain vehicle. At the three-day regional competition, teams are judged first through inspection for aesthetics, safety, manufacturability, serviceability, structural integrity, ergonomics, and their cost and design report for the development process. The second element of the competition is based on performance events such as acceleration, maximum speed, breaking, climbing, weight pulling, and maneuverability. The final component is a four-hour race over an off-road course including hills, moguls, jumps, sand, mud, and water. All teams must follow certain design guidelines and use a non-modified 10 HP Briggs and Stratton engine. Since all the vehicles need to use the same engine, drive train, suspension, and braking, design factors become important for winning this design competition and the race [14]. At the author's institution students took approximately two years to prepare for their first Mini Baja competition. Challenges led to a great learning experience in the areas below, while they successfully assembled a working prototype from scratch:

Figure 1: Climbing for the Prize, SAE Mini Baja Competition

- Team building and interpersonal skills, including both verbal and written communications and conflict management

- Project management with planning, scheduling, and resource management (time and money etc.)
- Marketing their project for potential donors
- Various forms of engineering design, including structural, mechanical, fuel, and braking system designs
- Manufacturing, including selection of vehicle body materials and integration of various subassemblies and systems
- Troubleshooting at the competition

The NISH National Award for Workplace Innovation and Design was established to remove the barriers preventing people with disabilities from either entering the workplace or advancing within the workplace. This is an individual or team competition and is open to undergraduate or graduate students [15]. Even though this has a service learning component built within its main scope, the author will treat this as a competition. In the ENGR 4801-Rapid Prototyping and Reverse Engineering course, the author challenged students to come up with a creative design that would address the main objective of the competition. A team of three students successfully designed a simple product and developed a prototype that can be utilized by handicapped people if they want to work in manufacturing. They did not win the 2007–2008 National Scholar Award, but they generated a product that was patentable. The outcomes of their project can be listed as:

- Learning about the intellectual property laws, including patents, copyrights, and trademarks
- Going through an actual experience of designing and developing a product that also included cost controls, material and manufacturing process selection, buy/make decisions, and prototyping
- Gaining experience in solid modeling and rapid prototyping

Case study reviews are another way to generate engagement for the manufacturing engineering students. This item is a good one to teach about areas like manufacturing systems, where you are concerned with the big picture or simply about real-life experiences or projects. The author utilized *Harvard Business Review's* (*HBR*) manufacturing related case studies in previous courses [16]. Other *HBR* tools, such as review articles, can be used as well as trade magazine articles on success stories or failed attempts. The outcome of his effort was greatly appreciated by his students because they also watched related videos before studying the subject and the case study. The main impact of watching related videos was that it helped students better visualize basic concepts. Students:

- Are actively engaged in the subject as they discuss the case producing interesting points and, at times, feasible and logical alternative solutions
- Learn about the big picture without losing the reality of details

Many faculty members fill in some time slots with video presentations. It could be a useful tool as long as the video shown is not too long or students actually take a break during the presentation. Another way of generating interest is through Q & A sessions. The author asks questions when the students return from their break or when the video is stopped at a critical junction. Additionally, the students are required to generate short write-ups, including one on critical concepts and terms learned. A similar way is followed to utilize movies like Class Action in the ENGR 4200 - Safety and Methods Engineers course [17]. Students watch the movie, which is about a lawsuit based on product safety that provides information on the lawful implications of engineering product development practice, including liabilities, law, and court structure. This type of activity is powerful in helping students:

- Learn law terms as they prepare to work as product developers. These concepts are hard to grasp if you have only a technical background. However, getting exposed to them through movies will help students better visualize and learn them.
- Learn law and court structure and their implications. This can also be employed in teaching ethics to engineers.

Movies were also used by other engineering educators for teaching leadership [18] or technology perspectives through science fiction [19].

Projects sponsored by industry are important but sensitive activities in attempting to create active learning environments. Keys for success are strong two-way communication and collaboration between the academic institution and the company. Expectations from both sides should be clearly drawn initially, and the industrial entity has to be on-board 100 percent. Industrial funding also adds to the importance of the project and simulates a real-life project with consequences. Critical steps are identifying the problem, gathering the necessary data for the project for determination of the constraints, and solving the problem. The difference between a course and capstone project is that students may have a longer time span available when dealing with the capstone projects. The capstone students most likely have the technical competency, since they have been taking courses on the background subjects. On the contrary, for a course project, limited time availability and lack in background are critical issues with this type of activity [20, 21]. By working on industry sponsored projects, students will gain experience in:

- Team building and interpersonal skills, including both verbal and written communications
- Project management with planning, scheduling, and resource management (time and money, etc.) components
- Real-life engineering problem solving and design and development processes

The author uses real-life and real-life like examples in his various courses. Students taking his ENGR 4400 - Device Control course utilize National Instruments (NI) LabView and Circuit Design Suite in designing, troubleshooting, and controlling electrical, electronic, and mechatronic systems. Cases such as analog controls in process control or digital manufacturing system controls are included within the curriculum. Students design and simulate their assignments, build to realize them, troubleshoot through data acquisition, and try to control, if there is a need for closed loop controls. The first example from the course is about designing and building an IC (integrated circuit) based digital control device for a materials handling system and packaging system. The system in question (shown in Figure 2) is followed by the problem statement [22]:

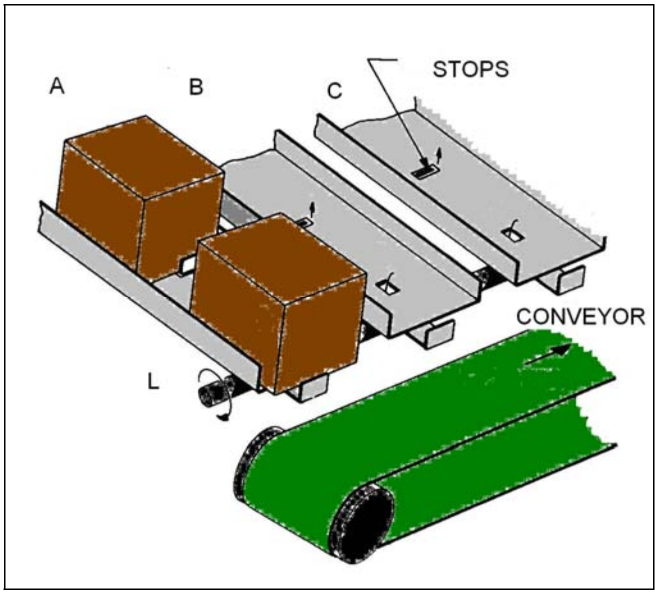

Figure 2: Boxes from Three Sources Drop on the Conveyor to Be Moved to the Palletizer

"Boxes from three (A, B, and C) sources are delivered to this conveyor loading mechanism. Each source delivers boxes with consistent weights: A–40 lb, B–60 lb, C–80 lb. The machine places boxes on the conveyor according to the requirements of an automatic palletizer at its right:

a. Boxes are not to be placed on the conveyor until it is ready by setting the signal R=1.
b. Boxes are to be delivered in groups with total weights of 100 lb or more.
c. No more than one box from a given source is to be included within each group.

Stops have been added to enforce requirement c of the problem statement. The presence of boxes at the loading points is sensed by switches A, B, and C."

Students are asked to follow the objective digital logic design process by:

- Generating the truth table depicting the problem statement.
- Using various methods (sum of products/product of sums and Boolean algebra) and Karnaugh maps to obtain optimized Boolean statements for the control logic.
- Generating the logic diagram for the control logic.
- Simulating the logic within NI LabView or NI Circuit Design Suite.
- Building and testing the control circuit on NI ELVIS (Electronics Virtual Instrumentation Suite), as shown in Figure 3.

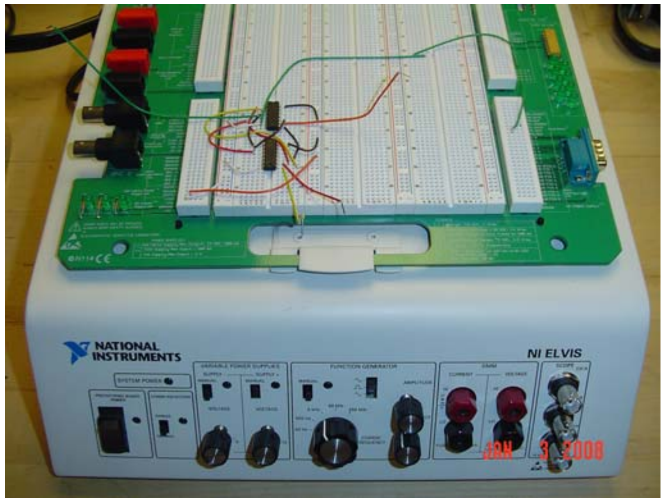

Figure 3: Prototype Control Circuit Built on a NI ELVIS Experimenter [23]

The second example is about an actual engineering project that Robert Morris University has been engaged in. Student involvement in this project at the undergraduate level was minimal. However, the author presented a mock-up system in his ENGR 4400 - Device Control class, giving students a taste of a real-life project, as shown in Figure 4.

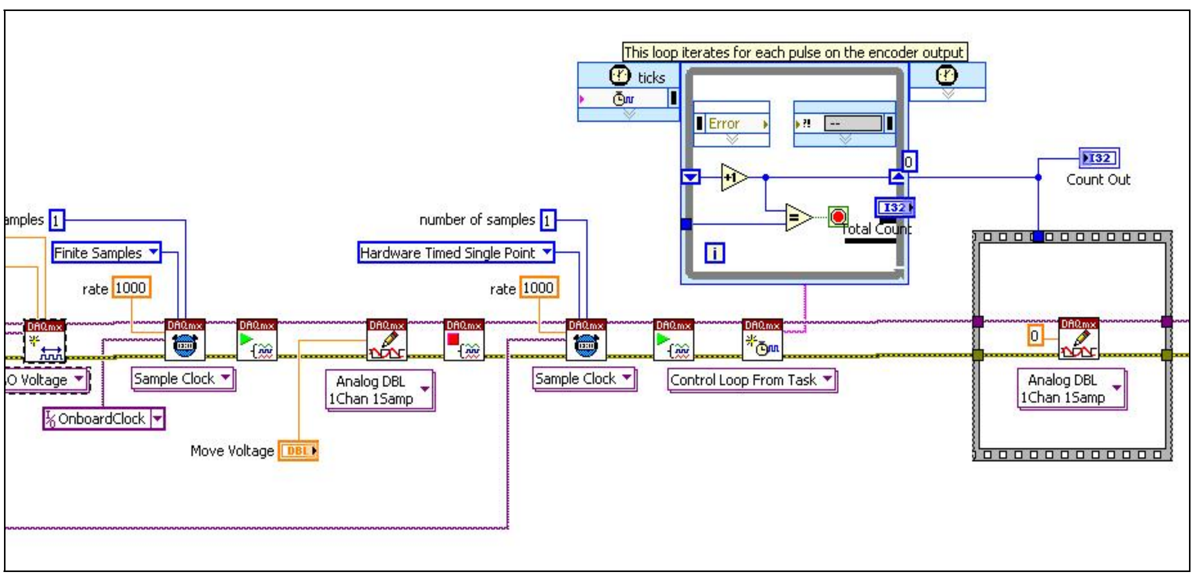

Figure 4: Partial Block Diagram of a 1-Axis Servocontroller for a Real-time Controller [23]

Being exposed to real-life or real-life like projects, students learn:

- Subjects and methods that are not covered in the curriculum in-depth
- Real-life problem definition generation and solution

- State-of-the-art technologies that may not be available to schools

Service learning is a pedagogy that provides engineering students with organized opportunities to learn, develop, and reflect through active participation in local communities [24]. This methodology relates academic content and engineering program learning objectives to the service activities. Engineering departments have been active in this field by offering technical assistance programs to local entities, especially in the form of university extension or faculty members acting as technical consultants or board members. In one example, Purdue University developed an innovative program creating partnerships between undergraduate student teams and non-profit organizations to solve engineering problems in the local communities [24]. According to Mariappan et al., thousands of California State University system students are providing service in California. Service learning can be applied to any course, including first year experiences or capstone projects [25]. Some examples of service projects from Purdue's First-Year Experiences from Fall 2003 are listed below [26]:

- Tutoring Head-Start students and reporting on how the educational technology can be used to enhance the classrooms
- Developing training materials for fixing computers and appliances for thrift stores
- Researching and identifying ways to improve data management of volunteers
- Designing curriculum modules for science outreach museums for a children's museum
- Creating displays for a children's museum

The author has witnessed various presentations in utilizing capstone courses in developing buildings for local communities or altered vehicles/tools for assisting handicapped people to become self-sufficient. Service learning:

- Will aid both the technical and social development of engineering students.
- Is still an effective practical and real-life experience.
- Will grow better global engineers, as the students work within different countries and understand other cultures of the world better.

Another pedagogy is getting undergraduate students involved in research. With this methodology, students are actively engaged in high level scientific activity leading to a successful learning experience. As the students study the basic premises of the research problems and get familiar with the research process, they develop excellent ideas and learn more about what types of tools are available for them. They can successfully replicate this experience even if they do not work as a researchers but instead as practicing engineers. This experience happens in individual studies courses and capstones, but working within a research team environment in group studies courses or cohort models increases students interaction with their surroundings since the environment grew from one (faculty member) to a few (students and the faculty member). Critical outcomes of the research-based learning are:

- High-level thinking and inquiry based work
- Developing engineers with greater confidence
- Enhancing students' knowledge-base and available tool arsenal
- Feeding more students into the researcher pipeline

Other means of engagement may come in the form of, but are not limited to, the following: online interactive training, webinars, interactive tools (e.g., chat rooms and message boards), factory tours, conferences, and classroom visitors.

Learning Factory

Penn State University's Learning Factory is defining itself as "a university/industry partnership where student projects are helping industrial clients, and industry is making a significant difference in engineering education at Penn State University" [27]. The mission of the Penn State Learning Factory is "to integrate design, manufacturing, and business realities into the engineering curriculum." Many other colleges utilize a similar concept where they try to tie their curriculum and laboratory activities into real-life projects and scenarios. Robert Morris University (RMU) is one of these colleges. RMU believes no engineering curriculum is complete without a comprehensive set of laboratories to enable seamless transitions of manufacturing engineering students from schools to industry [28].

All coursework is complemented by the laboratories within the approximately $5,000,000, 7,500 square foot RMU Learning Factory. The mission of this entity is to support engineering educational programs, serve as a test bed for research and development activities in conjunction with RMU CARES (Center for Applied Research in Engineering and Science), support outreach and recruitment activities, and provide an environment for lifelong learning through training to adult learners [28]. The major components of the Learning Factory are:

- Machine shop with welding and shaping abilities
- Materials Testing laboratory
- Metallography laboratories
- Metrology laboratory
- Reverse Engineering and Rapid Prototyping laboratory
- Powder Metallurgy laboratory
- Device Control laboratory
- Automated Identification Systems laboratory
- Automation Work-Cell and Robotics laboratory
- CAD/CAE/CAM abilities with design, analyses, and manufacturing tools
- Three Related Computer laboratories/classrooms
- Two Software Engineering laboratories/classrooms

The RMU model is slightly different than others. CARES pursues industrial projects, grants, and training opportunities. As the scope of the project becomes known, an initial decision is made whether the project is suitable for a class or capstone project. If the project requirements and the time span do not fit in the class resources and schedules, it becomes an industrial project where RMU students are treated as paid workers. In certain occasions, some of these projects can be counted as internship credit, where the student spends a considerable amount of time at the industrial partner or at RMU for the project. As smaller projects become class or capstone projects, student teams prepare for completing these activities. In both industrial and class/capstone projects, students gain critical experience and skills. They also use their knowledge acquired within the classroom and laboratory environment. Each RMU engineering course also carries a 2.5-hour laboratory component, increasing student exposure at the Learning Factory.

Value of Methods Utilized and Outcomes Assessment

As a part of its continuous improvements and preparations for subsequent ABET re-accreditation, the RMU Engineering Department takes outcome assessments very seriously. Multiple means are employed in gauging students' attitudes and aptitudes towards the methods utilized and their performance in their courses [29]. These means are:

- Faculty Course Assessment Reports (FCARs)
- Senior Exit Interviews
- Internship Assessments
- Capstone Design Experience Assessment
- SME Certified Manufacturing Technologist (CMfgT) Examination
- Fundamentals of Engineering (FE) Examination

This section presents information on two of the sources mentioned above, FCARs and Senior Exit Interviews. In addition to reviewing the annual assessment data, a span of five to seven years is used for tracing the trends in student performances and their feedback during course assessments and exit interviews, respectively. An example outcomes assessment on ENGR 4400 - Device Control course is also included in this section of the paper. The course is a practical one that follows a wide span of subjects from hard-wired relay logic to programmable logic controllers (PLCs), from fixed integrated circuits (ICs) to programmable automation controllers (PACs). The following is the listing for basic and manufacturing engineering specific outcomes observed by the RMU Engineering Department:

- ABET-derived Basic Engineering Outcomes**:** Engineering graduates have (1) an ability to apply knowledge of mathematics, science, and engineering; (2) an ability to design and conduct experiments, as well as to analyze and interpret results; (3) an ability to design a system, component, or process to meet desired needs; (4) an ability to function on multi-disciplinary teams; (5) an ability to identify, formulate, and solve engineering problems; (6) an understanding of the professional and ethical responsibilities; (7) an ability to communicate effectively; (8) the broad education necessary to understand the impact of engineering solutions in a global societal context; (9) recognition of the need for and an ability to engage in life-long learning;

(10) a knowledge of contemporary issues; and (11) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

- Manufacturing Engineering Track-specific ABET Outcomes: Engineering graduates have (M1) proficiency in materials and manufacturing processes, as well as understand the influence of manufacturing processes on the behavior and properties of materials; (M2) proficiency in process, assembly and product engineering, as well as understand the design of products and the equipment, tooling, and environment necessary for their manufacture; (M3) appreciate the necessity for manufacturing competitiveness and understand how to create competitive advantage through manufacturing planning, strategy and control; (M4) ability to design manufacturing systems through the analysis, synthesis, and control of manufacturing operations using statistical or calculus based methods, simulation, and information technology; (M5) have laboratory experience, which enables them to measure manufacturing process variables and make technical inferences about the process.

The ENGR 4400 course provides an in-depth treatment of the methods and techniques used for the implementation of automated device control, both digital and analog. The student will achieve a mastery of both open and closed loop control methods and algorithms, including sequencing control and potential/integral/derivative (PID) control. The student will also gain hands-on experiences with sensor technology, computer-based data acquisition and control, and programmable controllers. Applicable ABET-derived Outcomes are: 1, 3, 5, 7, and 8. Applicable Track-Specific ABET Outcomes are: M2 and M4. Currently, the designated threshold is 80 percent of the students receiving a B- (80 percent) or better grade. As shown in Figure 5,

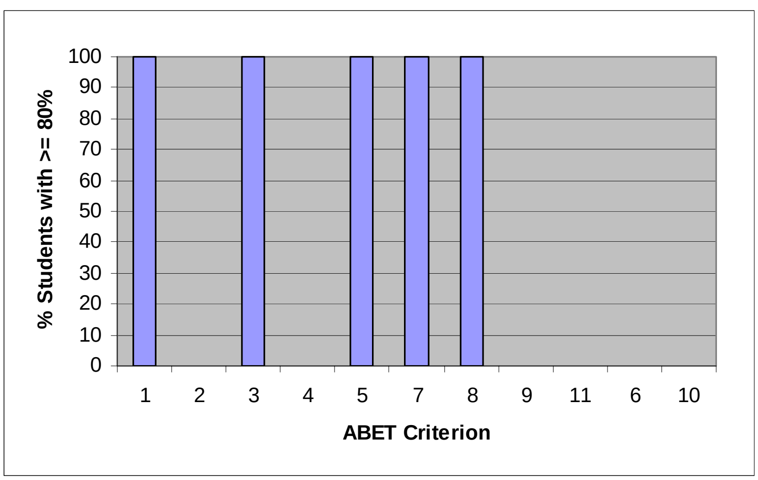

Figure 5: Class Performance with Respect to ABET-derived Basic Outcomes [23]

100 percent of the students satisfactorily performed above the 80 percent threshold value in the 2007–2008 academic year. Similar results were obtained for M2 and M4 outcomes as well. Coupled with student feedback, results become more meaningful. The instructor

employs the continuous feedback approach by regularly asking students for their inputs. Statements summarizing the course environment and students' comments are provided below:

- Students remain active in both class and laboratory periods. They especially enjoy being engaged in the class periods since the classes are also held within the laboratory space. This allows the instructor to access the hardware and software tools for demos and small assignments.
- Students appreciate practical experiences and real-life like problem solving as they model or control actual systems.
- Team projects especially elevated the learning experience to another level, as mentioned by the entire student body.

Starting with the 2002–2003 academic year, the seven-year FCAR data indicated a leap in 2004–2005 academic year, where multiple new faculty members, including the current head of the CARES, arrived energizing the environment with their engaging ways and industrial project opportunities. This trend also continued with the addition of 2.5-hour laboratory components in the 2005–2006 academic year. On the contrary, exit interview feedback on outcomes M1–M5 was negatively influenced by the addition of the laboratory sessions. Since then, this trend has been quickly reversed and can be seen in the following table.

Table 1: Exit Interview Results on M1–M5 Manufacturing Specific Outcomes [29]

Outcome / Year	**02–03**	**03–04**	**04–05**	**05–06**	**06–07**	**07–08**
M1	3.33	3.00	4.25	3.33	4.00	4.71
M2	4.33	4.00	4.25	4.33	4.14	4.86
M3	4.00	2.00	4.25	4.00	4.43	4.86
M4	4.00	4.00	4.50	3.33	4.29	4.57
M5	4.33	2.00	4.75	3.33	4.29	4.71

All the data from the individual courses mentioned in this paper and the accumulated data over the short lifespan of the RMU Engineering Department indicate that actively engaged manufacturing engineering students are performing better and feeling more confident about their education, regardless of the method used. Hands-on laboratory experiences, student competitions, industry driven real-life projects, real-life like assignments, reviews of movies, and case studies are all engaging the students directly or indirectly, resulting in a better educational experience for both the faculty and students.

Conclusions

Internship and co-op programs are important components of curriculum in preparing manufacturing engineers. They can be very powerful in giving students real-life experiences, both technically and socially. Since the internship programs tend to exist mainly in summers, students take advantage of them. Completing an internship during the regular academic year or taking part in co-op opportunities in consecutive terms may lead to discontinuity in students' progress towards their degree or may apply additional stress to them. However, they are still the two major components in giving students experience and consequent credentials for their job search. Compared with the two, other means mentioned in this paper can be used in better development of the students. They will be as effective in most cases, as indicated by outcome assessment tools. In some cases, engineering departments may accept a research project experience in place of an internship for graduation requirements. However, future employers may be looking for that phrase, "internship experience," on the student's resume.

As a final word, the author recommends faculty members use the various means included within this paper. When superimposed with the internship/co-op programs, they will influence the quality of the graduates drastically, as evidenced by the RMU Engineering program.

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Biography

ARIF SIRINTERLIKCI is currently an Associate Professor of Engineering at Robert Morris University. He has been the Coordinator of the RMU Learning Factory and Director of Engineering Laboratories. He holds a B.S. and an M.S., both in Mechanical Engineering from Istanbul Technical University in Turkey, and a PhD in Industrial and Systems Engineering from the Ohio State University. He has conducted research and taught in mechanical, industrial, manufacturing engineering, and industrial technology fields. He has been active in ASEE (American Society for Engineering Education) and SME (Society of Manufacturing Engineers) as an officer of the Manufacturing division and an advisor to technical communities and student chapters, respectively.

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