AC 2010-219: A HANDS-ON COURSE CURRICULUM FOR SUPPORTING DESIGN EDUCATION FOR MANUFACTURING STUDENTS

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A Hands-On Course Curriculum for Supporting Design Education for Manufacturing Students

1. Background

It is well established that both the breadth and rigor of the design content of the curriculum is paramount in every undergraduate engineering program[1]. Majority of the institutions have a sequence of courses that emphasize different aspects of design education[2]. The sequence finally ends with the completion of a year-long capstone design project as graduation requirement[3,4]. One of the stumbling blocks that students experience in this process is their limited ability to work with real materials and processes to build real products and prototypes that are needed to demonstrate their designs. These issues have been reported by several institutions. For example, "Learning by Doing" philosophy was implemented at CalPoly[5] by incorporating machining, foundry and welding laboratory exercises in their curriculum. An experimental session in an otherwise theory-based class helped improve learning quality and significantly stimulate student interest in the course at Illinois Institute of Technology[6]. At Texas Tech[7], efforts are being made to bridge a gap between the hands-on manufacturing processes knowledge of the entry level engineering graduates and the production, fabrication and manufacturing processes being practiced by their industry employers. Simulation using analogous systems / computer modeling[8 - 11] has also been tried to incorporate a degree of hands-on experience in manufacturing systems design education. Learning factory concept[12,13] has been utilized at Wayne State[14] to build student skills in product realization and manufacturing engineering.

The consensus in the above studies is that the students are not well exposed to using manufacturing and measuring techniques and equipment and thus are not comfortable using them. While students are usually eager to get their hands on the real stuff and start "cutting the metal", they are unable to do so because of a lack of appropriate instruction and training. The problem is exacerbated when institutions attempt to eliminate their machine shops due to liability and safety concerns.

This present paper describes efforts made at RMU to address these issues by developing laboratory tasks that will strengthen students' **product building skills**. The laboratory tasks were carefully chosen to expose students to those manufacturing, assembly and metrology technologies that would most likely be used to build products and prototypes during their subsequent engineering education. The two credit lecture, one credit lab course entitled 'Production Engineering' now includes significant hands-on work on traditional machines (lathes and mills), powder metallurgy, plastic injection molding, welding, 3-D co-ordinate measuring machine, and several rapid prototyping / rapid manufacturing technologies. Appropriate laboratory tasks were designed and applicable safety and operational instructions were prepared.

The laboratory curriculum was implemented since the Fall '06 term. Despite increased workload for the students that sometimes required them to work additional hours outside of the scheduled class times to complete the laboratory tasks, they seemed to be enthusiastic about it and enjoy the challenges. Further effectiveness of this hands-on curriculum is demonstrated in terms of student feedback, student performance in the course, and ABET outcomes assessment.

2. Laboratory Equipment

The course had 2.5 hours laboratory component to go along with two 50 min. theory classes. The students were given laboratory tasks during these lab sessions where they manufactured different objects using a variety of equipment shown in Figures 1 – 12. Brief information about these equipment and the objects students made using them is given as follows.

Figure 1 is a picture of stereo lithography (STL) equipment that uses a photosensitive resin exposed to a computer controlled laser beam to build parts in a bottom-up, layer-by-layer process. The process is capable of building complex part geometries including internal features, however it is a slow and not a very robust process. Figure 2 shows fused deposition modeling (FDM) machine, an alternative rapid prototyping (RP) technique that is comparatively faster and more reliable than STL technique. Metal RP system shown in Figure 3 allows for building of parts from metal powders. The parts are subsequently sintered to develop their full strength and density. Figure 4 shows a three dimensional scanner unit that is able to convert the scan from the camera to an **stl** file which can then be used to manufacture the original part using any of the RP methods. This is particularly useful to teach concepts of reverse engineering.

A three-dimensional co-ordinate measuring machine (3D CMM) is shown in Figure 5 while Figure 6 shows the cold isostatic press (CIP) used in the manufacturing of powder metallurgical parts. The laboratory is equipped with a conventional workshop that contains lathe, milling machine, drill press, belt grinders and power saw as shown in Figure 7. An advanced HAAS CNC machining center is shown in Figure 8. An injection molding machine that produces polypropylene and polyethylene parts is shown in Figure 9 while a MIG welder is shown in Figure 10. Figure 11 is a display case that exhibits some of the components made by the students in this lab. Figure 12 is a SAE Baja vehicle manufactured by RMU engineering students where they employed all of the hands-on skills they learned in this course.

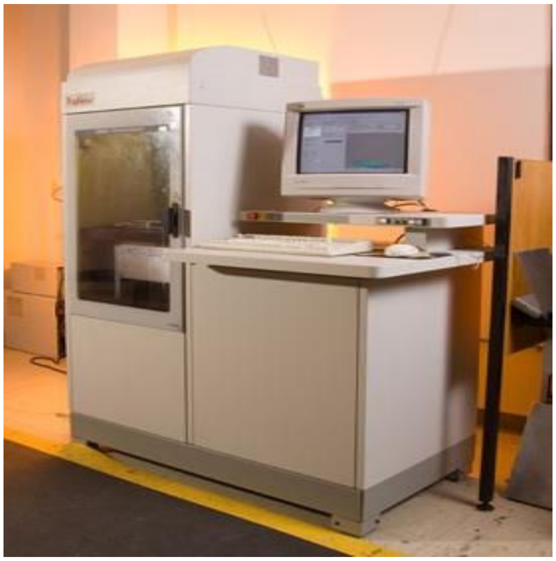

Figure 1: Viper STL RP System

Figure 2: Fused Deposition Modeling

Figure 3: Metal RP System

Figure 4: 3D Scanner

Figure 5: 3D CMM

Figure 6: Powder Metallurgy

Figure 7: Mill and Lathe

Figure 8: Machining Centers

Figure 9: Injection Molding Machine

Figure 10: MIG Welder

Figure 11: Student Projects

Figure 12: RMU Baja Vehicle 2009

3. Course Management

3.1 Course Objectives

The published description for this course includes the following: a presentation of techniques of production engineering, and fundamental manufacturing process concepts, at an introductory level. Methods of production are introduced, and productivity improvement methods are explored with an emphasis on quality, efficiency, and product cost. Basic metrology principles are also introduced. The course is designed as a three-credit, 6th semester (i.e. Junior year) core course for manufacturing and mechanical engineering majors. The student assessment tools employed were:

- Three take-home assignments, 10% each towards final grade, = 30%
- Three laboratory-based assignment, 10% each towards final grade, = 30%
- Mid-term written exam, 20% towards final grade
- Final comprehensive written exam, 20% towards final grade

3.2 Laboratory Curriculum

The students spent at least 2.5 hours per week in the laboratory working on the machines showed in Figures 1 – 10. During the first four weeks of the term, subsequent to the detailed laboratory safety instructions, machine demonstrations and training, each student manufactured a riveting steel hammer that involved many operations using traditional machining workshop such as power sawing, simple turning, taper turning, drilling, tapping, parting, groove cutting, vertical and horizontal milling, fitting, grinding and finishing (lapping). During the latter part of this section, the students used a 3D co-ordinate measuring machine (3D – CMM) to record dimensions of their hammer and compared these dimensions with the corresponding drawing specifications to assess the dimensional quality of their product. The next laboratory was three weeks duration in which the students created an AutoCAD or SolidWorks solid model of a design of their choice. The design constraint was that it must be smaller than 6” x 6” foot print with its thickness not exceeding 2”. The students manufactured these designs using any of the rapid prototyping techniques available in the lab, especially the fused deposition modeling (FDM) machine. The students were instructed in welding theory in the lectures and then they practiced welding on several pieces of sheet metal to create a variety of joint geometries (Tee, Butt and Corner) using metal inert gas (MIG) welding. They subsequently conducted visual observations and also sectioned these joints to examine the quality of the welds that they made. During the injection molding lab the students made appropriate adjustments for temperature, pressure and shot size for adequate process control to make defect-free poly vinyl chloride (PVC) six-inch rulers. In the powder metallurgy lab, they were given several rubber molds to make aluminum and stainless steel products (monkey, bunny etc.) using cold isostatic pressing. Some examples of the student projects are shown in Figure 11. The manufacturing skills that they learn in this class also come in handy when they take up the challenge of making the SAE Baja all-terrain vehicle as shown in Figure 12.

4. Student Performance

Final grade distribution is given in Table 1 below.

Table 1: Student final grade distribution for Production Engineering

Grade	Fall '06	Fall '07	Fall '08
A	37.5%	81.8%	40.0%
A-	-	18.2%	40.0%
B+	25.0%	-	-
B	12.5%	-	-
C+	12.5%	-	-
C	12.5%	-	20%

A: ≥ 90%; A-: 88, 89; B+: 85 – 87%; B: 80 – 84; C+: 75 – 79; C: 70 – 74%; D: 60 – 69%; F < 60

Reflection:

- Students have performed very well in this course.

5. ABET Outcomes Assessment

Criterion 3 ABET outcomes applicable for this course are as listed below.
RMU graduates have:
(1): an ability to apply knowledge of mathematics, science and engineering
(3): an ability to design a system, component or process to meet desired needs
(5): an ability to identify, formulate and solve engineering problems
(7): an ability to communicate effectively
(8): the broad education necessary to understand the impact of engineering solutions in a global societal context

Manufacturing Engineering track-specific ABET outcomes applicable for this course are:
(M2): proficiency in process assembly, and product engineering and understand the design of products and the equipment, tooling and environment necessary for their manufacture
(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

The outcomes were assessed via homework assignments, laboratory work and exams. The results of the outcomes assessment are shown in Figure 13 below.

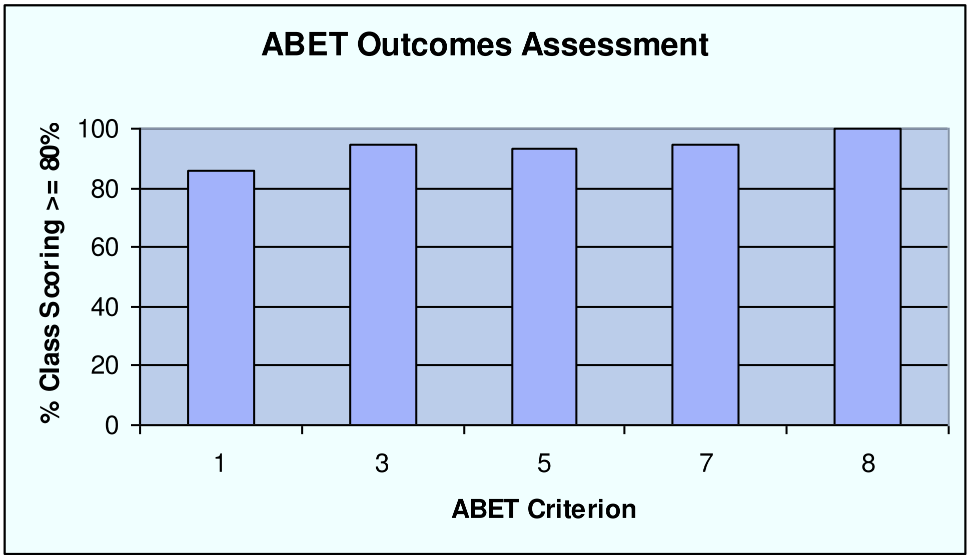

Figure 13: Class performance with respect to ABET outcomes in Fall '08 term. (The current RMU-designated benchmark for class performance is 80%).

Reflection:

- It can be seen from Figure 13 that the class performance in this course is above the RMU-designated benchmark (at least 80% students in the class score >= 80%) in all of the applicable ABET outcomes.

93.1% students scored >= 80% points in Outcome M2 as well as in Outcome M4 in Fall '08 term, which is well above the RMU benchmark.

Reflection:

- Outcomes assessment for both of the applicable track-specific outcomes, M2 and M4, demonstrates that RMU benchmark is being met.

6. Student Feedback

6.1 Overall Feedback

The students fill out Student Instructional Survey Report (SIR II) forms at the end of the course to give anonymous feedback to the faculty and university administration about the course. The salient points from the SIR II feedback survey are shown in Table 2.

Table 2: SIR II Course Survey Feedback.

SIR II Feedback Item (National Average)	Fall '06	Fall '07
Course Organization and Planning (4.23)	4.63	4.42
Communication Skills of Instructor (4.28)	4.43	4.31
Faculty / Student Interaction (4.27)	4.34	4.53
Assignments / Exams / Grading (4.02)	4.40	4.32
Course Outcomes - Student Learning, Interest (3.65)	4.03	3.96
Student Effort and Involvement (3.63)	3.71	3.39
Overall Evaluation (3.97)	**4.57**	**4.09**

It is clear from the data given Table 2 that the students have given this laboratory intensive course their thumbs-up in all the evaluation items, well above the national average.

6.2 Laboratory Specific Feedback

The students were asked to write a reflection section at the end of their laboratory reports. The following comments are extracted from this section from reports submitted over three years 2006 – 2008.

Feedback on Machining Lab:

- I really enjoyed myself doing this project. I think it is mainly because we finally were able to have a hands-on project and have something to show for it at the end. I enjoy **learning about the different machines and processes for different materials**, especially when I come from a family of home developers. It also gave me an opportunity to **work with other people** in the class and **interact** with them. My suggestion for improvement would be to allow for **customizing the project** – e.g. add rubber grip to the hammer, and a little paint job!
- This is the most hands-on project that I have done so far. The biggest difficulty was **finding time** when the machines were available. I would also suggest adding **more finishing steps** such as grinding, lapping and polishing.
- I liked the project especially because I had **something to show** for it bedsides a grade. I like learning about the different machines in the shop and having the opportunity to use them. It also gave me an opportunity to work with other people in the class and interact with them. Perhaps allowing for customization such as

engraving or special designs would make this project more fun so that the hammers would be unique for each creator.

- Once during my internship, a machinist told me that engineers would have a **better understanding** of how highly skilled machinists truly are and appreciate what they actually do if they themselves worked in a machine shop. This project allowed me to do just that. I enjoyed this project as I was able to go from design through manufacturing, assembly and finally inspection for quality. It was difficult at times to find time on machines.
- I believe I had **more pride** in the final product because of a greater **sense of accomplishment** in this project. Finishing operations should be added such buffing or electroplating.
- I learned a lot from this project. It gave me an opportunity to use some the machines that I had never used in my life before. Finishing processes could be added to make the job look **shinier and smoother**, select designs that would make them look **similar to the ones in stores**!
- The best part of the project was being able to use the machines in the workshop. This enabled me to have a better understanding of what a machinist has to do and why his or her job is important. **Knurling** could be added. **Creating angles** was a bit difficult.

Feedback on Rapid Prototyping (RP) Lab:

- Rapid prototyping lab was good experience. The ability to design parts on the computer and then print a three dimensional part was very educational. By measuring the part afterwards and comparing it to the original design we were able to see firsthand the **accuracy of this manufacturing process**.
- I think the project was very **fun overall**. I would have liked to build our own parts rather than being assigned specific parts to build.
- Project went well except for **unreliability** of the machines. Because only a few parts could be loaded at one time, the build process **took a while**. Part dimensions should be increased slightly to account for shrinkage that occurs in the build process.
- I really enjoyed doing this project as it made me aware of the **state of the art** technology in manufacturing. I used fused deposition modeling (FDM) machine that does not require curing of parts in UV oven, which made build process faster than conventional resin-based stereo lithography (SLA) technique.
- I thoroughly enjoyed this project as I am familiar with creating designs in Solid Works. The project could be made better if a more complete **set of operating instructions** for RP machines are made available.
- There were a lot of issues with the operation of RP machines (SLA), however overall the project was enjoyable. I liked the fact I could keep my product as a **souvenir from this class**!
- I enjoyed the project because it is the first time I used these RP machines. I enjoyed creating the structures in **AutoCAD and then seeing them actually created**. However, there is a difference in the design dimensions and actual dimensions of the RP parts.

7. Summary

The limited ability of the students to work with real materials and processes to build real products and prototypes was recognized as one of the areas for improvement in undergraduate engineering education. This issue was addressed by developing laboratory tasks that would strengthen students' **product building skills**. Several laboratory exercises including conventional and CNC machining, powder metallurgy, rapid prototyping techniques, MIG welding and plastic injection molding were developed and incorporated in the course curriculum. The hands-on curriculum was implemented since the Fall '06 term. The students' feedback was excellent as indicated by the SIR II survey feedback and students' reflection on the laboratory tasks. The new course had a greater work load as compared to the previous non-laboratory version, but the students seemed to enjoy it better and also their performance in the course was better. Further improvements to the course could be made by effective scheduling of the laboratory facilities and allowing students to customize their products.

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