Integrating Industry Projects into a Manufacturing Systems Course

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Abstract

In order to fill the existing skills gap in U.S. manufacturing, effective teaching techniques of manufacturing courses should be considered by academic institutions. Hands-on experiments and real life projects can be incorporated into the curriculums in order to produce new graduates with adequate knowledge of manufacturing skills. In this paper, we discuss project-based learning in an undergraduate manufacturing systems course. The course includes lectures, labs and industry projects. The lectures provide students with theoretical and technical content on manufacturing systems. The labs provide students with hands-on experience on design, analysis, and improvement of manufacturing systems. The industry projects enhance students understanding of manufacturing systems and provide them with real life experience. Students were divided into groups and a manufacturing project was assigned to each group. Moreover, an industry advisor was assigned to each group. Students, supervised by the course instructor, worked with local industry to identify project ideas, define problems, and set the goals for the projects. Qualitative and quantitative data were collected and analyzed to assess the learning outcomes and the impact of the industry projects. Course assessment is based on exams, quizzes, lab reports, and successful completion of the industry projects.

1. Introduction

Today, U.S. manufacturing relies on advanced technology and it requires intensive skills. However, there is a sizeable skills gap in U.S. manufacturing and it is expected that this gap will result in a shortage of 2 million manufacturing jobs in the next decade[1]. The future of U.S. manufacturing will be based, in part, on educating the new generations in manufacturing-related and computing skills to prepare them for skill-intensive jobs.

Teaching manufacturing system design and analysis to undergraduate students should provide them with the necessary skills to fill the gap. This can be achieved by incorporating real industry projects and having students exposed to real life problems and then apply their skills to solve such problems. Industry-based credentials embedded in manufacturing programs of study can serve as a powerful hook to attract students, win support from employers and promote articulation and linkages across educational institutions[2].

The incorporation of industry projects into academic courses has been discussed by some authors in current literature. For example, incorporating industry sponsored projects into online capstone courses was implemented and tested in two capstone courses[3]. Studies also discussed the benefits of industry involvement in capstone design courses to students, university, and industry participants[4]. By having industry mentors, students will gain exposure to professional industries in a structured nurturing manner[5]. Students will also gain professional skills, such as communication, presentation, and teamwork[5]. Moreover, industry feedback on skill gaps and curriculum changes can be obtained[6]. Studies found that the interaction with industry drives continuous improvement in capstone design courses[7].

For manufacturing-based courses, incorporating industry projects can provide many benefits to the students and increase their motivation and enhance their overall education. Manufacturing courses provide students with a vast amount of technical information. Students can effectively convert this information to knowledge if they use it in real life problems or projects[8]. Unlike some other topics that undergraduate students must comprehend such as mechanics, thermodynamics, or control systems, the issues of manufacturing systems integration are difficult to demonstrate, explore or manipulate in conventional lecture or laboratory sessions[9]. In practice, manufacturing engineers are under constant pressure to meet production targets and delivery schedules and reduce or eliminate disruption to normal production activities[9].

This study discusses the integration of industry projects into an undergraduate manufacturing systems course. Students are given a solid background on manufacturing systems design, analysis and improvement. Students are then asked to complete real life projects with local industry to apply the topics they have learned in class.

2. Description of the Manufacturing Course

This Manufacturing Systems course (IE470) aims to provide students with an understanding of modern manufacturing systems. The course is offered during the seventh semester. Students will learn different tools and techniques to the design, analysis, development, implementation, improvement, of modern manufacturing systems. The general concepts provided in this course are also widely applicable to service industries. The course involves hands on learning and exercises in laboratories as well as real industry projects. Laboratory assignments are used to enhance students learning. The course grade reflects the student's attendance and performance in the quizzes, lab assignments, industry project, and exams. Upon satisfactory completion of IE470 course, students should be able to:

- Understand the key performance measures of manufacturing systems.
- Understand the different techniques and tools for manufacturing systems design and analysis.
- Understand key techniques to improve manufacturing systems productivity and efficiency.
- *Be able to use process improvement methods in real manufacturing or service environments.*

The course includes the following topics:

- Introduction to modern manufacturing
- Basics of manufacturing systems
- Manufacturing strategies
- Demand planning and forecasting
- Material Requirements Planning (MRP)
- Factory dynamics and variability laws
- Lean manufacturing and Six Sigma methodology

The course assessment is based on the following items: Two midterm exams, four quizzes, five lab reports, a course project, and a final exam. Five percent of the overall grade is on attendance. The grades distribution of the different items is shown in Table 1. IE470 is a 15 week undergraduate course in the Industrial Engineering (IE) program at this University. Each week, the students are subject to two 50-minute classroom lectures and one 115-minute laboratory experience in the manufacturing laboratory. Each semester the course is offered, a real-world project is performed by the students.

Table 1. IE470 course evaluation

Item	Grade
Quizzes (4)	10%
Lab Reports (5)	10%
Course Project (1)	25%
Exam I (1)	15%
Exam II (1)	15%
Final Exam (1)	20%
Attendance	5%

2.1 Course Project Description

The course project represents 25% of the final course grade and it is performed in groups of three or four students. The project was implemented in foundry industry and it mainly focuses on implementing process improvement strategies to improve the production system's performance.

2.1.1 Selection of Projects

Several projects were provided by the company and five projects were selected based on two main criteria: 1) the degree to which the project fits the course, 2) the impact that the project will have on company's processes. Table 2 shows the summary of the problem statement and objectives for the five projects.

Table 2. Summary of project problem statements and objectives

Project	Problem Statement	Project Objectives
Core Coating and Dipping Processes	The core wash is causing veining in the final castings.	○ Create a standardized process for coating/dipping. ○ Increase process efficiency and reduce costs. ○ Create quality checkpoints to prevent rework.
Sand System (Fig. 1)	The overall quality of recycled sand is low.	○ Find a solution to detect parts of the cores in the recycled sand before it reaches the muller. ○ Decrease the number of overall defects in the parts due to sand system problems. ○ Increase the American Foundry Society (AFS) fineness number.
RF Testing R&R (Fig. 2)	Some defective casting pass the inspection and delivered to customer.	○ Analyze current process, suggest alternative methods. ○ Reduce defects escaped to 0%.
Plastics Mold Making Process	Molds are not being used an optimal amount of times.	○ Develop standards for the mold making process.
Pattern Handling Process	Workers have to lift each pattern six times in the current process which presents a safety hazard to the workers.	○ Reduce physical stress on the worker. ○ Eliminate/reduce temporary storage in the process.

The sand system, also known as DISA, is shown in Figure 1. The system is an automatic production line used for making sand molds. Figure 2 shows the apparatus used for testing the castings. This configuration is known as Radio Frequency (FR) testing.

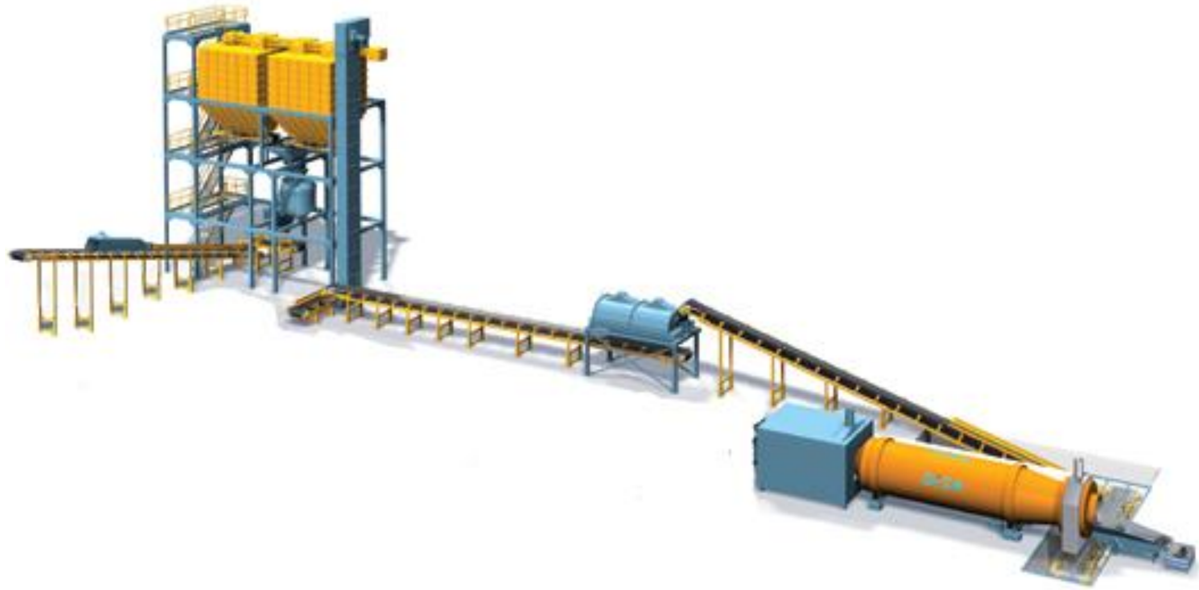

Figure 1. Sand Plant Tower (source: http://www.disagroup.com)

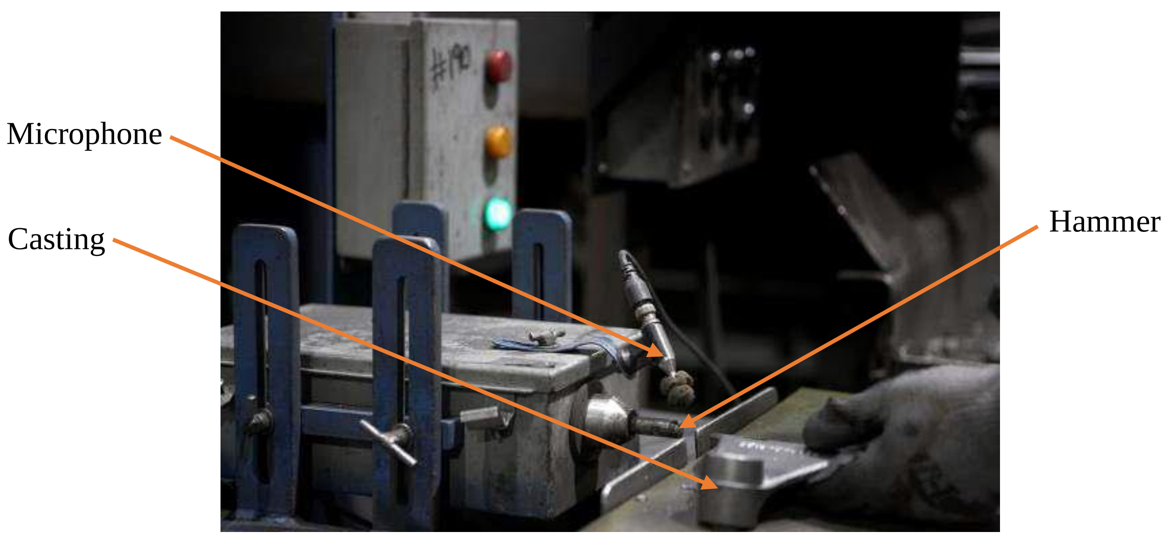

Figure 2. Radio Frequency Testing (source: http://www.modalshop.com)

2.2.3 Project Steps

The Lean 8-step problem solving methodology was used in the five projects. After identifying the problem statement and defining the project objectives, students developed a detailed process maps in order to understand the processes. A high level overview of foundry processes is shown in Figure 3. The main processes are: 1) pattern, core, and mold making 2) melting and pouring the metal, 3) shakeout and cooling, and 4) testing and inspection. The next step of the project was to identify the Lean wastes in the processes and perform value add analysis of the process steps. The identified Lean wastes are shown in Table 3. Potential root causes for the project problems were then identified by the teams. An example of Fishbone diagram used to identify the root causes for the "Pattern Handling" project is shown in Figure 4. The root causes are categorized into six main categories, namely Man, Machine, Method, Measurement, Material, and Environment (5 M's and E). The business problem for this "Pattern Handling" project was that the operators were lifting heavy patterns which can cause safety hazards to them. Similar root cause analysis was performed for the other projects. Table 4 summarizes the potential root causes for the five projects.

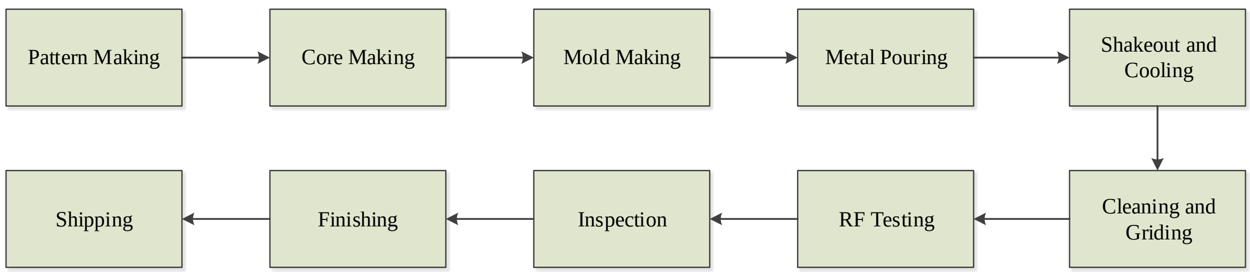

Figure 3. A high-level overview of foundry processes

Table 3. Identified Lean wastes

Project	Lean Wastes Identified	Types of Wastes
Core Coating and Dipping Processes	Waiting for cores to be dried	Waiting
	Veining of the cores	Defect
	Waiting for cores to be sent to pouring	Waiting
Sand System	Sand waits for the muller to empty	Waiting
	Storing more sand than needed	Inventory
	Worker moves around to scoop out sand test sample	Motion
	Defects are not obvious	Defect
RF Testing	RF testing machine and grinding machine are not ideally located which requires operators to move back and forth	Motion
	Testing the casting several times	Non-value add processing
	No standard procedure for testing which leads to scrapping good castings or accepting bad castings	Defects
Plastic Mold Making Process	Waiting for plastic to cure	Waiting
	Worker must observe the curing process	Waste of Employee Talent
	Search for tools to demold	Motion
	Pre-polishing of patterns	Non-value add processing
Pattern Handling Process	More patterns than needed in storage	Inventory
	Operator has to move patterns from storage to another storage location	Transportation
	Operators have to remove the pattern from a shelf and place on another shelf	Motion

Once the root causes were identified and validated, the teams developed and prioritized countermeasures for each problem. The countermeasures was developed based on discussion with the industry team as well as literature research. Table 5 summarizes the proposed countermeasures for the five projects. Each countermeasure was rated by the decision makers based on two main criteria: impact and ease of implementation. The table shows the average of the decision makers' rating. The selected countermeasures are shown in bold. These countermeasures were selected by the team because they have high impact on the problem and are easy to implement. Some countermeasures are already implemented by the foundry and other are still being implemented. This work is part of the Lean journey that is currently in place.

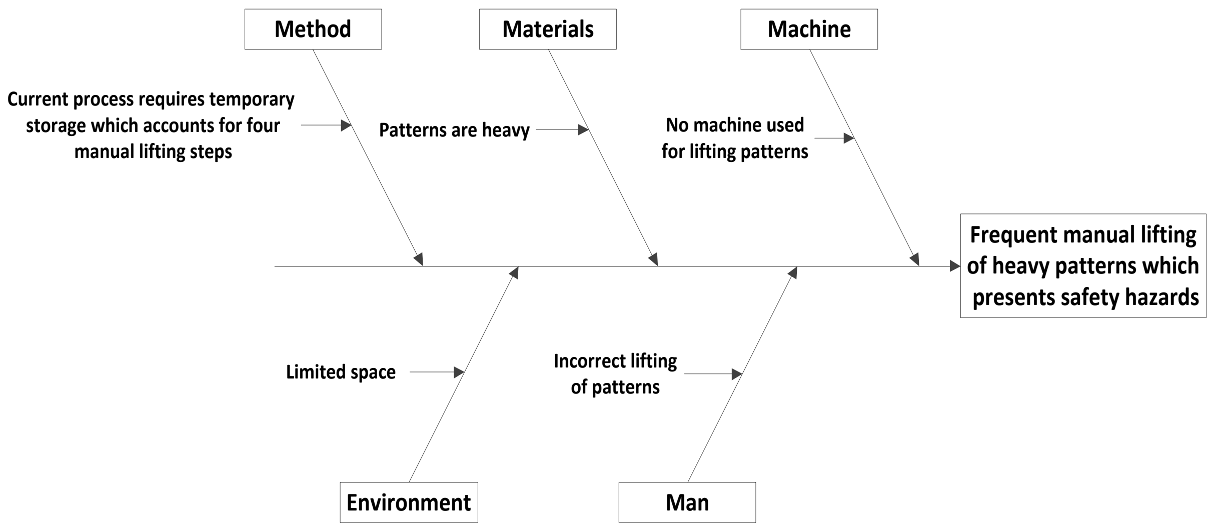

Figure 4. Fishbone diagram for the pattern handling project

Table 4. Potential root causes for the project problems

Project	Potential Root Causes	Root Cause Category
Core Coating and Dipping Processes	Outdated oven	Machine
	Incorrect core sand	Material
	No clear instructions or quality check	Method
	Lack of adequate training	Man
	Too warm/cold and dirty workplace	Environment
Sand System	Incorrect levels of temperature/humidity	Environment
	Muller is not adding sufficient bond resin, water, or new sand	Machine
	Incorrect shakeout or recycle time	Method
	Lack of adequate training	Man
RF Testing	Noise levels affect the reading	Environment
	Dirty workstations	Environment
	Damaged microphone or hammer	Machine
	Hammers are not set correctly	Measurement
	No checks/maintenance of current equipment	Method
	Operator hits the part in the wrong place	Man
Plastic Mold Making Process	Different types of plastics used	Material
	No checks on amount of plastic poured into pattern	Measurement
	No clear instructions	Method
Pattern Handling Process	No machine used for lifting patterns	Machine
	Incorrect lifting of patterns	Man
	Limited space	Environment
	Patterns are heavy	Materials
	Current process requires temporary space of patterns which accounts for four manual lifting steps	Method

Table 5. Proposed countermeasures for the five projects

Project	Proposed Countermeasures	Impact	Ease of Implementation
Core Coating and Dipping Processes	**Implement temperature gauge for drying**	**8.7**	**6.7**
	Only use cores with 100% coverage	**9.5**	**7.0**
	Dip cores a second time after drying	2.0	7.3
	Check core mixture consistency every 5 minutes	9.0	3.3
	Submerge cores for 3 seconds in wash	9.3	4.7
	Bake cores before dipping	1.3	6.7
	Dry for different length of time	8.0	2.3
	Implement quality checkpoints	**8.3**	**8.0**
Sand System	Change sand supplier	8.0	4.0
	Add higher amounts of new sand to the system	**5.6**	**7.5**
	Use control charts to measure sand quality	7.0	4.0
	Remove chunks of cores & large sand grains from recycled sand	2.0	4.0
	Linear program model to optimize muller productivity	1.5	6.0
	Remove second rotary screen	**5.9**	**5.5**
	Extend shake out period	1.97	7.3
RF Testing	**Standardize the stations**	**7.5**	**8.0**
	Standardize the process	**7.0**	**7.5**
	Calibration of current equipment	4.0	9.5
	Acquire new equipment	5.0	6.5
	Relocate test stations to quiet area	4.0	7.0
	Dedicate test stations to product types	**6.0**	**8.5**
Plastic Mold Making Process	**Create standard work instructions**	**8.0**	**8.5**
	Use different plastic compositions	6.5	4.0
	Use computer software to outline where to drill	**9.0**	**5.5**
	Add humidifier	**5.0**	**9.0**
	Faster wax and release of product	6.5	4.0
	Heat the local negatives in the oven to lower lead times	**5.5**	**9.0**
	Purchase another Bridgeport	8.5	2.5
	Add another milling machine	6.0	3.0
Pattern Handling Process	Optimize the current layout	2.0	8.0
	Purchasing a custom built fork truck	**9.0**	**7.0**
	Purchase a manipulator arm	**8.0**	**6.0**
	Purchase a new walking stacker for use in the pattern storage	8.0	5.0

3. Measuring Learning Outcomes

Assessment of the student learning is important to ensure that the students gained the proposed experience. In order to assess and measure the learning outcomes of the industry projects, we will discuss the outcomes form the perspectives of students, industry mentors, and course instructor.

3.1 Student's Perspective

The students' perspectives on the learning experience is assessed through surveys that were distributed to the students after completing the projects. Students' responses were analyzed using charts and word clustering. Table 6 shows part 1 of the survey which includes 10 questions. Students' responses for questions 1-9 are shown in Figure 5. Most of the students agree (or strongly agree) that the industry project helped them understand the topics discussed in class as well as the Lean manufacturing concepts and techniques. However, most of the students disagree (or strongly disagree) that there was sufficient time to complete the project. On average, Lean process improvements take three to six months to be completed and the course projects took only three months (or one semester).

Table 6. Survey questions for the industry project

No.	Question	Answer
Q1	The projects helped me understand the topics discussed in class.	4 3 2 1 NA
Q2	The projects helped me understand the Lean manufacturing concepts and techniques.	4 3 2 1 NA
Q3	There was sufficient time in the term to execute the industry project.	4 3 2 1 NA
Q4	The project tasks and/or expectations were clear.	4 3 2 1 NA
Q5	The project was integrated into course content.	4 3 2 1 NA
Q6	I got help and support from the professor and from the industry advisors.	4 3 2 1 NA
Q7	The project increased my interest in process improvement jobs.	4 3 2 1 NA
Q8	The project improved my ability to work as part of a team.	4 3 2 1 NA
Q9	The idea of having real industry projects in IE470 should continue in the future.	4 3 2 1 NA
Q10	Please rate your overall experience with this course project?	□ Excellent □ Good □ Fair □ Poor

4 = Strongly Agree 3= Agree 2 = Disagree 1= Strongly Disagree NA: Not Applicable

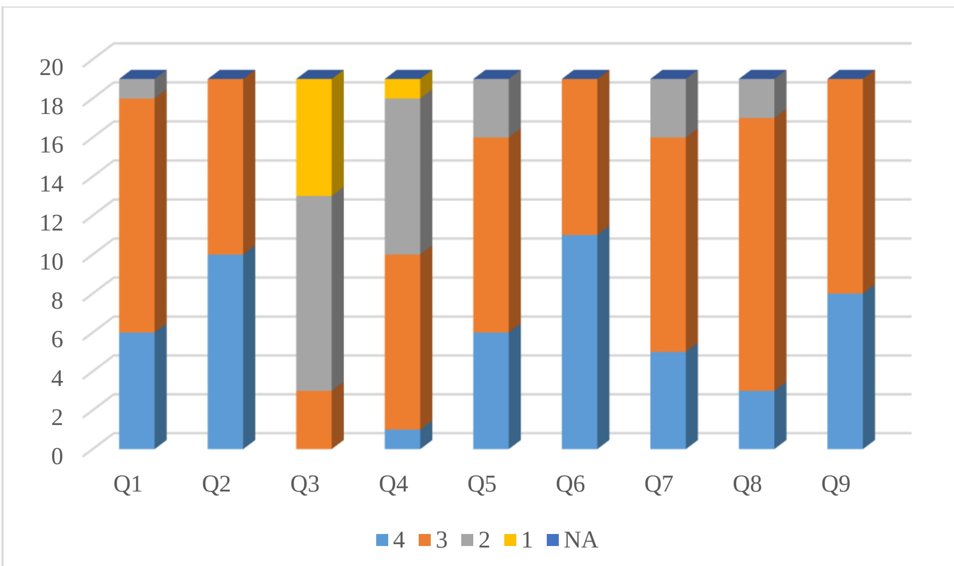

Figure 5. Students responses for the survey questions (1-9)

Qualitative questions were also considered to gather students' feedback on the projects. Figures 6 and 7 show the six questions and associated analysis using Word Clustering technique. For Question 11, students said that the skills they learned include communication, Practical Process Improvement (PPI), and problem solving. Responses for question 12 indicates that the most beneficial part of the course was the real project. Question 13 indicates that the most thing students like most about the project is that it is a real project. For questions 14-16, most responses indicate that the time for the project was not enough and also the project should start in the beginning of the semester. It should be noted that students started working on the project during the third week of the semester because it took two weeks to work on the logistics of the project.

Q11. What skills did you learn from the course and course project that may help prepare you for working in industry?

Q12. What aspects of IE470 course were most beneficial to you?

Q13. What did you like best or find most useful about the course project?

Figure 6. Word clustering for students’ responses to questions 11,12, and 13, respectively.

Q14. Things you did not like about the course project:

Q15. Challenges you faced during the lifetime of the course project:

Q16. Suggestions for improvement:

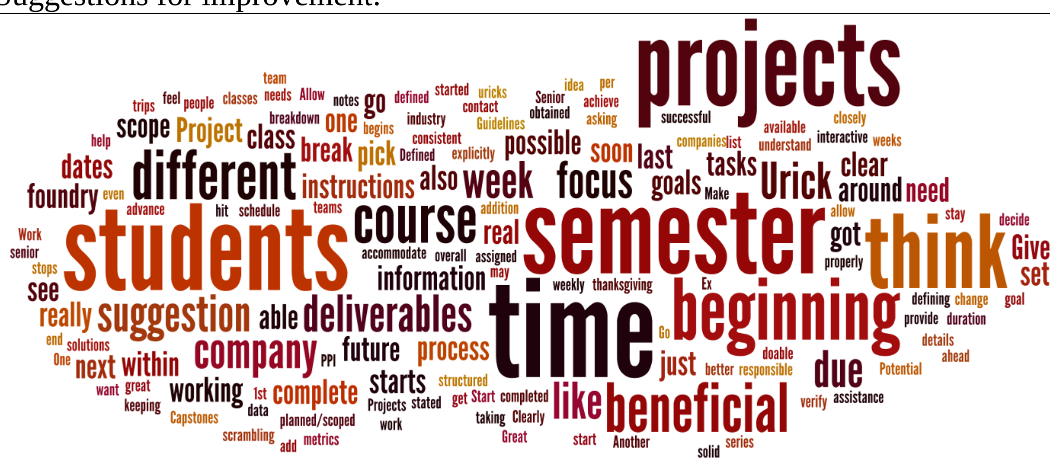

Figure 7. Word clustering for students’ responses to questions 14,15, and 16, respectively

3.2 Industry's Perspective

From the industry perspective, the projects helped in providing new technical skills to solve the identified problems. Below are some comments and feedback from the industry advisors on the projects.

- "Opportunities like this one is an excellent experience for bright, young minds to get a different perspective of the issue."
- "The outcome for our project was very good. We have implemented the suggestions that were made and our process is improving. It was a job well done."
- "I think the students working on my project did a good job considering the information and time they had available. Solving the problem, they were asked to work on requires quite a bit more time along with sampling of the different possible solutions. I think the students did good and communicated very well."
- "The students were attentive and listened to my descriptions about how the process works. Some of their ideas were pretty far out- like manually picking out the core pieces from the sand as it went by on a conveyor. But they also contributed an idea that I hadn't really considered- control charts for the sand properties."

3.3 Instructor's Perspective

Instructor's perspective on assessing the learning outcomes of the industry project are based on the course objective related to the project (i.e., *Be able to use process improvement methods in real manufacturing or service environments*). The instructor developed a rubric for evaluating the student performance, as shown in Table 4. The project was divided into phases and each phase was assigned a grade. Part of the grade was also assigned to peer evaluation. After completing each phase, students submitted a two-page report on their work related to that phase. Moreover, students submitted a final report to the instructor and industry mentor. The final report was a 15-20 page document that included detailed description of the project phases. The instructor served as the facilitator and mentor for all the projects.

4. Benefits and Challenges of Industry Projects

The main benefit to the students is the exposure to real life problems and applying what they learn in class to solve them. Students also improve their communication and teamwork skills. The faculty advisor benefits from the industry projects through collaborating and networking with local industry, using real life examples to illustrate course topics, preparing students for careers in engineering, and potential research and publication opportunities. Industry sponsors of the projects benefit by receiving additional technical resources to solve the identified problems.

Several challenges were encountered during the life cycle if the industry project. First, as indicated by the student survey, the time limitation was one issue. Another issues was the transportation. Even though the company location is only fifteen minutes driving from campus, not all students were able to makes all the company visits. These challenges will be addressed in the future industry projects.

Table 4. Instructor's rubric for evaluating student's performance

Performance Criteria	Poor	Good	Excellent
Problem Identification	Does not identify the problem clearly	Defines problem but has missing elements or does not include important information	Clearly identifies problem or reiterates given problem, including underlying principles and scope. Demonstrates depth of understanding
Lean Wastes and Value Add Analysis	Fail to identify Lean wastes and perform value add analysis	Identify some Lean wastes and performs incomplete value add analysis	Cleary identifies all the Lean wastes and perform complete value add analysis
Root Cause Analysis	Fail to identify the main root causes of the problem	Identify some of the root causes and missing other important ones	Cleary identify all the possible root causes of the problem
Root Cause Validation	Missing root cause validation	Incomplete root cause validation	Complete root cause validation which includes data collection and analysis
Develop and Select Solutions	No solutions are developed or solutions don't address the problem	Solutions generated are not enough and will partially solve the problem	Solutions are complete and will overcome the identified problem
Implement Solutions and Develop Control Plan	No implementation and/or control plan	Incomplete implementation and /or control plan	Solutions are implemented and a clear control plan is generated
Peer Evaluation	Each member evaluates the other team members in terms of teamwork, leadership, commitment to deadlines, and workload. *Teamwork (20%)*: Was the member a good and collaborative team member? *Leadership (20%)*: Was the team member a good leader and has lead and contribute to leading the project successfully? *Commitment to deadlines (20%)*: did the team member attended all the meetings? Was s/he committed to deadlines? *Workload (40%)*: did the team member contributed to the project satisfactorily and performed all the tasks required from him/her successfully?		

5. Conclusions

The collective experience of the authors with this one-semester industry project that was incorporated into the undergraduate manufacturing systems course has shown that the project was beneficial to both students and industry. Data collected from student survey has shown that the industry project helps the students to understand what they learn in class and acquire new skills. Challenges faced during the lifetime of this project were mainly related to the limited time as the project is limited to one semester. To continuously improve the outcome of the industry projects, future projects will start earlier and students will be provided with detailed instructions at the beginning of the semester. Furthermore, other industry sectors such as locomotive, healthcare and service industry may be considered.

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