AC 2011-17: INTEGRATING ENTREPRENEURSHIP INTO MANUFACTURING ENGINEERING EDUCATION

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Integrating Entrepreneurship into Manufacturing Engineering Education

Abstract

Among highly desirable soft skill sets, entrepreneurship has received increasing attention in recent years in the engineering education community. This paper describes a Project-Based Learning approach to integrating entrepreneurship into an upper-level undergraduate manufacturing course entitled Machining Theory and Applications that was taught by the author of this paper at Utah State University. The students in the class were divided into six teams working on a variety of projects. Each project included three tasks: developing a computer software program for machining simulations, developing the associated business plan, and writing the business plan and orally presenting the project results. A representative example of student projects and associated business plans is provided in the paper. The students’ attitudes toward and experiences with their projects were surveyed using a Likert-type and open-ended questionnaire at the end of the semester. The survey results indicated that 85.8% of students rated the overall experience with their projects positive or very positive, 81.0% of students agreed or very agreed that their business knowledge was improved by developing a business plan, and 90.4% of students agreed or very agreed that it is necessary and important to integrate entrepreneurship into manufacturing engineering education.
**Introduction**

In its report on *Moving Forward to Improving Engineering Education* \(^1\), the National Science Board made a series of keystone recommendations for the National Science Foundation to support innovations in engineering education programs in the 21st century. The report highlighted the importance of engineering students’ soft skills in the highly competitive and fast changing global world. These soft skills — also called professional skills \(^2\) — include communication, teamwork, leadership, entrepreneurship, ethics, and so on. The report discussed a variety of approaches to providing students a broader engineering educational experience, for example, dropping some of the existing traditional engineering curriculum (e.g., Fourier transforms) in favor of material related to soft skills \(^1\).

Among highly desirable soft skill sets, entrepreneurship has received increasing attention in recent years in the engineering education community due to its significant role in engineering innovation and globalization \(^5\). Some institutions of higher learning have established an engineering entrepreneurship minor, while others have entrepreneurship embedded throughout the curriculum and extracurricular activities \(^1,4-6\). The following paragraphs provide three examples of engineering curriculum with entrepreneurship embedded.

Schaufeld et al. \(^4\) developed a first-year course to introduce engineering students to the importance of innovation and entrepreneurship for the economy and to raise their awareness of the issues and solutions that surround the process. The course was co-taught by faculty from engineering and business departments. Students in the class develop an Innovation Plan to solve a medical challenge that applied a robotic approach solution to knee meniscus repair.

Chen and Ye \(^5\) integrated the concepts and practices of entrepreneurship into a college level facility planning course. Students were introduced to important entrepreneurial concepts, such as identifying opportunities, creating a business plan, and analyzing the market to determine the target customers. Students were required to develop a proper facility layout and a business plan.

Dahm et al. \(^6\) integrated two entrepreneurial assignments into a multidisciplinary sophomore design course to foster entrepreneurship in engineering students. Based on their assessment results, Dahm et al. reported that the appropriateness of entrepreneurial assignments is a key factor that affects students to pursue or not to pursue entrepreneurial projects.

All above-described entrepreneurial activities are based on the same pedagogical approach called Project-Based Learning (PBL). In the PBL \(^7-9\), students develop their understanding of curricular materials through conducting a specific project. Active learning \(^10-13\) and collaborative learning \(^14-17\) are typically involved in the PBL.

This study employs the Project-Based Learning approach to integrating entrepreneurship into an upper-level undergraduate manufacturing course entitled Machining Theory and Applications. The students who enrolled in the course worked on a variety of machining projects throughout a semester. This paper provides a detailed description of how entrepreneurial activities were integrated in student projects, followed by the description of a representative example of student projects and associated business plans. The students’ attitudes toward and experiences with their
projects were surveyed using a Likert-type and open-ended questionnaire at the end of the semester. The survey results are reported and analyzed in this paper.

**Integrate Entrepreneurship into Manufacturing Course Design**

The Machining Theory and Applications course has the following student learning objectives:

1. Identify correct tool geometry and their effects
2. Calculate and experimentally measure the shear-plane angle
3. Perform fundamental analysis on the cutting forces and temperatures in machining
4. Understand different tool material properties and tool-wear mechanisms and apply Taylor’s tool-life equation to predict tool life
5. Analyze factors affecting the machined surface quality
6. Develop and improve professional skills (such as communication, teamwork, business knowledge, and entrepreneurship) to help enable machining innovation

Note that learning objective No. 6 included entrepreneurship education. The students in the class were divided into six project teams with three or four students on each team. Each team was required to complete three tasks by the end of the semester. These three tasks included 1) developing a computer software program for machining simulations, 2) developing the associated business plan, and 3) writing the business plan and orally presenting the project results. The quality of the students’ project results was used as one of criteria for assigning final course grades to the students.

At the beginning of the semester, the instructor (who is also the author of this paper) provided a list of general project topics for students to choose from. These general project topics included the predictions of the cutting forces, the cutting temperatures, the built-up edge, tool wear, tool life, the machined surface roughness, and the residual stress of the machined parts. In regular classroom lectures, the instructor covered these general project topics to various extents. Students gained a more in-depth understanding of a specific topic by working on their projects through extensive research on machining literature, such as journals, magazines, conference papers, books, patents, Internet websites, and consultation with industry professionals.

Table 1 (next page) lists the six projects that the students chose and conducted. By the end of the semester, the students completed not only the development of a computer software program for machining simulations, but also the development of associated business plan. Both tasks required a significant amount of time commitment from each student. Therefore, each project team met both inside and outside the classroom throughout the semester.

The instructor has been working in the machining area for more than 20 years and also worked closely with an experienced business professional to bring one of the instructor’s patents to the marketplace via extensive market analysis and customer interviews. This provided the instructor a valuable experience with entrepreneurship. Therefore, the instructor was able to provide the students with constructive suggestions and timely help on many aspects of the students’ projects, from choosing an appropriate machining model, developing a computer simulation program, designing a computer Graphical User Interface, to performing marketing surveys and analysis.
Table 1. Student projects

<table>
<thead>
<tr>
<th>Team</th>
<th>Project title</th>
<th>Project objectives</th>
</tr>
</thead>
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| #1   | Predicting tool flank wear in machining composite materials | • Develop a computer simulation program to predict tool flank wear based on the fiber orientation angle and the cutting conditions  
     |                                                   | • Develop and write the associated business plan                                                                                                   |
| #2   | Cutting force calculators                         | • Develop a computer simulation program to calculate the cutting forces in turning operations  
     |                                                   | • Develop and write the associated business plan                                                                                                   |
| #3   | Tool life calculator                              | • Develop a computer simulation program to predict tool life for the given tool geometry and cutting conditions in turning operations  
     |                                                   | • Develop and write the associated business plan                                                                                                   |
| #4   | Cutting force predictions                         | • Develop a computer simulation program to predict the cutting forces based on work materials, tool geometry, and the cutting conditions  
     |                                                   | • Develop and write the associated business plan                                                                                                   |
| #5   | Tool wear predictions                             | • Develop a computer simulation program to predict tool flank wear based on the cutting conditions and a force ratio  
     |                                                   | • Develop and write the associated business plan                                                                                                   |
| #6   | Drilling forces for composite materials            | • Develop a computer simulation program to predict the drilling forces based on composite materials and their thickness, drill bit diameter, and the cutting conditions  
     |                                                   | • Develop and write the associated business plan                                                                                                   |

Because the machining course is not an Entrepreneurship course – the latter of which is a semester-long, stand-alone course typically offered by a business college – the students’ business plan only contained several key elements: executive summary, product description, target market, marketing plan, and the competition. Other components that are included in a business plan, such as strategic position and risk analysis, operations, management and organization, profit and loss statement, case flow projection\textsuperscript{20-21} were hence not required by the instructor.

**A Representative Example of Student Projects and Associated Business Plans**

The first project listed in Table 1 is employed as a representative example to show the students’ work. With four students on that team, Project #1 focused on the prediction of tool flank wear in machining composite materials. Figure 1 shows the table of contents of the business plan developed and written by Project Team #1.
The following paragraphs provide a brief description of four key sections listed in Figure 1, including production description, target market, marketing plan, and the competition. The original business plan written by Project Team #1 has 21 pages with text, figures, and tables.

Production description

The students described the function of their computer simulation program (product). They indicated that their computer program could be employed to predict tool wear in turning a glass composite material (fiberglass), and that their computer program would be helpful in minimizing tooling costs by knowing when the tool needs to be replaced.

Figure 2 shows the Graphical User Interface of the computer program developed by Project Team #1. The input parameters include the cutting speed, the fiber orientation angle, the depth of cut, and the feed rate. These input parameters can be entered in the computer program in two ways. The first way is typing the desired constant in the corresponding text box (see the upper-left screen in Figure 2). The second way is moving the slider (also see the upper-left screen in
Figure 2). The output parameter is the average tool flank wear length \((V_b, \text{ in mm})\) and is shown in the upper-right screed in Figure 2.

![Graphical User Interface of the computer program developed by Project Team #1](image)

Figure 2. The Graphical User Interface of the computer program developed by Project Team #1

The machining model that was employed to develop the computer program is the model suggested by Palanikumar and Davim \(^{22}\). That machining model \(^{22}\) can predict the tool flank wear length based on the cutting conditions and the fiber orientation angle. That model is applicable within the following ranges: the cutting speed of 75-175 m/min, the fiber orientation angle of 30-90 degrees, the depth of cut of 0.5-1.5 mm, and the feed rate of 0.1-0.5 mm/rev.

**Target market**

The students pointed out that composites make up a large portion of materials used in many manufacturing industries. They also pointed out that fiberglass is among the most commonly used composite materials, makes up approximately 65 percent of all the composites produced today, and is employed for boat hulls, surfboards, sporting goods, swimming pool linings, building panels, car bodies, and so on. The students interviewed a senior design engineer at a local composite manufacturing company. The students asked, “What current industries are utilizing the advantages of composites the most?” The design engineer replied:

“Currently, aerospace is using it a lot – especially airplane manufacturers such as Boeing and Airbus. Using composites for pressure vessels is also a large industry that will continue to grow. With the large focus on alternative fuels, such as Compressed Natural Gas (CNG) and Hydrogen, these all require pressure vessels for storage. This market is growing very rapidly.”
The students further stated that tool wear is an important issue in machining, especially in machining composite materials. For example, tool wear creates significant problems in the machined surface. A cutting tool cannot produce the part within the required tolerances when tool wear reaches a critical value. Therefore, predicting tool wear is very important in many industries. The students concluded that the industries that can benefit from their developed computer simulation program would include the automotive industry, aerospace industry, boat industry, and sporting goods industry.

The students further identified three targeted groups of customers in the above industries, including composite producers, machine shops that provide fiberglass machining services, and research and development staff that work on new fiberglass applications involving machining.

Marketing plan

In order to get a better idea of the importance of effective marketing, along with some real-world marketing techniques, the students interviewed a sales director at the local composite manufacturing company. The sales director offered some practical suggestions, for example, conducting market research first, establishing the costs/benefits of the new product, and raising market awareness such as offering the product to customers on a trial basis and using print advertising. Based on extensive research and interviews, the students presented the following strategies to get their product out into the market.

- Prepare a company website that highlights the features and capabilities of the product, such as the description of the software and its capabilities, software demonstration and downloadable trial version, cost of the software, software support offered by the company, and contact information for potential customers.
- Hold press release alerting the market that this new type of software is now available.
- Visit nearby companies and offer to do a product demonstration. The students identified a total of 15 local companies.
- Attend trade shows to meet new customers. The students identified a total of seven national and international trade shows that a large number of companies attend.

The competition

After extensive research, the students identified the major competitor of their products. The students indicated that their competitor currently offers a finite-element-based computer software package to predict the cutting forces and temperatures in machining. The information of the cutting forces and temperatures can be used to indirectly predict tool wear in machining. The students claimed that their product has the following advantages over their competitors:

- Simplicity. The software is very easy to operate and has a self-explanatory user interface. Its simplicity will drastically cut down on any user errors that could be very costly to the company. The current finite element software packages available today require extensive training and are very time consuming to learn.
- Highly specific to the composites industry. Companies in this composite market can buy and use this software without having to pay for all the “bells and whistles” of a
A machining program that is designed to handle metals, plastics and other types of materials in addition to composites.

- **Adaptability.** The software is highly adaptable and can be continually updated. It is currently designed to predict the tool flank wear for fiberglass; however it can be easily adapted to any type of material/matrix.
- **Low cost.** Due to its simplicity and being designed specifically for composites, the software will be able to be sold at a lower cost than that of competitors.

Finally, the students evaluated barriers of entering the market and potential future competition. The students indicated that their product is still in its early stage of development, and that its current limited functionality would hinder its acceptance in the marketplace.

**Assessment of Students’ Attitudes and Experiences**

The students’ attitudes toward and experiences with their projects were surveyed at the end of the semester by using a Likert-type and open-ended questionnaire. A total of 21 mechanical engineering undergraduate students who enrolled in the machining course responded to the questionnaire survey. Part of Likert-type questions that were employed in the survey are listed in the following paragraphs.

**Question I:** Do you agree that it is necessary and important to integrate entrepreneurship into manufacturing engineering education? Choose one from: very agree, agree, neutral, disagree, or very disagree

**Question II:** Do you agree that a team project with entrepreneurial activities is a good addition to classroom lectures because it makes learning more meaningful? Choose one from: very agree, agree, neutral, disagree, or very disagree

**Question III:** What is the overall experience with your team project? Choose one from: very positive, positive, neutral, negative, very negative

**Question IV:** Do you agree that your business knowledge was improved by developing a business plan? Choose one from: very agree, agree, neutral, disagree, or very disagree

**Question V:** Do you agree that the team project that you have done enhanced your teamwork skills? Choose one from: very agree, agree, neutral, disagree, or very disagree

The students’ responses to each question are shown in Figures 3-7. The statistical results indicate that

- 90.4% of students agreed or very agreed that it is necessary and important to integrate entrepreneurship into manufacturing engineering education
- 81.0% of students agreed or very agreed that a team project with entrepreneurial activities is a good addition to classroom lectures
- 85.8% of students rated the overall experience with their team project positive or very positive
• 81.0% of students agreed or very agreed that their business knowledge was improved by developing a business plan
• 85.8% of students agreed or very agreed that the team project that they have done enhanced their teamwork skills

4.8% neutral 4.8% very disagree 42.8% very agree

47.6% agree

Figure 3. Student response to Survey Question I

4.8% 4.8% 28.6% very agree
9.5% neutral disagree very disagree

52.4% agree

Figure 4. Student response to Survey Question II

4.8% neutral 9.5% negative 19.1% very positive

66.7% positive

Figure 5. Student response to Survey Question III
In addition, the students were asked to describe what they had learned most from developing a business plan. Representative student responses are as follows:

- “I learned how to approach the average investor, business owner, and customer with the idea.”
- “[I learned] how to compete against other companies and be competitive in industry.”
- “[I learned] how important it is to ‘push’ your design after it has been created.”
- “Target market is very important and it is the basis for successful business plan.”
- “I was responsible for the marketing sections of the business plan. I gained an understanding of some real life marketing techniques that companies use in industry.”
- “I learned a few useful techniques for marketing a product.”
- “I learned about different aspects of a business. Some I had not thought of.”
“[I learned] how to write a business plan and I have used this learning in my own personal business plan.”

When the students were asked what they had learned most from conducting the team project, the students responded:

- “[I learned] how to do effective research in a team working environment.”
- “[I learned] how to work as a team.”
- “I learned a lot about tool wear because we all share our research.”
- “Parallel work between team members was very useful.”
- “[I learned] time management is very important.”
- “[I learned] we must set deadlines and milestones in order to complete our project.”

Concluding remarks

This paper has described a Project-Based Learning approach to integrating entrepreneurship into manufacturing engineering education. The students enrolled in an upper-level machining course formed six project teams with three or four students on each team. Each team conducted a semester-long project that included three tasks: developing a computer software program for machining simulations, developing the associated business plan, and writing the business plan and orally presenting the project results.

Student projects covered a variety of important topics in machining, such as tool wear, tool life and the cutting forces. This paper has provided a representative example of student projects and associated business plans. The students’ business plan included several key elements including product description, target market, marketing plan, and the competition.

A Likert-type and open-ended questionnaire has been developed to survey students’ attitudes toward and experiences with their projects. The survey results reveal that 90.4% of students agreed or very agreed that it is necessary and important to integrate entrepreneurship into manufacturing engineering education, 85.8% of students rated the overall experience with their team project positive or very positive, and 81.0% of students agreed or very agreed that their business knowledge was improved by developing a business plan. The students’ responses to open-ended questions indicated that they learned how important it is to “push” their design to the next step after it has been created, and how to work as a team.

Bibliography


