Improving Entrepreneurial Skills Through Problem-Based Learning on Sustainability

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Abstract

Engineering success comes not only from technical prowess but also through a spirit of innovation and an awareness of the business context of engineering ventures. Thus it is vital that engineering students are prepared for this environment and given opportunities to develop a fuller set of skills necessary to contribute to business success. This paper discusses a problem-based learning (PBL) module on the topic of sustainability which sought to develop students’ abilities in and sense of the importance of collaboration, market analysis, innovative problem solving, as well as other entrepreneurial skills. Sustainability is an ideal topic for such a study, providing timely and meaningful means for exercising these skills.

This module, supported by a grant from the Kern Entrepreneurial Engineering Network (KEEN), was co-developed and implemented by mechanical engineering faculty at four U.S. universities. The effectiveness of the module was assessed in part using a pre- and post-survey in which students rated the importance of and their own ability in a number of facets of entrepreneurial skill. A description of the project and analysis of survey results is included.

Introduction

Engineering employers know that business success comes not only from technical prowess but also through a spirit of innovation and an awareness of the business context of engineering ventures. Thus it is vital that engineering students are prepared for this environment and given opportunities to develop a fuller set of business-related skills. Exercises in these skills can complement a wide range of topics in traditional engineering courses. This paper discusses a problem-based learning (PBL) module on the topic of sustainability created to develop students’ abilities in and sense of the importance of innovative problem solving, collaboration, market analysis, and other entrepreneurial skills.

As a footnote, it should be understood that the authors are using “entrepreneurship” in a larger sense than its traditional definition. It does not here necessarily imply starting a new business organization. Rather, it refers to the creativity, innovation, risk management and other skills essential for creating and exploiting market opportunities, whether as an individual or as an employee of a larger organization (“intrapreneur”).

The PBL module was co-developed by mechanical engineering faculty at four universities: Ohio Northern University, Lawrence Technological University, Gonzaga University, and St. Louis University. Project sponsorship was provided by the Kern Entrepreneurial Engineering Network (KEEN). This module was delivered in two semester courses at each of the four schools, impacting a total of 219 students.

Pre- and post-project surveys, using a common instrument at all schools, were given to all students to measure students’ confidence in their own abilities concerning fourteen different entrepreneurial-related metrics. The surveys also asked the students to rate their own perception
of the importance of these same skills. Improvement in both confidence and awareness was achieved in many of these areas.

Instructional Goals

The goals of this exercise fell into two primary categories, sustainability education and entrepreneurial education. For the first category, the authors aimed to give students an introduction into the topic of sustainability and its application for engineers. Sustainability is not a simple term to define, as there are many ways to measure it. For instance, one may define it in terms of development: “Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” Or more specifically, one may view it from a general environmental perspective: “The quality of not being harmful to the environment or depleting natural resources, and thereby supporting long-term ecological balance.” Other definitions are concerned more specifically with community, society, industry, or agriculture.

Students should be aware of these definitions and understand the impact of their personal and engineering decisions on these various scales. The team project required students to explore opportunities for improving the sustainability of an engineering product. Instructors provided students with several tools for doing this, including the Ecodesign Strategy Wheel and Life Cycle Assessment.

The second category of instructional goals was to use the exercise to develop students’ entrepreneurial skills and increase their awareness of the importance of these skills. Five behaviors were specifically targeted which support the KEEN Student Outcomes:

- Apply critical and creative thinking to ambiguous problems
- Construct and effectively communicate a customer-appropriate value proposition
- Effectively collaborate in a team setting
- Persist through and learn from failure
- Discern and pursue ethical practices

The full set of KEEN Student Outcomes may be found in the appendix.

The topic of sustainability provides excellent opportunities to exercise these skills. There are plenty of engineered products and processes today which are simply not sustainable from the perspective of resources or ecology. So the problems are easy to find, but not always as easy to solve; ecologically sustainable solutions are not always financially viable or they may compromise some feature critical for customer acceptance. Drawing on the synergy of a team, however, students can persist through these obstacles and put together an effective solution more sustainable than the one it replaces.

Project Description

Students were first given one or more introductory lessons on the concept and facets of sustainability, as described in the previous section. At least one instructor “flipped the
classroom” for this introductory portion, assigning students to watch several sustainability-related TED Talks outside of class and discussed and debated the topics in class. Following this, they were assigned a project consisting of the following five basic steps:

1. Identify a product with opportunities for improvement in sustainability.
2. Research product’s current design and manufacture.
3. Analyze sustainability of current design and manufacture.
4. Identify alternative design and manufacturing approaches which may increase product’s sustainability.
5. Communicate proposed solution(s) through written and oral summary reports.

Some students at one school applied this analysis to an industrial process rather than to a particular product.

To help them effectively and realistically evaluate their ideas, students were encouraged to seek expert guidance from someone in a field closely related to their product of choice. Students also had use a rubric similar to that shown in Table 1 to analyze and weigh various opportunities according to their impact on the product’s use, ease of manufacture, marketability, and a number of other measures. They were not required to use all of the evaluation measures shown, but could tailor the rubric as appropriate for their product.

Table 1 displays a sample analysis performed for a disposable, non-refillable, mixed-material pepper grinder such as shown in Figure 1. This type of product has become popular in restaurants, but its limited lifespan and recyclability present some opportunities for improving sustainability. The numbers in the table were not intended to reflect reality, only to provide students with an example of what the analysis might look like.

![Figure 1: Disposable, non-refillable pepper grinder used for sample sustainability analysis](image)

Business measures such as cost, profit, and marketability were included in the table. The entrepreneur must also understand that a product must be “sustainable” in an economic sense as well; an extremely “green” product which no one would buy due to cost or inconvenience is not a sustainable one.

Students were also required to conduct a market analysis to determine the potential acceptance of the modification. Each student group ultimately generated a written report with their final proposal, and “sold” their proposal to the instructor and class via a presentation or YouTube video.
Table 1: Performance measures of sustainability for alternative product development

<table>
<thead>
<tr>
<th>Change</th>
<th>Business measures</th>
<th>Sustainability / Performance Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cost</td>
<td>Profit</td>
</tr>
<tr>
<td>Original design: Disposable pepper grinder</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Top separates to refill/recycle</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>All-PET body</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>All-aluminum body</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Final proposal: All-aluminum refillable body</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

*Scale factor (1 – Worst, 5 – Best)

Implementation

The authors chose problem-based learning (PBL) as the delivery method for this module. There is extensive and consistent support for the efficacy of this method in improving achievement and knowledge retention, critical thinking and higher-level reasoning, an accurate understanding of others’ perspectives, and teamwork skills.  

While the four collaborators discussed and agreed upon a common topic, framework, survey instrument, and particular emphases, the instructional delivery methods varied from school to school. All instructors formed heterogeneous student groups rather than allowing students to self-select teams. But some instructors formed groups arbitrarily and others did so based on project interest or other method. Teams of 3-4 students were the norm at three schools, but the instructor at Gonzaga chose teams of 5 students for his large classes.

The project module duration also varied by school and by semester. The project duration was somewhat compressed during fall semester for all schools, as the final details were not sorted out until the beginning weeks of that term. The ideal, however, was to introduce the topic early and enable the project to span over half of the semester. Some instructors allowed class time for working on the project, and others did not.

As stated previously, students were encouraged to seek expert guidance related to their chosen product or process. At least two instructors made this compulsory, assigning specific graded tasks for obtaining expert input and modifying design proposals accordingly. Grant money was available to reimburse student travel costs for this purpose. Anecdotally, students reported this interaction as a valuable part of the project. Those projects in which external expert guidance was provided yielded results generally superior to those in which it was not.
The sustainability modules were implemented in different courses at the participating schools, summarized in Table 2. Lawrence Tech (School “W”) taught the module in a Manufacturing Processes class both semesters. Ohio Northern (X) used the module in a Process of Design class during the fall and Manufacturing Processes in the spring. Gonzaga (Y) stretched the material over a two-semester sequence in Thermodynamics with the same group of students.* St. Louis University (Z) taught the module in courses on Mechatronics and Material Science. In all, approximately 219 students worked through this module.

Table 2: Courses and participation in which the sustainability module was taught

<table>
<thead>
<tr>
<th></th>
<th>Fall 2013</th>
<th>Spring 2014</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>#students</td>
<td>#students</td>
</tr>
<tr>
<td>W</td>
<td>Manufacturing Processes</td>
<td>24</td>
</tr>
<tr>
<td>X</td>
<td>Process of Design</td>
<td>34</td>
</tr>
<tr>
<td>Y</td>
<td>Thermodynamics 1</td>
<td>76</td>
</tr>
<tr>
<td>Z</td>
<td>Mechatronics</td>
<td>19</td>
</tr>
</tbody>
</table>

Total students (accounts for students taught the module in two diff. classes) 219

Results and Assessment

A survey instrument was developed to assess students’ self-reported confidence in their abilities in and their perception of the importance of various entrepreneurial skills. This list of skills is essentially an expansion of the four KEEN Student Outcomes targeted by this project. The same survey, displayed in the appendix, was given to all students before starting and after the completion of the module. Students rated their confidence in and the importance of the following tasks:

- Communicate ideas
- Act in a leadership role
- Creatively solve problems
- Work in a team environment
- Conduct market analysis
- Develop new methods and designs
- Take responsibility for decisions
- Problem-solving skills
- Collaborate in a team setting
- Sell your ideas to others
- Employ innovative techniques and develop innovative ideas
- Work in an uncertain / ambiguous environment
- Construct and effectively communicate a customer-appropriate value proposition
- Persist through and learn from failure

Students reported their confidence on a four-point Likert scale as (4) very confident, (3) confident, (2) somewhat confident, or (1) not confident. Students similarly rated the importance
of each skill from (5) high to (1) low. For statistical purposes, the research hypothesis was that through the sustainability learning module, student confidence in (or perceived importance of) each given skill increased. $P$ values were calculated based on a 1-tailed, unpaired T-test with unequal variance. Values of $p \leq 0.05$ were considered statistically significant.

These results must be somewhat qualified, because the PBL modules were not executed in exactly the same manner both semesters. The authors made some adjustments in the module instruction and timing between semesters, and there were naturally other differences in content delivery and team dynamics. And because the fall semester schedule had been compressed, there was more time available for the project in the spring. Also, over half of the students who participated in the module during spring semester at School X had just completed it in another course in the fall. Thus for them, the pre-survey results for spring semester are likely similar to their post-survey results from the fall. This would tend to suppress any differences between pre- and post-survey results.

School-specific and composite results are shown in Figure 2 (student confidence) and Figure 3 (student view of importance). Note that, because School Y stretched the single project across two semesters with the same students, the pre- and post-survey were given at the start and finish of the academic year. The combined results for all course offerings are displayed graphically in Figures 4 and 5.

![Table showing student confidence and view of importance across different semesters and schools.](image)

**Figure 2**: Student confidence in their own abilities.
Figure 3: Student perception of the importance of entrepreneurial skills

<table>
<thead>
<tr>
<th>Importance</th>
<th>School X, Semester 1</th>
<th>School X, Semester 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communicate my ideas</td>
<td>N 33 POST 4.39</td>
<td>N 33 POST 4.62</td>
</tr>
<tr>
<td>Act in a leadership role</td>
<td>4.14</td>
<td>4.17</td>
</tr>
<tr>
<td>Creatively solve problems</td>
<td>4.13</td>
<td>4.27</td>
</tr>
<tr>
<td>Work in a team environment</td>
<td>4.04</td>
<td>4.07</td>
</tr>
<tr>
<td>Conduct market analysis</td>
<td>2.81</td>
<td>3.17</td>
</tr>
<tr>
<td>Develop new methods/design</td>
<td>4.00</td>
<td>4.07</td>
</tr>
<tr>
<td>Take responsibility for decisions</td>
<td>4.52</td>
<td>4.40</td>
</tr>
<tr>
<td>Problem-solving skills</td>
<td>4.46</td>
<td>4.53</td>
</tr>
<tr>
<td>Collaborate in a team setting</td>
<td>4.31</td>
<td>4.40</td>
</tr>
<tr>
<td>Sell your ideas to others</td>
<td>3.94</td>
<td>4.13</td>
</tr>
<tr>
<td>Employ innovative tech/ideas</td>
<td>3.61</td>
<td>4.03</td>
</tr>
<tr>
<td>Work in uncertain/ambig. env.</td>
<td>3.44</td>
<td>3.83</td>
</tr>
<tr>
<td>Construct/comm. a value prop</td>
<td>3.44</td>
<td>3.83</td>
</tr>
<tr>
<td>Persist / learn from failure</td>
<td>4.43</td>
<td>4.50</td>
</tr>
</tbody>
</table>

Figure 4: Student confidence in their own abilities, for all schools and both semesters

Student Confidence in Abilities: Composite Results

Pre-Survey  | Post-Survey
Communicate my ideas | 4.42 | 4.43
Act in a leadership role | 4.35 | 4.30
Creatively solve problems | 4.39 | 4.36
Work in a team environment | 4.29 | 4.32
Conduct market analysis | 3.08 | 4.25
Develop new methods/design | 3.25 | 4.38
Take responsibility for decisions | 4.46 | 4.43
Problem-solving skills | 4.57 | 4.64
Collaborate in a team setting | 4.44 | 4.42
Sell your ideas to others | 3.85 | 4.00
Employ innovative tech/ideas | 4.23 | 4.25
Work in uncertain/ambig. env. | 3.57 | 3.77
Construct/comm. a value prop | 3.54 | 3.64
Persist / learn from failure | 4.75 | 4.75

Figure 4: Student confidence in their own abilities, for all schools and both semesters
Conclusions

Based on survey data, discussions with students, and assessment of the student work for these projects, the sustainability module was effective. Not only did students learn about a vital aspect of social and ethical responsibility for citizens and engineers, they also increased their confidence in and awareness of the importance of a number of key traits in the entrepreneurial mindset.

Examining first the composite survey results for all schools, statistically significant gains were made with respect to several skills for both student confidence and perception of importance. The strongest consistent gain in confidence was for “conducting a market analysis.” The engineering students started out unsure of their ability to conduct a market analysis, probably even inflating their confidence beyond what they should have reported. But the project forced them to plan and execute such a market analysis, attempting them to think beyond what they thought was a good idea, and consider what their prospective customers would think – indeed, if the product would sell, or if their customers would pay more for the proposed improvements in design and sustainability.

Students also grew in their confidence to creatively solve problems. They saw that, when they forced themselves to contemplate a problem for an extended time and from a number of different
angles, they could indeed come up with promising solutions that could not be found on the market.

Student confidence was also significantly increased in every area except four: working in a team environment, problem-solving skills, taking responsibility for decisions, and persisting through / learning from failure. Teamwork and problem-solving are skills typically exercised throughout the engineering curriculum, so it is less surprising that the first two skills were not markedly impacted by one learning module. All four of these are areas in which students reported a fairly high confidence at the start of the project (3.26 – 3.38). Only one other metric started out in this range and saw a substantial increase (collaborating in a team setting).

Statistically significant gains in students’ perception of these skills’ importance were seen in the need to act in a leadership role ($p = 0.004$), develop new methods and designs ($p = 0.032$), and taking responsibility for decisions ($p = 0.035$). Slightly weaker gains were realized for the need to creatively solve problems, working in a team environment, selling your ideas to others, and working in an uncertain or ambiguous environment. None of the skills dropped in importance in the composite measure.

Other skills saw significant gains for one or more terms at one or two schools. The fluctuation was likely due to the varied project implementation in different courses and terms, as well as instructor emphasis. For instance, confidence in persisting through and learning from failure was the second highest increase at School X during the second semester ($p = 0.043$), though this measure showed no significant gain at any other school. The instructor observed during this term that students often felt like they had a promising idea, only to be humbled by critique from their industry contact or through further research of their own. Students’ efforts at innovation and redesign were not immediately successful, so they grew in their ability to persist through and learn from failure. There was much less time allotted to the project at School X in the prior term, and few groups had made contact with an expert. Without such a reality check, “persisting” was not exercised as much.

Three skills saw nothing close to a significant gain in confidence during any term at any school. Foremost was taking responsibility for decisions, which slightly decreased as previously mentioned. Responsibility is a scary proposition, and students realized it; this skill saw one of the largest gains in “importance” in the survey. Student confidence was unchanged in working in a team environment, probably because these junior and senior engineering students have already had extensive experience in teamwork. Constructing and communicating a customer-appropriate value proposition did not appreciably increase in either confidence or importance, quite possibly because these engineering students were unfamiliar with the business jargon and did not understand the phrase.
Acknowledgement

The authors would like to thank the Kern Entrepreneurial Engineering Network for the opportunity, encouragement, and funding to pursue this project. We do have a responsibility to our children to take care of the planet, and acting on this responsibility can often mean financially-sustainable results for our personal and corporate enterprise as well.

Bibliography

Appendix 1

**KEEN STUDENT OUTCOMES**

**ENTREPRENEURIAL MINDSET**
- **CURiosity**
  - demonstrate constant curiosity about our changing world
- **CONNections**
  - integrate information from many sources to gain insight
- **CReating VALUE**
  - identify unexpected opportunities to create extraordinary value
  - persist through and learn from failure

**COUPLED WITH**

**ENGINEERING THOUGHT AND ACTION**
- **APPLY** creative thinking to ambiguous problems
- **APPLY** systems thinking to complex problems
- **EVALUATE** technical feasibility and economic drivers
- **EXAMINE** societal and individual needs

**EXRESSED THROUGH**

**COLLABORATION**
- **FORM** and **WORK** in teams
- **UNDERSTAND** the motivations and perspectives of others

**AND**

**COMMUNICATION**
- **CONVEY** engineering solutions in economic terms
- **SUBSTANTIATE** claims with data and facts

**AND FOUNDED ON**

**CHARACTER**
- **IDENTIFY** personal passions and a plan for professional development
- **FULFILL** commitments in a timely manner
- **DISCERN** and **PURSUE** ethical practices
- **CONTRIBUTE** to society as an active citizen
Appendix 2

**KEEN Sustainability Project: PRE-Survey**

Date: _______________________

This survey is anonymous and ungraded. Please rate how confident you are in your ability to perform the following tasks and how important they are.

<table>
<thead>
<tr>
<th>I am ...</th>
<th>Very confident</th>
<th>Confident</th>
<th>Somewhat confident</th>
<th>Not confident</th>
<th>How important to you?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communicate your ideas</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Act in a leadership role</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Creatively solve problems</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Work in a team environment</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Conduct market analysis</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Develop new methods/design</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Take responsibility for decisions</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Problem-solving skills</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Collaborate in a team setting</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Sell your ideas to others</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Employ innovative techniques and develop innovative ideas</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Work in an uncertain / ambiguous environment</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Construct and effectively communicate a customer-appropriate value proposition</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Persist through and learn from failure</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

*Note that though the title says “PRE-Survey,” pre- and post-surveys were identical.*