Project Based Learning in an Introduction to Materials Course

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Abstract

The University of Dayton is part of the Kern Entrepreneurship Education Network (KEEN) which aims to instill the entrepreneurial mindset in engineering students through a collaboration among 14 colleges and universities across the US. To facilitate this, KEEN offers a variety of resources to individual engineering faculty as well as its network institutions. Among these resources include various grants and conferences and workshops for faculty. One such workshop is the Integrating Curriculum with Entrepreneurial-Mindset (ICE) Workshop which was developed by Lawrence Tech and Saint Louis University through support from KEEN. The objective of this workshop was to help engineering faculty understand innovative teaching strategies such as active and collaborative learning (ACL), project/problem based learning (PBL) and entrepreneurially minded learning (EML) and then develop with a content cohort group EML modules that could be integrated into an existing engineering course. This paper will describe four EML/PBL/ACL modules that were developed as a result of this workshop for an Introduction to Materials course. The efficacy of these modules in improving the students learning of the course content was assessed by comparing the final exam scores of the students who participated in these modules with those of a control group. Additionally, the students' perception of their learning was captured through student feedback forms facilitated at the conclusion of three of the four modules. Results from the assessments suggest that the modules did not have a significant impact on the overall learning of the students as measured by their performance on a common, cumulative final exam. Students generally liked the opportunity to apply their knowledge to real world problems and to be able to work in teams. Likert scale assessment data as well as qualitative feedback suggests that the clarity of the module affected the students overall perception of the efficacy of that module.

Introduction

The Kern Entrepreneurship Education Network (KEEN) supported by the Kern Family Foundation was created to "champion the entrepreneurial mindset in undergraduate engineering students."[1] In an effort to achieve this goal, the Kern Family Foundation created a network made up of private engineering schools that are committed to developing the entrepreneurial mindset in their undergraduate engineering students through the network schools' faculty and programs. The mission of KEEN is, "to graduate engineers with an entrepreneurial mindset so they can create personal, economic, and societal value through a lifetime of meaningful work." [2] The entrepreneurial mindset is based on three key components: curiosity, connections and creating value that are coupled with engineering thought and action.[2] Student learning outcomes aligned with curiosity include demonstrating constant curiosity about our changing world and exploring a contrarian view about accepted solutions to problems. Student learning outcomes aligned with connections include integrating information from many sources to gain new insight and assessing and managing risk. Student outcomes aligned with creating value include identifying unexpected opportunities to create extraordinary value and persisting through and learning from failure. These are coupled with student learning outcomes aligned to engineering thought and action that include applying creative thinking to ambiguous problems, applying systems thinking to complex problems, evaluating the technical feasibility and economic drivers of potential solutions and examining the societal and individual needs of the stakeholders.[3]

KEEN empowers its network schools to foster the entrepreneurial mindset in its students by supporting collaboration among faculty, staff and administration from its network schools and through a variety of programs and opportunities offered to individual faculty as well as entire departments and units. Among these opportunities include KEEN network meetings, topical, institutional and small group grants, webinars, blogs, publications and a variety of faculty development opportunities.[2] One example of a very successful project that has been supported by KEEN is the Kern Innovative Teaching program that was developed by KEEN network school, Lawrence Technological University. The overall objective of this program is to transform the educational experience of and develop the entrepreneurial mindset in undergraduate engineering students.[4] A key component to this project is fostering innovative teaching methods in faculty through instructional coaching in a cohort setting. Having achieved great success at their own university, Lawrence Technological University faculty with support from KEEN and in collaboration with Saint Louis University, facilitated a workshop for faculty from other network schools. The objective of the Integrating Curriculum with Entrepreneurial-Mindset (ICE) Workshop was to help engineering faculty understand innovative teaching strategies such as active and collaborative learning (ACL), project/problem based learning (PBL) and entrepreneurially minded learning (EML) and then coach these faculty as they worked with a content cohort group to develop EML modules that could be integrated into an existing engineering course. This five-day workshop occurred in June of 2014 at the University of New Haven. Workshop participants were required to attend the workshop, develop EML learning modules for a course, facilitate these modules during the 2014-2015 academic year and then share these modules through the KEEN portal for other faculty to use. The five day workshop included instruction on innovative teaching strategies, opportunities for faculty to work with their content cohort groups to develop modules, feedback from the workshop facilitators and a variety of other activities.

The Pedagogy of Entrepreneurial Minded Learning

Active learning is any pedagogical technique where the student becomes actively involved in their own learning. Active learning differs from traditional lecture based learning where the student is a passive "receiver of information" from the instructor. There are a variety of forms of active learning such as active collaborative (ACL) and project/problem based learning (PBL). Michael Prince provides a good overview of these techniques in his review article, "Does Active Learning Work? A Review of the Research."[5] Some of the reported benefits of ACL and PBL over passive learning include enhanced critical and creative thinking and a better understanding of course material with a higher level of learning.[5-9] ACL and PBL have been implemented in engineering courses for a number of years. One very common example is the project-based, capstone design courses that are required in nearly all engineering programs. Many of the capstone design courses described in the literature include industry-sponsored or professor driven, real world projects that are multi-disciplinary in nature and focus on the development of a product. These courses represent both ACL and more specifically, PBL. Some of the educational benefits noted with PBL capstone courses include enhanced technical, project management, communication, teamwork and leadership skills, ethical decision making, persistence, creativity, innovation, creative problem solving as well as increased motivation and interest of the students involved in these projects. [11-13] ACL/PBL have also been incorporated into traditional lecture based engineering courses. For example, Jonassen and Khanna discuss redesigning a Material Science course to include seven PBL modules over the course of the semester.[13] Bee and Meyer discuss the incorporation of three team based PBL assignments and one individual design project into a Manufacturing Process engineering course.[9] Although these authors acknowledge some of the challenges and concerns associated with incorporating PBL into a traditional lecture course, they, like many authors feel that these pedagogical practices provided a positive learning experience for their students. [5,13, 14]

Service-learning or community engaged learning is another example of ACL/PBL that has been widely adopted in engineering courses at numerous universities with excellent results. Community engaged learning is the integration of community service projects into the curriculum that also helps to develop fundamental engineering skills through experiential learning. Community engaged learning has been found to have all of the benefits of ACL/PBL but also provide additional educational benefits such as developing racial and cultural sensitivity, enhancing a student's commitment to civic responsibility and increasing the student's awareness of the impact of professional decisions on society and the environment. [12-19]

Entrepreneurial Minded Learning (EML) is a student-centered pedagogy developed by KEEN that employs ACL/PBL with the goal of also developing the entrepreneurial mindset in the students. A key element of EML is to provide students with PBL opportunities to learn how to identify opportunities to create value in a product or process. EML supports the student's acquisition of both content knowledge and creative thinking strategies and skills. EML represents learning that supports the intersection of engineering, business and societal needs. Opportunities are identified in EML through various methods such as gap analysis, societal and economic trends, creative use of new or existing technologies and other such techniques. As such, EML requires the synthesis of knowledge and experience from a variety of resources making it not only active learning but also a form of constructivist learning. [21]

Integration of ACL/PBL/ECL into an Introduction to Materials Course

The University of Dayton (UD) is one of 14 colleges that is part of KEEN. In June of 2014, three UD engineering faculty and the associate director of the UD Ryan C Harris Learning Teaching Center participated in the KEEN sponsored ICE Workshop described above. As previously mentioned, this workshop provided the opportunity for faculty from different schools to interact and collaborate in content area cohorts to develop PBL and EML modules for a course of their choosing. Additionally, workshop participants were introduced to a variety of different ACL techniques through activities and presentations given by the workshop facilitators. Furthermore, workshop participants were provided coaching and feedback on the modules they developed during this workshop from the facilitators as well as other workshop participants. Workshop participants were then required to develop at least one additional module for their course and facilitate these modules during the 2014-2015 academic year.

As a result of this workshop, one of the faculty participants from UD developed, facilitated and assessed four PBL or EML course modules for an Introduction to Materials Course, MEE 312 (Materials). This course is a three semester hour, junior level course that is a requirement for the Bachelors of Mechanical Engineering degree at UD. This course covers basic material science topics such as chemical bonding, crystal structure, diffusion, mechanical testing and material properties, solidification, phase diagrams, heat treatment, metals and alloys, polymers, composites and ceramics. There is an accompanying one credit hour laboratory that covers primarily mechanical testing and material properties, data analysis and technical report writing and is fairly well aligned with the lecture portion of the course. The faculty member that teaches the lecture portion also coordinates the laboratory with assistance from graduate student teaching assistants. This faculty member had been teaching the materials course and associated laboratory for approximately 13 years when she participated in the ICE workshop. During these 13 years, this faculty member had employed some ACL techniques in her classroom and typically assigned at least one project during the course of the semester. These projects varied from semester to semester but were typically either a community engaged learning project relating to eco-efficient cookstoves, failure analysis of some product or a student selected material selection project. Integration of EML and multiple “mini” projects were new to the course.

Four mini-project modules were developed for the Materials course during the summer of 2014. These team based modules were designed to be completed primarily during class time, to be somewhat evenly spaced over the course of a semester and to meet specific learning objectives. Each of the four modules embedded multiple active learning techniques such as jigsaw (expert teams) and think-pair-share within the project. The modules were facilitated in two sections of Materials that were taught by the same instructor during the fall semester of 2014. Each section had approximately 40 students each, a majority of which were junior level mechanical engineering students. All of these students were also enrolled in the laboratory course (eight sections of approximately 10 students each) that was overseen by the instructor but facilitated by teaching assistants. Since the students do a significant amount of technical writing in the laboratory (there are four required reports and one optional), the modules were designed using a worksheet format instead of project report format. This also helped to provide for a more manageable grading workload for the instructor.

Module 1 – Bottleneck:

The first module, entitled Bottleneck was developed to occur on the first two days of class. The course specific learning objectives for this module were that by the end of this module students would be able to: identify the major classes of materials; describe the general characteristics and properties of the major classes of materials; select “the” appropriate material for a particular application. The KEEN learning objectives for this module were that by the end of this module the students would be able to: define problems, opportunities and solutions in terms of value creation and apply creative thinking to ambiguous problems. One additional objective of this module was to introduce students to project and problem based learning and to set the tone for this class as being one that made use of active learning techniques.

As the students walked into the classroom on the first day of class they were randomly assigned to a home team through a lottery type system. The students were asked to sit with their team as indicated by table tents that were placed on the student tables. Students were then presented with the problem statement related to sustainability concerns associated with the use of disposable plastic water bottles. After watching a short video on some of the environmental problems caused by the use of plastic water bottles and discussing what is meant by sustainability, the students were presented with the following problem statement:

> *You are a member of the Flyer Enterprise development team and also the president of the Sustainability Club on campus. You have decided to join forces with SGA to come up with a product that you can sell to incoming first year students that will make money, increase school spirit, raise awareness about campus sustainability initiatives and also provide an item that will authentically support sustainability efforts. After significant conversation among the various entities, you decide to focus on reusable water bottles to replace plastic water bottles. As the engineer, you have been asked to work with other engineering members to research various types of water bottles that are commercially available, can be imprinted with the UD logo, would be "durable," cost effective, safe and have an excellent "coolness factor," then use this information to recommend an option that fe should pursue. You will need to prepare a one page tech sheet that summarizes the "technical aspects" of the material and provides rationale as to why the option your team is recommending should be selected (this need cleaned up a lot)…perhaps there is a D2D trip at stake?*

Students within a team were then assigned to an expert team. As such, an expert team was made up of students from various home teams. The expert teams were assigned to research a specific material class such as polymer, composite, ceramic or alloys. Each member of the expert team was expected to do individual research for homework so that they could share this information with other members of their expert team the following class period. After each member of the expert team shared what they had found out about the material class through individual research, the students were asked to take back what they learned from their expert team to their home team. Members of the home team then discussed what they found and selected a material for the water bottle based on the design requirements presented in the problem statement. Student teams prepared a "Tech Sheet" by hand and then teams were randomly selected to give an elevator pitch to the entire class.

Module 2 - Bubbles Unit 1 Review Activity:
The second module entitled Bubbles was designed to occur at the end of the first unit and to serve as a unit review prior to the first test. This module was facilitated during the fourth week of a sixteen week semester. The course specific learning objectives for this module were that by the end of this module students would be able to: estimate the general properties of a material based on type of bonding; estimate the general properties of a material based on crystal structure; identify the slip system for common crystal structures; and select the more appropriate material for an application by applying concepts of crystallographic imperfections and slip. The KEEN learning objectives for this module were that by the end of this module the students would be

able to: define problems, opportunities and solutions in terms of value creation; apply creative thinking to ambiguous problems; demonstrate resourcefulness and collaborate in a team setting. An additional objective of this module was to help students synthesize knowledge gained from four separate chapters and relate this information in a practical manner to a real world problem.

For this activity, students were allowed to self-select their teams of approximately four students each. Students were given two class periods to finish this module which entailed completing a worksheet and writing a professional e-mail to explain their rationale for choosing a specific material. The module was meant to be on the lighter side in that it involved selecting a material for an outrageous application for a character from the Trailer Park Boys sitcom that appears on Netflix. Students were presented with the following scenario and then asked to narrow down their material choice based on their knowledge of the effect of atomic bonding, crystal structure, and crystallographic defects on the properties relevant to this particular application.

> *The beloved Bubbles from Trailer Park Boys has a few passions: kitties, shopping carts and space. Your team is challenged with helping Bubbles choose a material for his shopping cart, so he can use this cart to carry his kitties to space with him. The material selected for this application:*
>
> - *must be strong in both tension and compression and have adequate fracture toughness (you have seen shopping carts fly across parking lots and hit parked cars…imagine what might happen in space!).*
> - *must be able to withstand temperature variation of – 400 F to 500 F but maintaining dimensional stability is NOT important (but we may not want it to have a Ductile to Brittle Transition Temperature – DBTT).*
> - *must have sufficient stiffness at room temperature to support the weight of the kitties and function as a shopping cart does (pretty sure you have all used a shopping cart at one time or another). According to funtrivia.com, Bubbles has 135 kitties. We will assume that he can fit about 15 kitties in each shopping cart and the average weight of a cat is about 9 lbs. (catchow.com)*
> - *must be a thermal conductor and be nonmagnetic as Bubbles has plans to instrument the shopping cart with some heating elements to keep the kitties warm, but also wants to avoid issues with the magnetic poles of the earth.*
> - *can only be one of the following materials due to availability issues: 1040 steel (unalloyed, plain carbon steel); 1100 aluminum (commercially pure aluminum alloy); 7075 aluminum alloy (Aluminum with Zinc); Concrete (ceramic); Polyethelylene (themoplastic polymer)*

Module 3 - Skateblade:

The third module entitled Skateblade was designed to occur at the beginning of the third unit to support course content related to heat treating. This occurred in the tenth and eleventh week of a sixteen week semester. Additionally, students were simultaneously working on a complimentary heat treating experiment through their laboratory course. The course specific learning objectives for this module were that by the end of this module students would be able to: identify the major types of Stainless Steel; describe martensite and the properties associated with this microconstituent; describe the age hardening process, prescribe the age hardening process for a material using a phase diagram and predict the relative properties. The KEEN learning objectives for this module were that by the end of this module the students would be able to: define problems, opportunities and solutions in terms of value creation; apply creative thinking to ambiguous problems; and collaborate in a team setting.

For this activity, students were allowed to self-select their teams of approximately four students each. Students were given two class periods to finish this module which entailed completing a worksheet. Prior to the project, students were divided into four expert teams to research the following topics: hockey skate blades/sharpening (what are hockey skate blades made from, how they are sharpened), types of stainless steel, heat treatment of steel, age hardening of aluminum. As was done for the first module, each member of the expert team was expected to do individual research for homework so that they could share this information with other members of their expert team the following class period. After each member of the expert team shared what they had found out about their assigned topic through individual research, the students were asked to take back what they learned from their expert team to their home team.

Expanding on the Trailer Park Boys module presented previously, the problem statement for this module was as follows:

> *Help Bubbles figure out why his "friend" had to leave the ice in the middle of a hockey game (after all the Sunnyvale team was beating his "friend's" team)…Could you design the next great Hockey Skate?*

The teams were presented with various data including hardness data, fractographs, chemical analysis data and other information that would help them to determine why the recently sharpened hockey skate had failed during regular use. Specific questions were embedded within the worksheet to help guide the students in using and applying this data to find a solution. Additionally, the students were asked to consider if an alternate material would provide an opportunity for new business in the hockey skate blade industry.

Module 4 – Material Selection:

The fourth module was designed to occur at the end of the semester and to provide an inquiry based learning experience related to both material selection and various types of materials. Since this project was worth 100 points (~ 12% of their grade), they were given significant class time to work on this project. Additionally, students had a library research day where they were required to meet with the instructor at the Library to research their topic. The main goal of this project was to reverse engineer a product component, research the material that component was currently made from and then use the material selection process to research and select alternative materials for that application. Student teams were allowed to define their own goals for that product. For example, they may have chosen to find an alternative material that would make the product more cost effective, environmentally friendly, perform better, etc. A "speed dating" technique was used to assign students to teams. Students were asked to bring in three ideas for products that they would be interested in reverse engineering for this project. Students then lined up in two lines, facing each other and had about a minute to talk to the person across from them. At the conclusion of the minute, the students rotated through the line to speak to a new person. The intent of the "speed dating" was to form teams based on product interest as opposed to letting the students select their own teams or randomly assigning the students to a team. It was believed that this project would have more meaning if students were interested in the product they were researching.

The course specific learning objectives for this module were that by the end of this module students would be able to: translate product design requirements and objectives to specific material properties, use Ashby diagrams as a tool for material selection, use the method of weighted factors as a tool for material selection, access material property data from a variety of reliable web sources, handbooks and text books and properly apply this information for the purpose of material selection, speak knowledgeably about the different material classes. The KEEN learning objectives for this module were that by the end of this module the students would be able to: define problems, opportunities and solutions in terms of value creation; apply creative thinking to ambiguous problems; and collaborate in a team setting.

In an effort to keep the students on track with their project, they were provided with a project Gantt chart at the beginning of the project and a daily agenda at the beginning of each class. The students were also provided with a five to ten minute lecture at the beginning of most class periods to address specific new course content related to the project such as use of Ashby diagrams, etc. The rest of the class time the students worked on the project as the instructor walked from team to team to check on their status and answer questions. To complete their project, the student teams filled out a worksheet that had guiding questions and essay prompts to ensure that they were addressing all of the requirements for the project. The students were provided with a grading rubric at the start of the project and were also required to fill out a project peer review form. The peer review scores impacted their individual project grade by approximately 5%.

Module Assessment

Assessment of the modules was completed in several ways: Likert scale assessment of all but the first module by the students and comparison of scores on a common final exam between the groups of students that were exposed to the modules. It is understood that these methods of assessment are qualitative, but they did provide some meaningful information to the instructor. The Likert scale assessments were developed to measure the students' perception of the efficacy of the modules in addressing the learning outcomes, to determine if the students enjoyed the modules and to seek qualitative feedback so that the modules could be modified and hopefully improved. Time limitations prohibited facilitation of an assessment of the first module. In order to assess if the modules had an overall impact on the students' learning over the course of the semester, the instructor used the same final exam that she had used the previous semester (Spring 2014) for two sections of materials as the final exam for the students enrolled in the semester where the modules were facilitated (Fall 2014). Finally, it was the intention of the instructor to compare teaching evaluations between for the fall of 2014 (made use of modules) with those from the spring of 2014 (did not incorporate learning modules). Unfortunately, however, the university changed the evaluation forms and questions, so this would not have provided a valid comparison. A summary of the responses generated through the Likert scale surveys are provided in Tables 1-3.

Table 1. Feedback obtained from Module 2 – Bubbles

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Score
This activity was a fun way to review	11	36	15	7	1	3.70
This activity helped me to better understand the concepts in this unit	8	47	12	4		3.83
I had sufficient time in class to complete this activity	3	24	27	12	5	3.11
The worksheet helped guide us through the process of applying basic concepts to choose a material in a very clear manner.	27	29	8	7		4.07

Table 2. Feedback obtained from Module 3 – Skateblade

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Score
This activity was a fun way to apply my knowledge of heat treating.	8	29	22	7		3.58
This activity helped me to better understand the concepts in the unit.	5	31	19	11		3.45
I had sufficient time in class to complete this activity.	37	21	7	1		4.42
The worksheet helped guide us through the failure analysis and in considering AA for the application	21	24	18	2	1	3.94

Table 3. Feedback obtained from Module 4 – Materials Selection

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Score
This activity helped me to understand how to translate product design requirements and objectives to specific material properties.	23	37	1	1	0	4.32
This activity exposed me to the use of Ashby diagrams as a tool for material selection.	31	27	3	1	0	4.42
This activity helped me learn how to access material data.	15	43	3	0	1	4.15
This activity helped me to gain a better understanding of material properties, in particular speak knowledgeably about the different material classes.	17	34	10	1	0	4.08
This activity helped me to better understand the process of selecting a material for an application.	25	34	1	0	0	4.40
I had sufficient time in class to complete this activity.	37	21	5	0	0	4.51
The worksheet helped guide us through the material selection process.	36	23	3	0	0	4.53

Students were also asked to answer three questions: What did they like about the activities, what did they like least about the activities and what would they change. Some common responses to these questions were:

What did they like the most about the activities:

- working in teams/group work;
- the real world example/application;
- having time in class to work on the modules;
- for the material selection project, being able to choose their own product;
- the structure and flow of the worksheets.

What did they like least about the activities:

- lack of clarity of some of the questions on the worksheets;
- difficult to find some of the information;
- took away class time that could have been used for other things;
- too simplistic/too difficult.

What would they change:

- make worksheets/modules shorter;
- make them easier/more straight forward;
- clearer instructions/questions on worksheet;
- more in-class learning or guidance on new topics;
- smaller teams (there were a few teams of five)

The format of the common final given during the spring and fall semesters of 2014 was 75 multiple choice questions. The final intended to assess their materials vocabulary, ability to read and interpret phase diagrams and determine Miller indices as well as apply basic concepts. The final was worth 150 points. The final was never returned to the students, they were just given their scores. Average scores are provided in Table 4.

Table 4. Summary of Final Scores out of 150 points

Semester	n	Mean	St. Dev	Median	Mode
Spring 2014 (did not incorporate modules)	78	120.47	10.11	120	120
Fall 2014 (incorporated modules)	82	115.90	15.35	117	124

Summary of Findings:

In the article, *Does Active Learning Work? A Review of the Research*, Prince discusses the difficulty in defining or categorizing the various forms of ACL as well as particular practices used to implement these, facilitating meaningful assessments and interpreting the data and information obtained from these assessments. Test scores have been found to increase slightly or stay the same, but many of these tests do not assess some of the other benefits that are believed to exist with active learning strategies such as practical and professional skill development. Despite this, Prince reports that there is consistent evidence to support that ACL and in particular, PBL, promote positive student attitudes. [5] The findings from this work appear to support what Prince reported. The modules did not have a significant impact on the overall learning of the students as measured by their performance on a common, cumulative final exam. The scores on the finals were within one standard deviation of each other. Additionally, even though the modules were a new addition in the fall of 2014, this instructor had employed multiple active learning strategies in her class, including projects and in class assignments in the past. As such, the insignificant decrease in final scores observed during the semester the modules were facilitated in not indicative of the efficacy or lack of efficacy of these modules.

Students generally liked the opportunity to apply their knowledge to real world problems and to be able to work in teams. Likert scale assessment data as well as qualitative feedback suggests that the clarity of the module affected the students overall perception of the efficacy of that module. For example Modules 2 and 4 appeared to be presented more clearly to the students than Module 3. Module 3 was related to a topic, heat treating and microconstituents in metals that is generally very confusing to students. Furthermore, the nature of this module required the students to synthesize and apply their knowledge in order to solve a very ambiguous problem that they had never seen before. This may have been too much to ask of the students without greater guidance or instruction. The course instructor will use the information obtained from the assessment data to modify the modules accordingly and will also seek to assess the modules at developing the entrepreneurial mindset in the students. This will be equally challenging as assessing the affect that these modules have on the practical and professional skills of the students.

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