Incorporating Active Learning and Sustainable Engineering Concepts into a Required Materials Class

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Abstract

In Baylor University's Mechanical Engineering program we have a required materials engineering course taken during the junior year. This paper describes two sustainable materials engineering modules that were added to this. Active learning techniques were used to introduce these topics. This project focused on using an Entrepreneurial Minded Learning (EML) approach to the materials course.

The first module was about how a material's structure affects its properties. The class examined the materials used in baseball bats. A jigsaw approach was used where students were originally broken into expert groups based on the different materials used for the bats. After they had researched this, they were then broken into project groups that had expert members on each material. Each group then chose what bat to recommend from a performance perspective and from a sustainable perspective. Each group created a report using no more than four Powerpoint slides.

The second module was corrosion. After an introduction to corrosion, student groups were asked to go around campus and photograph something that was corroded. They then created a report on one Powerpoint slide. On the slide they showed their photograph, what form of corrosion was shown, and how could this corrosion have been prevented. This led to a class discussion about sustainable metals. Recyclability of different metals was an integral part of the assignment.

Several different assessment approaches were used. They included self-assessment, peer assessment, and assessment by the professor. By very large majorities the students reported they learned these sustainable materials engineering topics better than the other topics in the course.

Course

This project deals with a required three semester hour junior level course in materials engineering. It is required for all Mechanical Engineering Majors at Baylor University. It is also required for students in the generic Engineering program. Mechanical Engineering students also take a one semester hour materials laboratory course.

This course has been taught as a traditional introduction to Materials Engineering. Over the years the author has used a number of editions of William Callister's *Materials Science and Engineering* [1], now in its Ninth Edition.

The course topics are rather typical for an introductory materials course. The topics covered are shown in Table 1 below.

Table 1 ME 3322 Materials Engineering Baylor University Course topics for years 2014, 2017, 2018 2014 shows what has traditionally been covered 2017 and 2018 show after new topics were added into the course				
Chapter in Callister	Topic	2014 Number of classes	2017 Number of classes	2018 Number of classes
1	Introduction	1.5	1	1
6	Mechanical Properties of Metals	3	3	3
2	Atomic Structure and Interatomic Bonding	1	1	1
18, 19	Electrical and Thermal Properties	2.5	2	2
22	Economic, Environmental, and Societal issues		2.5	3
3, 4, 5	Metallic materials	5.5	5.5	6
7, 8	<ul style="list-style-type: none"> Dislocations and Strengthening Mechanisms Failure 	6.5	5	5
9, 10	<ul style="list-style-type: none"> Phase diagrams Phase transformations 	5.5	5	4.5
11	Metal Alloys	3.5	3	3
17	Corrosion	2.5	3	3
14, 15	Polymeric materials	4.5	5	5
16	Composite Materials	2	2	2
	Exams and review for exams	4	4	3.5
	Number of class days	42	42	42
Topical areas added or changed significantly				
Topical areas reduced in amount of time spent				

In spring 2017 Sustainable Materials was added to the topical list. The author was concerned that adding in this topic at the end of the course could mean it would not be covered in sufficient detail if he got behind in the lecture schedule. Therefore the first module on this topic was covered in the third week of the semester and the second module in the 12th week of the class. This ensured that adequate time was devoted to the topic.

The corrosion section did not require a significant increase in time for this topic. The addition of the sustainability section required that three class periods covering other topics had to be removed.

This required materials class is very crowded. The textbook by Callister includes enough material for six semester hours of topics. The course pace had to be very carefully controlled so that all of the topics can be covered.

Sustainability

Sustainable engineering and sustainable development are relatively new topics for engineers to deal with. The National Society of Professional Engineers (NSPE) states in Section III.1.2.d [2].

“Engineers are encouraged to adhere to the principles of sustainable development in order to protect the environment for future generations.”

While most engineers would agree with this policy, it should be noted that it was not added to the NSPE code until 2006.

The NSPE Code goes on to define sustainable development by the following statement [2]:

"Sustainable development" is the challenge of meeting human needs for natural resources, industrial products, energy, food, transportation, shelter, and effective waste management while conserving and protecting environmental quality and the natural resource base essential for future development.”

The author is indebted to the sustainable engineering program at Villanova University [3] for the following very succinct definition of sustainable development:

- Enough
- For All
- Forever

Sustainable engineering is becoming a more common elective course that many programs offer, including our own. There are some good books that introduce the topic to engineering students. Two good books on this subject are those by Bradely and Striebig [4] and by Allend and Shonard [5]. However, there are not many books aimed at the materials engineering area from a sustainable perspective.

One interesting book by Thompson and Thompson [6] describes sustainable materials manufacturing. This book is a very good introduction to sustainable materials manufacturing. It has very few equations and it would not be very helpful when doing a final design. However, it could be very helpful for an engineer to sort out what manufacturing options would be available. Each process has qualitative ratings on availability, durability, recyclability, and biodegradability. It also has relative comparisons of environmental impact in the areas of energy required to produce it, resources, pollution, and waste.

Michael Ashby has written two very good books that could be used as texts for an entire course on sustainable materials. His 2013 book is *Materials and the Environment* [7]. It introduces students to the environmental issues involved with the resourcing, manufacturing, use, and disposal of materials. In 2016 Michael Ashby published *Materials and Sustainable Development* [8]. This is a broader book and looks at sustainable development as well as the environment. The second half of the book is largely a series of extended case studies.

Sustainable engineering can also serve as a motivator for broadening participation in engineering [9]. When potential students see engineering as a helping profession (and care for the world is part of that), some people will be attracted to engineering who otherwise would not have

considered it. Incorporating sustainable topics can also be related to societal issues [10], which is part of the ABET student outcomes requirements.

Projects in this Course

This paper describes two different modules that were created for this course. Before the first module was done, the author made a presentation about sustainable materials engineering. It was partially based on Callister's text [1] and part on reading material the author learned while on sabbatical in fall 2016. This provided a background to the issues the students would need to consider.

Module One: Baseball bats

The first module dealt with sustainable engineering issues by examining the materials that are used in baseball bats. Bats can be made from wood, aluminum, and composite materials. The following "hook" statement and scenario was provided to the students:

Why are the baseball bats made from very different materials? Using the concepts of sustainable materials engineering we will explore that topic. We are depleting many of the earth's material resources. To provide for a prosperous future we need to understand how to do materials design in a sustainable way. We will examine materials design using baseball bats. Which bats are the best from a sustainability perspective? Which ones are best from a performance perspective?

Table 2 Learning Objectives for Bats Sustainability Module (in parentheses below are the Entrepreneurial Learning [EML] topics that are covered)	
1	For baseball bats, what are the advantages of each of the materials? (Constant curiosity, ambiguous problems)
2	Know how to evaluate materials by performance (information from many sources)
3	Know how to evaluate materials by cost (economic drivers)
4	Know how to evaluate materials by sustainability (economic drivers)
5	Know how to evaluate materials by other means such as tradition (ambiguous problems)

This work follows an active learning approach. It has been well documented that active learning helps students to more effectively learn the material. The author has learned a great deal about this from the paper by Smith, et.al. [11]. Within this broad topical area, we used teams to work on the project. We used a particular type of active learning called Entrepreneurial Minded Learning (EML). This has been well described by Doug Melton [12].

Doug Melton contrasts EML with other active learning strategies in reference [12]. He writes: "EML is an emergent pedagogy that emphasizes discovery, opportunity identification, and value creation... EML builds upon other widely accepted pedagogical methods so the approach can be complementary stacked alongside others." [12] What he means by this is that EML has a different set of goals that various active learning techniques might not have by themselves.

However, this approach can then use some of the other active learning techniques to solve problems. In this project we used several different active learning approaches that have EML goals as their basis.

For the first project on baseball bats we used what is called a jigsaw approach. In this approach we first formed expert teams for the three different materials we are considering (bats made from wood, aluminum, and composite materials). These groups were randomly assigned. Each student submitted one Powepoint slide outlining the material they were assigned. They then looked at its performance as a bat, as well as economic and sustainability issues. They examined whether different markets made choices not based on performance or sustainability.

At the next class the students were self-selected into groups of 6 where there was at least one expert in each group. These groups then created a presentation containing not more than four Powerpoint slides stating what they thought was the best choice and why. They were not required to deal with a specific market (like Major League Baseball or high school baseball), though many groups did discuss a specific market. Since there is market demand for all three types of bats, the next time the course was offered (spring 2018) student groups had to choose the best bat for a specific market.

The learning outcomes were based on the three C's that have been developed by the KEEN program for entrepreneurial engineering education [13].

- “Curiosity
 - In a world of accelerating change, today’s solutions are often obsolete tomorrow. Since discoveries are made by the curious, we must empower our students to investigate a rapidly changing world with an insatiable curiosity.”[13]
- “Connections
 - Discoveries, however, are not enough. Information only yields insight when connected with other information. We must teach our students to habitually pursue knowledge and integrate it with their own discoveries to reveal innovative solutions. “ [13]
- “Creating Value
 - Innovative solutions are most meaningful when they create extraordinary value for others. Therefore, students must be champions of value creation. As educators, we must train students to persistently anticipate and meet the needs of a changing world.” [13]

This first module took three class periods. This appeared reasonable to the author, since students were learning more than just sustainability, but also how different materials perform when subjected to impact loading. In spring 2017 this was taught in two sections, one with 91 students and one with 30 students. The author taught the larger section, but did these modules in both sections. In the larger section there was optional extra credit given for about 1/3 of the class who also did oral presentations.

For a professor to implement this project, there are several things that need to be done before it:

- Introductory lecture about sustainable materials.
- Introduction to metals, polymers, and composites so students have a context in which to interpret the bats performances.

Module Two: Corrosion

The discussion above about active learning and using EML to teach these concepts also applies to this project. The following “hook” statement was used at the start of this module:

How has corrosion hurt your life? Examples of how corrosion can affect your life will be illustrated. Students will then go into the community and find their own examples of how corrosion has damaged something. After an introduction to the fundamental nature of corrosion, we will look at how to design parts so that corrosion can be resisted.

The lecture topics addressed by this module are an introduction to corrosion engineering and assessing how to change the design of a part to resist corrosion. The learning objectives of this module are shown below. They are also based on the EML framework that has been developed by the KEEN network [13].

Table 3 Learning Modules for Corrosion Sustainability Module (in parentheses below are the Entrepreneurial Learning [EML] topics that are covered)	
1	Understand the eight basic forms of corrosion. (curiosity)
2	Understand the significance of corrosion in our society. (curiosity)
3	Investigate examples of corrosion from the students’ daily life.(information from many sources)
4	Learn how to design to resist the form of the corrosion they have found (manage risk, ambiguous problems)

The first objective is accomplished by a lecture based on the corrosion chapter of Callister’s textbook [1]. On this module the students worked either individually or in self-selected groups of up to four students.

After being introduced to corrosion and various ways to resist corrosion, students were given their assignment. They were to go out into their community (on campus or off campus) and photograph an example of a corroded part. They then submitted one Powerpoint slide that showed the corrosion. They assessed which type of corrosion it was and how it could have been designed better to resist corrosion. This module raised several important issues that are broader than just the details of the corrosion chemical reactions.

- How different materials behave differently when exposed to the same corrosion environment
- How to do materials design so that corrosion can be resisted
- Resisting corrosion is a very significant part of materials design

Assessment of the Projects

As part of the final exam, students filled out an anonymous survey about this course. If they filled out the survey and signed their name on the large envelope that was used to collect them they received full credit for a question that was worth 12% of the final exam grade. This method assured the professor of getting feedback from everyone, and by making the survey anonymous, honest answers were provided.

Included in that were specific questions about these two new modules.

Some of the questions that were asked were:

- What is your opinion of adding in materials sustainability topics into the course?
- What did you think of the bats project?
- We had a very different corrosion homework problem. What did you think about going out and photographing examples of corroded parts?
- Compare how much you learned with these two topics compared to the other topics in the course.

Interpretations of some of the open ended questions are shown below.

Table 4			
What is your opinion of adding in materials sustainability topics into the course?			
	Negative response	Neutral response	Positive response
Number of students	6	12	73
Percentage of students	7	13	80

The author considers this a very positive response by the students. Many of the positive responses were very positive. Example positive statements are shown below:

- It was an important topic to discuss
- I liked it, it is the engineering challenge of the future
- I thought it was a great idea. It took engineering beyond just worked out problems. It also helped me understand the importance of engineering and being good stewards.
- I enjoyed the topics and found them practical
- It's good because it's an important topic of materials and it can be eye opening for some.
- I enjoyed it. It might be a field I study in grad school
- I thought it was very interesting, it taught us more about the ethical side of engineering decisions. Especially the green design section.
- I think it is a good idea because as engineers we need to consider how our actions might affect Earth and the generations that come after us.

Some examples of more neutral response are shown below:

- Unopposed, but it didn't help the course
- It was interesting but seems like there is more to the subject
- Good topic, but I felt the assignment was too simple

There were a few negative responses. Some of them are shown below:

- I think it was a poor use of our class time. There are topics in the book that would have been more valuable in my opinion.
- I think there is too much material already, not needed.
- The material is already a lot of course load

The author takes surveys of this nature in most courses. This is the most positive response to a course change he has ever seen.

Table 5 What did you think of the bats project?			
	Negative response	Neutral response	Positive response
Number of students	18	16	57
Percentage of students	20	17	63

There were a number of positive comments. Examples of them are shown below:

- I liked the idea how we made separate individual slides first then came together as a team for the whole Powerpoint
- I liked being able to do my on research independently
- I liked it. It was enjoyable and different
- It was good to have a real work example of sustainability

There were several relatively neutral comments. One of the most interesting was:

- More variety. Have one group do project on bats and another do one on something else.

In the spring 2018 offering of the course the author continued to do the bats project. However, another professor is having some students do a bats project and other students do a project about canoes (since they also can be made from wood, aluminum, and composite materials). Multiple basic projects will decrease the redundancy in the student reports as they examine different applications of these materials.

Among the negative comments, there were two common complaints that were related to implementing this in a large class. Many teams had 6 members, which was large for the scale of this module. Another common complaint was not being able to get the extra credit for doing the oral presentation. In future semesters, everyone will make a presentation so this will no longer be a negative response.

Table 6			
We had a very different corrosion homework problem. What did you think about going out and photographing examples of corroded parts? Was this an effective way to teach about corrosion?			
	Negative response	Neutral response	Positive response
Number of students	13	13	65
Percentage of students	14	14	72

Several students wrote that the project helped conceptually, but they still think they need to do some traditional homework problems involving calculations. This can be changed the next time the course is taught.

One student suggested an interesting change to the assignment. In addition to having some students go out and find something corroded and explain what type of corrosion it is, assign other students to go out and photograph a specific type of corrosion (such as uniform attack, galvanic, stress corrosion, etc.)

Table 7			
Compare how much you learned with these two topics compared to the other topics in the course			
	Less than other topics	About the same as other topics	More than other topics
Number of students	16	23	52
Percentage of students	18	25	57

While it is hard to quantify it appears that many of those who said they learned less on these two topics were also those who were either negative or neutral to adding in these topics to the course. While these numbers are not as positive as in the first question, the results are still very positive. This is consistent with literature that states students learn more from active learning than from more passive lectures.

Conclusions and Recommendations

Bats Module

Students were very positive about the project and reported remembering this material better than what was presented during traditional lectures. Materials economic sustainability was new topic for this course and it appears it can be taught in the three class periods that were used.

It would be better if all students did oral presentations. Even though this was extra credit, some students complained about not getting the chance to do the extra credit. Having 91 students in one section kept us from having the time to let everyone present. With smaller classes (even as large as 40 students) this could be done. In the next time the course is offered (spring 2018) all students will do presentations. Half of them will present on the bats module and half of them will present on the corrosion module.

To allow the students to be more focused in their analysis, in spring 2018 we are having the students each choose a particular market for bats and then analyze what is the best bat for that market.

This project could be expanded into any product that can be made from a variety of different types of materials. In spring 2018 another professor added in canoes made from different materials. We could also do a project using beverage containers. Some beverages can be purchased in cans and others in plastic or glass bottles.

Corrosion Module

Students were very positive about the project and reported remembering this material better than what was presented during traditional lectures. Students saw how corrosion affects their daily lives. Most of the examples were from around the campus area.

We probably need more than the two class periods for this. We should probably require all students to work in teams. There were no oral presentations when this was offered for the first time in spring 2017. The author believes that oral presentations on this would be helpful. This was added into the course during its offering in spring 2018. In spring 2018 all students were required to make presentations. Half of the class presented on the bats project and half the class presented on the corrosion project.

A number of students requested they still get some more traditional homework type problems on corrosion. This will be done in the spring 2018 offering of the course.

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