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Implementation of Materials for Energy Storage Course

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Implementation of Materials for Energy Storage Course

Abstract

A course has been developed in Materials for Energy Storage at Grand Valley State University. This course studies the components of electrochemical cells and the various materials used for these components. The initial offering of the course has been completed. Following the completion of the course, a confidential student survey was administered in order to assess the course and provide feedback for further modifications and improvements. The feedback obtained from the survey instrument assessed the course documents, course organization, learning expectations, specific course components, as well as an assessment of the overall course. Additionally, a survey was used to assess the confidence of the students in their ability to meet the course objectives. These assessments will allow for adjustment of future lesson plans, homework assignments, and projects.

This paper presents an overview of the course, lessons learned, and the feedback obtained from the pilot offering. The plans for further modifications and improvements based on the evaluation of the pilot offering are discussed.

Introduction

As battery manufacturing increases in the United States, there will be an increase in demand for employees with the skills and training necessary to work in this industry. To meet this demand, colleges and universities will need to update existing curricula with alternative energy concepts and skills, as well as develop new curricula, certifications, and degrees[1]. One way that this need for energy curricula is being addressed is through programs in energy storage for stationary and vehicular applications[2-5].

The School of Engineering at Grand Valley State University is preparing students to compete for jobs in the advanced energy storage (AES) field by developing a three-course certificate in advanced energy[6]. To complete this certificate, students may choose three of the following four courses: 1) Electrochemistry, 2) Alternative Energy Systems and Applications, 3) Materials for Energy Storage, and 4) Electric/Hybrid Vehicle Battery Systems. This certificate is available to undergraduate engineering students earning a Bachelor of Science in Engineering (B.S.E.) degree, undergraduate non-engineering students with appropriate pre-requisite knowledge, graduate engineering students earning a Master of Science in Engineering (M.S.E.) degree, as well as non-degree seeking students with appropriate pre-requisite knowledge.

This paper describes the Materials for Energy Storage course that was developed for the advanced energy certificate. Research has shown that the general strategies of questioning, organizing lessons, providing feedback, starting lessons with a review, and ending with closure are relevant across all levels and content areas[7]. These strategies have been incorporated into the structure of the individual class periods as well as organizing the topics to integrate review and feedback prior to progressing to new topic areas. Research has also shown that students tend to take one of three approaches to their courses[8]. There are students that take a surface approach by relying on memorization, students that take a deep approach by asking questions and exploring the limits of applicability of new information, and students that take a strategic approach by taking a surface approach when sufficient and only taking a deep approach when necessary. The assignments, quizzes and examinations in this course were designed to require a deeper approach to understanding the information presented. Students were required to research information on their own and then relate that information to what had been presented by the instructor as well as by other students.

This paper describes the implementation and assessment of the Materials for Energy Storage course. The pilot offering of the course for both undergraduate and graduate students took place during the Fall 2012 semester. Feedback from the students that participated in the pilot offering is presented as well as modifications that will be made for future offerings.

Course Description and Objectives

This course is a study of the materials for advanced energy storage. Topics include electrochemical reactions, anode and cathode materials, electrolyte materials, electrochemical testing of materials, typical responses of common materials, and life testing. In addition, tradeoffs in material performance are discussed. This course focuses on the properties of the different materials used in electrochemical energy storage systems, the benefits and drawbacks of the various materials, and the selection of materials based on a specific application. As there are various active materials within an electrochemical cell, the interaction between the materials for the individual components is also examined. Following the discussion of the individual components, the entire energy storage system is considered, along with the testing and performance of the electrochemical cells and batteries.

At the completion of this course, a student should be able to:

1. Explain the various components of a battery and the electrochemical reactions that occur within a battery;
2. Describe the material characteristics of battery components;
3. Evaluate the tradeoffs in battery material performance;
4. Describe the testing methods and typical responses of common materials.

In addition to the above requirements for all students, students who are receiving graduate credit should also be able to:

5. Apply the concepts of various capacity fade mechanisms to identify methods to increase the service life of a battery. This requires the research of the factors contributing to capacity fade (the components and materials involved) and identification of methods to reduce capacity fade during the initial formation procedure as well as over the life of the battery.

This was a three credit hour course with the pre-requisite that students have successfully completed the Materials Science and Engineering course or the Electronic Materials and Devices course. The textbook used for this course was "Advanced Batteries – Materials Science Aspects" by R.A. Huggins[9], and a second main reference used was "Lithium Batteries: Science and Technology" edited by G.-A. Nazri and G Pistoia[10]. This course was developed by Lindsay

Corneal, Assistant Professor in the School of Engineering at Grand Valley State University, and Suresh Mani, Associate Director of the Michigan Alternative and Renewable Energy Center (MAREC). The pilot offering of this course was taught by Lindsay Corneal.

This course was designed to teach for a deep understanding by students as described by Eggen & Kauchak[7] and Burden & Byrd[11] through: identifying clear learning objectives; selecting teaching strategies that most effectively help students achieve the objectives; providing examples and representations that help students acquire a deep understanding of the topics; guiding students as they construct their understanding of the topics; and continually monitoring students for evidence of learning.

Organization of the Course

The pilot offering of the Materials for Energy Storage course was 15 weeks long. It was offered as a night class one night per week for three hours. There were 11 senior undergraduate (B.S.E.) students and five graduate (M.S.E.) students that participated in the pilot offering.

During the first week of the course, there was a review of chemistry and electrical concepts. There were review materials provided for the students to study on the chemistry and electrical topics as well as materials science and engineering, which were pre-requisites for enrollment in the course. There were also in-class activities where the students built some simple electrochemical cells using common materials for the electrodes and electrolytes. They measured the voltage and current for each system and observed how the values compared when the cells were arranged in series and in parallel. At the beginning of the second week's class, a quiz was given on the review materials before covering a more in-depth introduction to batteries and various battery systems and chemistries.

Over the next couple of weeks, the topics of battery manufacturing processes, electrochemical reactions, reaction mechanisms, important practical parameters, and binary and ternary phase diagrams for electrode materials were covered. After these topics were covered, a quiz was given to assess the students' understanding of these topics before beginning the discussion of electrode and electrolyte materials.

In the following few weeks, the materials, properties, and performance of cathode, electrode, and electrolyte materials, as well as the solid electrolyte interphase (SEI) were discussed. The students were required to research and give presentations on various electrode materials as well as read research articles and answer questions on various electrolyte topics. There was a quiz given on the topics of cathodes, anodes, electrolytes, and SEI.

The topics of electrochemical testing and typical responses of common materials, material characterization techniques, life testing and capacity fade mechanisms, recent advances in battery technology, and other advanced energy storage methods were covered over the next three weeks. The students receiving graduate credit were required to review technical publications on the topic of capacity fade and write a report on the factors that contribute to capacity fade and methods to reduce capacity fade during the initial formation procedure as well as over the life of a battery. All students were also required to complete a homework assignment to identify other (non-electrochemical cell) energy storage methods and their applications.

During the twelfth week of the semester, the students attended a tour of a local battery manufacturing facility. They were able to observe the various manufacturing processes and see how the various elements come together to form the electrochemical cell. They were also able to observe the balancing and assembly of battery packs from the individual cells.

The following week, the applications of battery technologies for transportation, portable electronics, space, and biomedical uses were discussed. This topic tied in the various battery systems and why certain battery chemistries and systems are appropriate for certain applications.

In the final class period, the students made presentations on the topics they studied for the term paper they wrote for the semester. For their term paper and final presentation, each student selected a single energy storage system and reviewed technical research papers to identify the active materials within the system, the applications, and the current research being done on the particular energy storage system. There was a comprehensive final examination given during a separate examination period.

Assessment of the Pilot Course

During the final class of the pilot offering, the students provided feedback in the form of a confidential survey. The feedback allowed the students to respond on a Likert scale within the range of agreement with the statements in the survey instrument from “not at all” to “extremely”. One exception to the rating scale was the last question, which asked the respondents to compare the workload for the course to other courses. This question was rated on a scale between “very light” to “very heavy”. The survey questions and the response ratings are provided in Table 1.

Although there were a total of 16 students in the course, there were only 14 students that chose to participate in the survey. The students that did choose to participate in the survey read and signed a consent form. To ensure confidentiality, there was no personally identifiable information collected on the survey forms.

From the feedback on the questions that assessed the course documents (questions 1 and 2), the greatest number of respondents indicated that they “mostly” agreed with the statements. Questions 3 and 4 assessed the course organization. Here again, the greatest number of respondents indicated that they “mostly” agreed with the statements. The fifth question assessed the clarity of the learning expectations in the course. Although the majority of the respondents indicated that they “mostly” agreed with the statement in this question it had a slightly lower rating than the previous questions.

The next five questions (questions 6-10) assessed specific course components. For question 6, which assessed whether the lectures improved their understanding of the course material, the majority of the respondents indicated that they “extremely” agreed with the statement in this question. Questions 7, 8, and 9 assessed the classroom discussions, group work, and assignments, projects, tests, and/or papers, respectively. For these questions, the majority of the respondents indicated that they "mostly" agreed with the statements in these questions. For question 10, which assessed the course textbooks and readings, the greatest number of respondents indicating that they "moderately" agreed with the statement in the question. The responses to this question ranged from one respondent that agreed "not at all" to one respondent that agreed "extremely".

Table 1. Student ratings ($\bar{X} \pm 1\ SE$) for the End-of-Semester Course Assessment survey

Question	Rating (n = 14)
1. The course outline was clear.	4.1 ± 0.2
2. Information about tests, assignments, or projects was clear.	4.3 ± 0.2
3. The course topics were arranged in a logical manner.	4.3 ± 0.2
4. The course instructor moved through course concepts at a comfortable pace.	4.0 ± 0.2*
5. Learning expectations for students in the course were clear.	3.9 ± 0.2
6. Course lectures improved my understanding of the course material.	4.6 ± 0.1
7. Classroom discussions improved my understanding of the course material.	3.9 ± 0.2
8. Course group work improved my understanding of the course material.	3.8 ± 0.2
9. Course assignments, projects, tests, and/or papers highlighted important concepts of the course.	4.1 ± 0.2
10. The course textbook and/or readings contributed to my learning of the subject matter.	3.1 ± 0.3
11. The course provided information on important issues in the subject matter.	4.3 ± 0.2
12. Compared to other courses, the workload for this course was: very light, light, average, heavy, very heavy.	2.9 ± 0.1

Possible responses for questions 1-11 were: 1 = not at all, 2 = somewhat, 3= moderately, 4 = mostly, 5 = extremely. Possible responses for question 12 were: 1 = very light, 2 = light, 3 = average, 4 = heavy, 5 = very heavy
*n = 13

The final two questions of the survey (questions 11 and 12) assessed the overall course. Question 11 assessed whether the respondents felt that the course provided information on important issues in the subject matter. The majority of the respondents indicated that they "mostly" agreed with the statement in this question. Question 12 asked the respondents to rate the workload for the course in comparison to other courses. For this question, the possible responses ranged from "very light" to "very heavy". The majority of the respondents indicated that the workload was "average" compared to other courses.

In addition to the End-of-Semester Course Assessment survey a second survey instrument was used as an assessment of the students' confidence in meeting the course objectives. The feedback for this survey also allowed the students to respond on a Likert scale within the range of confidence in their ability to meet the course objectives from "not at all" to "extremely". The survey questions based on the course objectives and the response ratings are provided in Table 2.

Table 2. Student ratings ($\bar{X} \pm 1\ SE$) for the Assessment of Student Confidence in Meeting Course Objectives survey

Question	Rating (n = 13)
Please indicate your confidence in your ability to:	
1. Explain the various components of a battery and the electrochemical reactions that occur within a battery.	4.2 ± 0.2
2. Describe the material characteristics of battery components.	3.5 ± 0.2
3. Evaluate the tradeoffs in material performance.	3.5 ± 0.2*
4. Describe the testing methods and typical responses of common materials.	3.0 ± 0.3
5. Explain capacity fade mechanisms and identify methods to increase the service life of a battery.	3.4 ± 0.4*

Possible responses were: 1 = not at all, 2 = somewhat, 3= moderately, 4 = mostly, 5 = extremely.
*n = 12

Although there were 14 students that chose to participate in the End-of-Semester Course Assessment survey, only 13 students completed the Assessment of Student Confidence in Meeting Course Objectives survey.

From the feedback obtained with this survey, the highest rating was obtained for question 1, which assessed the confidence of the respondents in their ability to explain the components of the battery and the electrochemical reactions within the battery. The greatest number of respondents was equal between those that felt "mostly" confident and "extremely" confident. These were some of the earlier topics covered in the course and were built on through the remainder of the course.

The next highest ratings were obtained for questions 2 and 3 which assessed the confidence of the respondents in their ability to describe the material characteristics of battery components and evaluate the tradeoffs in material performance, respectively. To meet these objectives, the students had to have a more in-depth understanding of the battery systems. For question 2, the majority indicated that they were "mostly" confident in their ability to meet this objective. For question 3, the greatest number of respondents was equal between those that felt "moderately" confident and "mostly" confident.

Question 4, which assessed the confidence of the respondents in their ability to describe testing methods and typical responses of common materials, had the lowest rating of the questions on the confidence survey. For this question, the greatest number of respondents was equal between those that felt “somewhat” and “mostly” confident.

Question 5 assessed the confidence of the respondents in their ability to explain capacity fade mechanisms and identify methods to increase the service life of a battery. The greatest number of respondents (four) indicated that they were “moderately” confident; however, there were three respondents that indicated that they were “extremely” confident. This split in the responses could be due to the fact that the five graduate students in the course were required to complete an extra assignment on the topic of capacity fade, which would likely have increased their confidence in this topic. Because no personally identifiable information was gathered with the survey though, it is not possible to determine if the higher confidence ratings were given by the graduate students.

In addition to the self-assessment of the student confidence in meeting the course objectives, an analysis of the results of the students’ achievement on the various assignments, quizzes, and examinations was also performed. The objective to explain the various components of a battery and the electrochemical reactions that occur within a battery was assessed with a quiz. The students rated this as the topic that they felt the greatest amount of confidence by the end of the semester and from the results of the quiz that immediately followed the coverage of the topic, the average grade obtained was a B.

The objectives to describe the material characteristics of battery components and to evaluate tradeoffs in material performance were assessed with a quiz for the former and with a homework assignment for the latter objective. Although the students were moderately to mostly confident in their abilities to meet both of these objectives, the results of the quiz was an average grade of C, while the results of the homework assignment was an average grade of A. In general, the students performed better on the homework assignments than they did on in-class quizzes. The format of the homework assignments was such that it required them to research topics and interpret the information they found by making comparisons and drawing conclusions. Although this required a deeper approach than portions of the quiz that required them to be able to apply equations and describe components of the electrochemical cells, the students tended to perform better when given the opportunity to delve into each topic with greater depth without the time constraints of an in-class quiz.

The topics that covered the objectives to describe the testing methods and typical responses of common materials as well as to apply the concepts of capacity fade mechanisms to identify methods to increase the service life of a battery were covered near the end of the semester. The students receiving graduate credit for the course had a homework assignment specific to the topic of capacity fade mechanisms. The average grade for this assignment was a B+, which is why it is believed that it was the graduate students’ responses that were on the higher end of the confidence ratings in the ability to meet this objective. The objective with the lowest confidence rating was in the ability to describe testing methods and typical responses of common materials. As this topic was covered near the end of the semester, there was less time for the students to digest the information and this topic was assessed only on the final exam rather than with a quiz or homework assignment. Having an additional opportunity to review the topic with a quiz or homework assignment would enable the students to better meet this objective and improve their confidence in this area.

Updates for Future Offerings of the Materials for Energy Storage Course

From the results of the End-of-Semester Course Assessment survey, one area where additional focus should be given for future offerings is in ensuring that the learning expectations for the students is clear. Providing a review sheet or study guide prior to quizzes and examinations would help with this clarification, in addition to the feedback that the students received from their graded homework assignments.

The rating for question 7, pertaining to the classroom discussions, was one of the lower ratings. There were a few respondents that provided additional comments for this question, indicating that they felt that studying material and preparing a presentation for class was a good way to learn. There was a respondent, however, that indicated that one student tended to interject during the classes and that the respondent was not always able to understand the interjections. This type of discussion and interjections were encouraged by the instructor, because there were often very good comments and insights made by the students in the class. For future offerings of the course, there should continue to be requirements for the students to prepare and give presentations and open discussion and interjections will be encouraged. To improve the understanding by other students, however, the discussions should be summarized periodically and feedback about any comments made should be solicited from the other members of the class.

Question 8, pertaining to group work, was also one of the lower rated questions. There were only two respondents, however, that provided additional comments regarding this question. One indicated that the in-class activities the first day of class were quite effective in helping improve the understanding of the course material. Another respondent indicated that the thinking and passing ideas around was an effective learning tool (this student is referring to some think-pair-share activities that were performed during the classes). Without any other comments, it is unclear whether the lower ratings were due to the students wanting more group activities or that that they felt that the group work that was performed was ineffective. Based on the limited comments that were provided, for future course offerings, in-class activities, small group discussions and passing around of ideas will be continued and will be included in more of the topics covered. This should be assessed again in future offerings.

The lowest rating received was for question 10, which assessed the course textbook and readings. Some comments provided indicated that the textbook could be difficult to read and it was quite expensive. One respondent suggested basing more readings on relevant journal articles. Another respondent indicated that the lecture notes/handouts that were provided were very helpful, as some of the other readings were more difficult to digest. These concerns were also noted by the instructor of the course. Although the textbooks used were relevant to the course material, they were not ideal. It is difficult to find a textbook for the specific topic of this course. The ones chosen best covered the topics of the course. For future offerings, the one required textbook ("Advanced Batteries – Materials Science Aspects" by R.A. Huggins[9]) will continue to be used while other textbook options will be continually evaluated for use in the course.

The rating of the assessment of the workload for the course indicated that the workload was slightly lighter than the average workload for other courses. One reason for this could be that the majority of the undergraduate students participating in the course were on a mandatory co-op work placement during the semester that this course was offered. Because the course was offered in the evenings, this allowed them to work for their co-op employer during the days and take this class one evening a week. Therefore, the majority of the undergraduate students were only taking this one course during the semester, making the workload quite manageable. The graduate students participating in the class tended to only be taking two classes during the semester, again making the workload quite manageable. This also indicates that it would be possible to add an additional assignment or two without overwhelming the students.

The Assessment of Student Confidence in Meeting Course Objectives survey was administered during the final class of the semester, which was one week prior to the final examination. Therefore, the respondents had completed all of the classes but had not necessarily completed a thorough review prior to the final examination. The students' confidence should be assessed again in future offerings of the course through the administering of a survey during the final examination period, after the students have completed the course and thoroughly reviewed the topics in preparation for the final examination.

The high level of confidence in the respondents' ability to explain the various components of the battery and the electrochemical reactions indicate that the organization of the course, with these topics being introduced early and built on throughout the semester, was quite effective. A similar course organization will be used in future offerings.

Although there were homework assignments and quizzes that required the students to describe the material characteristics and evaluate the tradeoffs in material performance, the respondents were only "moderately" to "mostly" confident in these areas. Additional time should be spent focusing on these topics. Students prepared presentations on various materials used for the components of electrochemical cells. Following these presentations, an additional discussion should be completed to summarize the various materials presented and compare the performance and tradeoffs between the various materials. Also, specific data should be required to be presented for the various materials so that there is consistent information being presented that can more easily be compared and contrasted between materials. Without specifying the required material characteristics, each student identified certain features and characteristics for the material that they presented but did not always mention characteristics that might not have been as noteworthy.

Because the lowest confidence was identified in the respondents' ability to describe testing methods and typical responses of common materials, these topics should be covered in greater depth during future offerings of the course. One method to obtain a greater depth of coverage would be to provide some journal articles that describe the testing of various battery materials which can be reviewed by the students in preparation for the class and then discussed in small groups during the class.

To ensure that all students in the class (including both undergraduate and graduate students) are confident in their ability to apply the concepts of capacity fade mechanisms to identify methods to increase the service life of a battery, in future offerings of the course, the graduate students that complete the additional assignment on the topic of capacity fade should be matched with undergraduate students in small groups to present the information. The graduate students would discuss the information that they gathered from a thorough review of technical publications. This would build the confidence of the graduate students and would also provide exposure of the topics to the undergraduate students in addition to the exposure that they obtain from the lecture on the topic. This additional exposure should also increase the confidence of the undergraduate students in this topic.

Conclusions

There was considerable positive feedback received through surveys of the students that participated in the course. Areas were identified where some changes should be made for future offerings of this course. Clarification of learning expectations could be accomplished by providing review sheets or study guides prior to quizzes and examinations. There will continue to be requirements for the students to prepare and give presentations and participation in open discussion will be encouraged. To improve the understanding by all students, however, the discussions should be summarized periodically and feedback about any comments made should be solicited from the other members of the class. In-class activities, small group discussions and passing around of ideas will be continued in future offerings of the course and will be included in more of the topics covered. For future offerings, the one required textbook will continue to be used while other textbook options will also be evaluated for use in the course. Future offerings of the course should continue to be assessed to identify the effectiveness of these updates to the course and identify other items that must be addressed.

The students' confidence should also be assessed again in future offerings of the course through the administering of a survey during the final examination period, after the students have completed the course and thoroughly reviewed the topics in preparation for the final examination. Following the in-class presentations made by the students, an additional discussion should be completed to summarize the various materials presented and compare the performances and the tradeoffs between the various materials. Also, specific data should be required to be presented for the various materials so that there is consistent information being presented that can more easily be compared and contrasted between materials. Journal articles that describe the testing of various battery materials should be provided to the students in preparation for the class on this topic and then discussed in small groups during the class to increase the students' confidence in this topic. As the graduate students were only required to complete an assignment on capacity fade mechanisms, they should be placed in small groups with undergraduate students to discuss the information that they gathered from a thorough review of technical publications. This would build the confidence of the graduate students and would also provide additional exposure of the topics to the undergraduate students.

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