Experiences Combining Technology, Assessment, and Feedback to Improve Student Learning in Mechanical Engineering Thermal Science Courses

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Abstract - This paper describes techniques that have been developed to combine technology, assessment and feedback in two different required undergraduate courses in mechanical engineering. In both thermodynamics and fluid mechanics, technology was incorporated in a variety of ways. For example, the daily learning objectives and class syllabi were provided to the students via the web, which allowed for the inclusion of just-in-time responsive content for the courses. Assessment of student learning was incorporated into all aspects of the course, for example, hand-in assignments were made for reading assignments. Feedback was provided on these reading assignments. Summative feedback was provided through exams and homework. The exams included conventional problems in addition to concept questions. Technology, assessment, and feedback were combined through the use of a personal response system, and in-class assessment questions. The in-class assessment questions included concept questions and questions that allowed students to assess their understanding of specific skills needed in thermodynamics and fluid mechanics.

A post course survey method was used in evaluating the effectiveness of these techniques on student study habits, student learning, and long-term retention of the material, in addition to issues about class size. In general, students found these methods to be very helpful to their learning, allowing them to form a somewhat robust conceptual framework for the course material.

Index Terms – Technology, Assessment, Feedback, Learning

INTRODUCTION

In 2002-2003, we formed 2 different focus groups of students. One of the groups was comprised of six students that had recently completed our undergraduate course in fluid mechanics. The other group contained eight students that had recently completed our undergraduate course in heat transfer. The students were selected after an application process, and included students that had received grades in each of these courses ranging from BC to A. We paid the students an hourly stipend to participate in the focus groups. These groups were established specifically so that we could investigate student learning and student understanding in two upper level courses in mechanical engineering that we teach, and that are considered to be foundational for a mechanical engineer that will be working or studying in the energy area.

The first activity that we had the students engage in was to take the textbook that they had used in the class, review it, and give us a list of what was important and what they thought the understood well, and what was unimportant and not understood well. This was, at best, only partially illuminating. While the list they generated was not that same as a list the faculty generated, the student list did not really provide detailed information related to the level of understanding of any of the students in heat transfer or fluid mechanics. This result made it clear that we needed to get the students to dig deeper if they were to reveal to us what they truly had learned in fluid mechanics and heat transfer.

After some deliberation, our next step was to videotape the students in discussion of specific topics or questions that we provided. For example, we asked the students to discuss Fourier’s Law, or to describe, in detail, the definition of a fluid. These discussions were typically one and a half or two hours in length. Sometimes the discussions focused on a single idea from fluid mechanics or heat transfer, other times the discussion covered a number of topics. For some of the discussions, we were present; for others, the students were by themselves.

We then viewed the videotapes and made observations on student understanding of specific topics, and used these observations to probe deeper with the students in later videotaping sessions.

What we observed from the videotaped discussions of the students can be summarized as follows: 1) Students are not confident with their understanding of the material. Very often, the group conversation would circle around the issue being discussed, with no one in the group having sufficient confidence in their understanding to be able to provide an explanation that resolved the apparent confusion of the group. 2) Much of the knowledge displayed appeared as unconnected information. This was evident in that a complete, conclusive understanding of the issue under consideration was a rarity, the vocabulary used by the students was normally imprecise.
and there was little demonstration of an understanding of how the subjects were interconnected. 3) Students have misunderstandings, as well as misconceptions. We assumed that we would encounter misconceptions, which we observed. We were often surprised, however, by misunderstandings that were exhibited. For example, during a discussion on the different modes of heat transfer, one of the students expressed dismay that there were three different modes of heat transfer, and wondered why three different modes were necessary. It was also interesting that none of the other students attempted to explain why three modes might be needed. 4) Students exhibited frustration with their performance in discussing the issues. It was clear that they felt that they should be able to have a reasonable technical discussion from what had been covered in their coursework, and were frustrated with their lack of understanding. 5) Students indicated that they often don’t understand material but can solve complicated problems. 6) Students have misunderstandings that faculty could not possibly anticipate. For example, students talked about how energy might reside only on the surface of a solid steel sphere, similar to charge. We did not anticipate this. And finally 7) There was no lack of interest in understanding material. At the end of several sessions, students waited, on their own time, for us to provide explanations of what they had been discussing.

Finally, at the conclusion of the focus group work, we asked the students to describe how they thought faculty viewed the students. Students responded that faculty routinely overestimated the student grasp of concepts, and that the faculty often missed student confusion on “simple” aspects. In addition, it was felt that faculty emphasize coverage, and focus on developing skills, rather than understanding.

As a result of the focus group work with the students, work that we and others had been doing in development of concept inventories [1-5], work on peer instruction by Mazur [6] and Darmofal [7], among others, and study of the seven principles of effective instructors [8], combined with a move to larger class sizes in our thermal science courses, we decided to develop a new methodology for use in Mechanical Engineering Thermal Science courses was needed. We have been developing, implementing, assessing and refining the methodology since the summer of 2003.

As a result of this activity and the work of others, the instructional method we are evolving is a combination of a number of different pieces. For example, we think there are some very important opportunities for improvements in student learning from the use of technology. We also believe that specific instruction in concepts is required if students are expected to learn concepts. Assessment can be combined with a course in a natural way if students are actively involved in assessment of their own learning. And feedback should be frequent and timely for feedback to assist the students.

In the following we discuss how we have incorporated each of these different parts into instruction in these courses.

**USE OF TECHNOLOGY**

Our interest in the use of technology may be different from what is normally envisioned. For example, use of technology very often refers to distance learning or web-based instruction. In this case, our courses remain conventional in terms of a direct, face-to-face regularly scheduled interaction between the instructor and students. The sole purpose of our integration of technology is to enhance the learning of the students, given the possible enhancements technology might provide and current constraints such as increasing class size.

The first practice that was technology enabled was the incorporation of just-in-time syllabus and daily learning objectives. In other words, in a course centered on student learning, it is essential to have the capability to continuously change the syllabus and daily learning objectives. The use of the web and a course homepage allows the syllabus to change for every class period, and the learning objectives for each class period can be developed and defined for the students as part of the regular routine of preparing for the class. The enhancement that technology provides involves both presentation and practicality: If one was confined to providing paper copies, it is unlikely that either the resources or time are available to provide updated syllabi with learning objectives for every student every class. In addition, the learning objectives descriptions by the end of the course can become quite lengthy, and again it is not reasonable to assume that all of this information would be continuously provided to the students via paper updates.

One additional note on how the just-in-time methodology proceeds is appropriate here. At the beginning of the course, the syllabus the student sees first includes all of the class meeting dates, and dates for exams, and one or two word descriptions of what will content will likely be covered during the course, and the approximate time during the semester that topic might be covered. The assignments for the first week are also shown. As the semester progresses, the syllabus/learning objectives document is updated, typically prior to every class meeting. At times, if the assessments being made in-class or via homework indicated that students needed additional opportunities for learning on a particular topic, the syllabus/learning objectives documents are revised, extending the amount of time spent on a particular topic. Revision also is common because with this method, topics are not fixed to dates on the calendar and what material is actually covered in any particular class meeting evolves naturally.

Technology was also used to do in-class simulations and virtual experiments, and more generally, to access the vast amount of teaching material and other information available via the web. Neither of these courses have laboratories. While it is likely that laboratories would greatly enhance student learning, economic constraints and the fact that the curriculum is already overloaded with credits means that laboratories are unlikely to be added. The intent here was to use web-based information to assist students in visualizing, and experimenting with, the physics and engineering of a particular topic. Often the web-based presentation provided opportunities for student learning that could not be duplicated in a student laboratory. For example, it unlikely to be possible to demonstrate aerodynamically induced flutter on a flight surface. However NASA [9] and others provide numerous...
different mpegs of real flight controls undergoing flutter. Also, to encourage student exploration, all of the web-based information was provided directly to the students through a set of organized links that they could access at their leisure.

Technology also enhanced the ability to perform in-class assessments of student learning, primarily through the use of a personal response system, in this case the CPS system provided by eInstruction [10]. While in-class assessments can be performed without using a personal response system, as suggested by Mazur [6], use of the technology provides two distinct advantages. First, students are assured of anonymity in their initial response, and second, the automatic recording of student responses allows instant summarization for the students and convenient archiving for the instructor.

The in-class assessment or personal response system can be used for another activity that can be particularly helpful. Used as a polling device, it can be used to assess other information that might be of use to the instructors, students, and perhaps the department. For example, it can be used to conduct rapid surveys on student attitudes and learning methods that can be helpful in improving not only the course, but also the program.

**USE OF ASSESSMENT**

Assessment of student learning was incorporated into all aspects of the course. At the beginning of the course, concept inventories were administered to provide a measure of student understanding of the subject before the student had been through the course. At the end of the course, the concept inventories were administered again. This provided the instructors with an assessment of how much the students had learned as a result of participating in the course [3].

As has been mentioned, a personal response system was used to enable in-class self-assessment. Our experience suggests that self-assessment is one of the most powerful methods we have found to actively engage students in learning. While we have no specific data to support this, it is not surprising that students are motivated to check their own understanding, particularly if this is done without having an effect on their grade. In addition, peer-to-peer interactions are also a natural follow on to in-class self-assessment, because in preparing their answer to the self-assessment, students prepare themselves to discuss the issue with their peers.

As is typical, homework was collected and graded. In addition to the normal problems that were assigned, students were given reading assignments. This was motivated by the focus group work with the students illustrating how little reading of the text was actually occurring. The reading assignments involved making notes, drawing figures and diagrams, and writing out the mathematics as if the students were preparing to teach the material to someone else. In order to make this something that students would engage in with care, however, it was necessary to make the reading assignments short, typically 4-6 pages.

Finally, exams were also part of the assessment process. In other words, exams were not just for evaluation of the student grade. If the students did poorly on an exam, an option to redo the exam was provided that most of the students took advantage of.

**USE OF FEEDBACK**

For formative feedback, feedback was provided on the reading assignments. In addition students provided written answers to questions on concepts, and again feedback was provided. In-class assessment questions with peer instruction were included as part the activities of each class. The in-class assessment questions included concept questions and questions that provided feedback to the students on their understanding of specific skills and concepts needed in thermodynamics and fluid mechanics.

Summative feedback was provided through exams and homework. The exams included conventional problems in addition to concept questions.

**STUDENT RESPONSE TO OVERALL METHOD**

To learn more about the student response to the overall method, we asked two educational research professionals (Sandy Courter and Mary McEniry) to assist us in development of an appropriate assessment. As a result, an seven-question survey was developed and administered to the students. Our objective was not to determine if students liked...
the methods, but to determine if the methods had, in fact, had an effect on student study habits and student learning methods. We were also interested in their opinion on the effect of the methods on their conceptual understanding in the courses.

Shown in Figure 1 is the first question in the survey, examples of student responses to each of the questions, and a summary of the student responses. In each case we have included several student comments. Students comments included were chosen because they were representative of the response of the class. The summary provided are our attempt to capture the overall sense of the comments made by the more than 100 students that participated in the survey.

Our focus group work suggested that students will often work on homework as the primary means of studying for a course. We hoped that the methods used here would change and extend the studying habits of the students. As shown in Figure 1, some students did tell us that they had changed their study habits to include careful reading of the text and writing notes from the text.

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2. Briefly describe the methods that have helped you learn in this course. Comment on how this course has, if at all, affected your usual learning methods. That is, are your learning methods similar or different than those you use for other courses?

- I learned most when reading assignments were assigned.
- The learning method is different, compared to my other classes; I found that studying is more interesting and thorough.
- One method that helped me was having to hand in notes on sections we were to read. It forced me to read and try to understand material as I read it. See the problem, break it down, and derive the equations used to solve it. In my eyes this it crucial for an engineer instead of finding an equation and using it. I don’t have to do that in any other courses.
- Reading the text, trying to understand the concept questions and relating those things to problem solving.
- Concept questions during class helped me to learn a lot. As long as I knew the concept I could derive an equation without having to memorize it and I always knew how to apply it.
- The methods of learning the basic concepts and making sure everyone has an understanding of the basic concepts has affected me very much. Learning methods are much different.
- Classroom interaction kept my attention. I have now tried to pay more attention during lectures. Different.

Summary:
Many students found the most effective learning methods were taking notes on the required readings from the text, and concept questions in lecture.

The second question was designed to provide information related to which of the different methods were helpful, and if the course had an effect on their learning methods. As shown in Fig. 2, many students indicated specific methods that they found useful, or described how their learning methods had changed.

The focus group activities indicated that students seemed to have a surface understanding of the subjects, and no real sense of the whole of the subject. The results shown in Fig. 3 indicate that students think that they did develop an understanding for the “fluid mechanics model.” They also indicated that their understanding was basic.
4. After taking this course, do you feel that you now have a conceptual framework in fluid mechanics? If so, how would you best describe it?

- Yes I look at problems with a more fundamental approach then just looking for numbers and equations.
- Yes, I have a conceptual framework in fluid mechanics. It definitely has some holes and topics I don’t understand. But the foundation is there.
- I would say that I have a good enough grasp to explain basic fluid phenomena.
- Yes, I feel like I know the governing equations and principles and can apply the concepts to any problem.
- Yes. I believe I know how to apply a control volume and control surface. Look at the mass flow and decide if it is a laminar or turbulent flow.
- Yes. This class has helped me to see a larger conceptual framework for all of engineering. There are few basic laws that must be upheld in all cases and many approximate models that give a good picture of a system.

Summary: All of the students feel they have some sort of a conceptual framework in fluid mechanics; most of the students describe the conceptual framework they have as “basic.”

5. After taking this course, how would you describe concept-based instruction? In your own words, describe how this method has made a difference, if at all, in your learning?

- Concept based instruction entails focusing on concepts rather than working problems in specific applications. Because of this approach, I was able to achieve a better grasp of fluids in general, which is a more valuable trait of a graduating engineer.
- Concept based instruction is essentially instruction with continuous feedback from students. It has helped me have an understanding of the material instead of regurgitating information.
- I really like it. I think that it is a great teaching tool. Before this class I think I spent far too much time doing homework problems and not attempting to learn the concepts behind the problems. To this end, if I got a problem that was different than the homework, I would not know how to solve it.

Summary: Some of the students indicated a deep understanding of the objectives of the method.

6. Comment on how, if at all, this course will help you remember the concepts for use in other classes and on-the-job. How do you think your retention of the concepts from this course will compare to your retention of concepts in other courses that you have taken?

- It will definitely help in the ways that I approach real life problems-mostly how to visualize them.
- I will remember much more from this class because it fundamentally makes sense to me. The material was all fully understandable and was made interesting by relating it to real life problems.
- I think the practical applications and videos that were shown to demonstrate the concepts will make me remember the material conceptually.
- Repetition was a good thing. Plus, most of the concepts build on one another.

Summary: Most of the students thought they would remember more from this course than in others due to the reinforcement of the concepts. Some thought they would lose problem solving skills, but retain the concepts from fluid mechanics.
to do in-class simulations and virtual experiments. Multimedia demonstrations found on the web were routinely incorporated into the class.

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<tr>
<th>7. Did the class size affect your learning? If so, briefly describe how.</th>
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<tbody>
<tr>
<td>- No (12)</td>
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<tr>
<td>- Yes, the intimate setting of about 35 students really aided in my learning experience. The smaller setting allowed for a better environment to ask questions and make sure everyone understood the material.</td>
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<tr>
<td>- The smaller class size was helpful because it allowed for questions and a more personal learning experience.</td>
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<tr>
<td>- Yes. It felt like a smaller class than it probably was and that helped me learn better.</td>
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**Summary:** A little over half of those surveyed did not feel that class size affected their learning. The other half believed the “smaller” class size benefited their learning experience; the (smaller) class size allowed for good discussion, and made it much easier to ask questions.

Assessment of student learning was incorporated into all aspects of the course. For formative feedback, reading assignments were made and feedback was provided, students provided written answers to questions on concepts, and again feedback was provided, and in-class assessment questions with peer instruction were included as part the activities of each class. Summative feedback was provided through exams and homework. The exams included conventional problems in addition to concept questions.

Technology, assessment, and feedback were combined through the use of a personal response system, and in-class assessment questions. The in-class assessment questions included concept questions and questions that allowed students to assess their understanding of specific skills needed in thermodynamics and fluid mechanics.

The effectiveness of these techniques in improving student understanding was assessed using post-course student focus groups and student surveys. In general students found these methods to be very helpful to their learning, allowing them to form a conceptual framework for the course that they thought they would not have formed with more traditional instructional methods.

**ACKNOWLEDGMENT**

This work was supported by the Engineering Education Program of the National Science Foundation under Award Number EEC-9802942.

**REFERENCES**


