

Application of Transformative Learning Theory in Engineering Education

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Abstract - The goal of this work-in-progress is to improve student engagement and learning in courses that form the core of a discipline. Such gateway courses represent critical milestones in a student's academic career and have a strong influence on his or her attitude and future success in engineering. We contend that students who struggle in gateway courses do so because they are having difficulty with conceptual transformation, and this project aims to facilitate this change through the ideas advocated within Transformative Learning Theory. The essential elements of this project include the integration of information technologies, provision of rapid feedback to students and instructor, conceptual learning, and peer-assisted learning. This paper summarizes the theory, provides details of the project design, and describes preliminary results.

Index Terms – Conceptual learning, Peer-assisted learning, Rapid feedback, Tablet PC, Transformative Learning Theory

INTRODUCTION

Many students who leave engineering after the first year do so because of poor performance in so-called 'gateway courses.' These courses are foundational in that future courses build on the concepts learned in them, and therefore poor performance often discourages students from continuing to pursue engineering as a career track. Furthermore, poor performance early on in a student's career can have a lasting, deleterious effect on his or her attitude toward engineering studies and engineering, even if the student persists in the major.

We contend that students who struggle in gateway courses do so not because of their innate abilities or intellect, but that they are struggling with conceptual transformation. Students come to engineering programs with firmly held beliefs about the physical world. Often, these beliefs are derived from personal experiences or from previous schooling, in which an oversimplified definition or approach was taken. When they encounter new knowledge or concepts in engineering courses, they struggle to fit these into the existing schema of their understanding. When a new concept does not fit neatly or logically or, even worse, when it runs counter to this schema, they often resort to rote memorization of rules or develop misconceptions. Evans and Hestenes [1] give an example of this: "...students entering an introductory physics course know that if a large truck and a small car collide head on, they would rather be in the large truck. When discussing the concept of forces, they turn this tightly held knowledge into a

misconception that the small car applies a smaller force than the large truck in the collision." What students need in such cases is transformative learning to confront and resolve such misconceptions and to accommodate the new concepts. This paper presents a discussion of Transformative Learning Theory [2-6], how it may be applied in engineering education, and finally a plan for implementation and preliminary results.

BACKGROUND

Recently, there has been much interest among engineering educators to teach students a deeper, conceptual understanding of the content in our courses, to diagnose misconceptions about the critical topics, and to go beyond mere transmission of facts, rules and formulas [e.g., 1, 7-13]. This trend results from the realization that many of our students have a thin knowledge of the critical concepts and that this knowledge is neither durable nor transferable [14]. As Perkins [15] points out, "Learning facts can be a crucial backdrop to learning for understanding, but learning facts is not learning for understanding." If we want to help students to truly understand material in our courses, we need to help students make conceptual transformations to either accommodate new concepts or to correct misconceptions.

Transformative Learning Theory provides a framework for overcoming this challenge. Mezirow [2] describes it as "... the process of becoming critically aware of how and why our assumptions have come to constrain the way we perceive, understand, and feel about our world; changing these structures of habitual expectation to make possible a more inclusive, discriminating, and integrating perspective; and finally, making choices or otherwise acting upon these new understandings." It is in contrast to what students are most comfortable with, which is assimilative learning in which new information is acquired that merely supplements and integrates with their existing knowledge. In most engineering courses, both types of learning are present and necessary.

According to the theory, transformative learning results from several required events and processes. McGonigal [16] nicely summarizes these as: "(1) an activating event that exposes the limitations of a student's current knowledge/approach; (2) opportunities for the student to identify and articulate the underlying assumptions in the student's current knowledge/approach; (3) critical self-reflection as the student considers where these underlying assumptions came from, how these assumptions influenced or limited understanding; (4) critical discourse with other

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students and the instructor as the group examines alternative ideas and approaches; and (5) opportunities to test and apply new perspectives.” Once these occur, a student is likely to revise his or her schema of understanding and adopt a new paradigm and be successful at applying it [5].

PROJECT DESIGN AND IMPLEMENTATION

We plan to implement this project in a sophomore/junior-level thermodynamics course. This course is prerequisite to many upper-level mechanical and chemical engineering courses, most of which have a heavy reliance on application of concepts from it. Unfortunately, it is also well known to be a course in which students are “weeded out” of engineering. Thermodynamics is challenging for a variety of reasons, including the rapid pace of the materials presented and the challenging concepts that continually build upon one another in increasing complexity. We believe that lack of conceptual understanding, especially early on in the course, leads to misconceptions and reliance on rote memorization as the course progresses. Thus, it is crucial to diagnose these problems and correct them as they occur. The students’ grasp of the concepts involved are just as valuable as their performance on calculation-based problems, especially given the need for the learned concepts to be durable and transferable to future courses.

This project will be implemented in two sections of thermodynamics, both taught by the author. A crossover design of experiment [17] will be employed and is intended to eliminate confounding factors that cannot be controlled for using multiple-regression analysis. To bring about the required events and processes for transformative learning, the in-class portion of the course will make use of a fleet of Tablet PC computers, with which the students will take notes and respond to questions and short assignments (described later).

In a crossover design, one of two study groups – course sections in this case – is randomly chosen to receive instruction with the Tablet PC’s (the ‘treatment’ group) while the other group will act as the ‘control’ for a fixed period of time (or ‘treatment period’). For the next treatment period, the two sections simply swap the roles of treatment and control, and this continues for the duration of the course. In this manner, each student acts as his or her own control in the data analysis to eliminate the non-correctible confounders. Other than the deployment or not of the Tablet PC’s, the course content and pace will be identical between the two sections.

The performance of the cohorts will be compared to each other through a diagnostic quiz administered at the end of each treatment period, which may last from one to two weeks. The quiz will focus on the concept covered during the just-completed treatment period. In order to control for the effects of other variables (or covariates) that might affect the response variable, analysis of covariance will be employed [17]. The covariates will be based on our past experience and intuition, and will include, for example, performance in prerequisite courses, the section the student is in, the treatment period (since one topic of a period may be inherently more difficult than another), and the student himself or herself. We

emphasize that the quizzes will focus on the students’ conceptual understanding of each topic rather than algorithmic calculation or procedural skill.

The software we will use with the Tablet PC’s will be Classroom Presenter (CP), a freeware developed at the University of Washington [18]. CP allows the professor to distribute his classroom presentation or notes electronically across the students’ Tablet PC’s. The professor writes on his Tablet PC, just as he would onto a whiteboard or transparency. The students can see and capture the professor’s writing in real time and are able to further annotate the same presentation. CP has a built-in polling functionality, which will allow the professor to pose multiple-choice questions to the students along with the correct answer and several distracters (incorrect solutions). The students, working in pairs, would discuss the question, and then submit an individual answer to the professor’s computer. After all responses are received, the tallied responses would be displayed as a histogram to provide feedback to the students. In addition to polling, CP permits students to submit free-form answers (e.g., drawings, equations, multi-step solutions) to the professor, which is displayed as a series of thumbnail images that he could scan through quickly. He would then select specific ones to display for the class in order to clarify misunderstandings or correct misconceptions. Such free-form answers, we believe, will be extremely powerful for diagnosing and correcting misconceptions among the students. The social benefit of this will be to demonstrate to the students, anonymously, that they are not necessarily the only one in class who misunderstands the material being presented.

In-class instruction will be structured such that the professor begins class by distributing the Tablet PC’s to each student. Each student will be paired with another to form a peer team. The professor would present a new topic or concept for no more than 10 minutes using traditional lecture, demonstration, or sample problem solution. Thereafter, he would pose a concept question (explained later) through the Tablet PC’s to gauge the students’ understanding. If the tallied responses or the submitted solutions show that a high percentage of students do not understand the concept (low percentage of correct answer), the professor would further explain the topic since most students did not grasp the concept enough to help each other in this case. If the responses show that a reasonable percent of students understands the concept (a distribution of answers with a substantial number having the correct answer), the professor would direct the peer teams to explain the answer to each other (similar to the active learning techniques known as TAPPS [19] or Think-Pair-Share [20]). Thereafter, the students will be asked to either respond again to the same question or a different question on the same concept may be posed. The final scenario occurs when student responses show a high percentage of the correct answer, indicating that they understand the concept. In this case, the professor would simply move on to the next topic.

In summary, the necessary elements for transformative learning can be accommodated in our project design. Specifically, an activating event can occur (through concept

quizzing), opportunities for students to identify his or her current state of knowledge, critical self-reflection and discourse with other students are all present, and opportunities to test and apply new perspectives are available. The other critical components of our in-class project design are providing rapid feedback to students and the professor, conceptual learning, and peer-assisted learning. We will describe each of these three components in more detail to show how they are integral to this study and how they support transformative learning.

Rapid Feedback. Providing feedback to students of their current level of understanding is critical for effective learning. It is also important for the professor. This feedback is typically accomplished with homework sets, quizzes and tests. These feedback tools, however, suffer the faults of being too slow, too late, and too tedious (for the professor) to apply frequently. For students, 'rapid feedback' improves understanding better than feedback via homework, quizzes, and exams [21, 22]. We demonstrated in previous studies that rapid feedback improves student learning and knowledge durability [23-25].

Freeman and McKenzie [26] discuss several issues that inhibit better student learning in higher education. For students, there is a lack of individual feedback on learning; few opportunities for dialogue to improve learning; and a feeling that the subject is impersonal. From the faculty members' perspective, the difficulties lie in knowing what students are really learning, providing individualized feedback, addressing students' specific misconceptions, attending to diverse learning styles, and engaging students. Bransford et al. [14] note that "[l]earners are most successful if they are mindful of themselves as learners and thinkers. In order for learners to gain insight into their learning and their understanding, frequent feedback is critical: Students need to monitor their learning and actively evaluate their strategies and their current levels of understanding."

Conceptual Learning. Bransford et al. [14] state that "[l]earning must be guided by generalized principles (concepts) that are widely applicable. Knowledge learned at the level of rote memorization of rules and algorithms inhibit transfer and limit durability." In this project, we aim to teach courses at a conceptual level without sacrificing the calculation-based skills or knowledge. We will do this, as we mentioned earlier, through the use of concept questioning in class. Specifically, we intend to adapt Concepts Inventories for this purpose.

Concepts Inventory (CI) was originally devised in the physics education community for diagnosing student misconceptions in Newtonian mechanics [27]. The physics CI, called Force Concepts Inventory (FCI), contains 30 multiple-choice questions that test students' understanding of concepts. All of the questions in the FCI require little or no calculation to arrive at the solution, which minimizes the students' tendency to use rules and formulas. Furthermore, incorrect solutions, referred to as 'distracters,' are devised so that application of common misconceptions will lead to their selection. Concepts Inventories in thermodynamics have been

or are being developed by various groups [8, 9] and we will adapt these for use as the diagnostic quizzes in this study.

Peer-Assisted Learning. In this study, we will provide rapid feedback to students and faculty using a fleet of Tablet PC's in a peer-assisted learning environment. An extensive body of literature exists in educational research on the benefits and effectiveness of peer-assisted learning [22, 26]. We define peer-assisted learning as students learning from and with each other in pairs, with the roles of 'teacher' and 'learner' being either undefined or shifted often during the experience. Students appear to learn a great deal by explaining their ideas to others and by participating in activities in which they can learn from their peers [28]. They deepen their own understanding by organizing their arguments, working collaboratively with others, giving and receiving feedback, and evaluating their own learning. It forces them to take responsibility for their learning. It is not a substitute for teaching and activities designed and conducted by the professor, but can be an important complement to it. Peer-assisted learning places emphasis on the learning process, including the emotional support that learners offer each other, as much as the learning task itself.

PRELIMINARY RESULTS

In Fall 2006 the author taught a section of Statics and recruited six student volunteers to use the technologies during the course. This work was limited by the fact that only two Tablet PC's were available, so the students used them in two-week shifts.

Figure 1 below shows typical uses of CP and Tablet PC's in the classroom. A page from a student's notes in CP is shown in Fig. 1(a). As can be seen, CP allows the instructor to provide detailed notes to students so that they do not need to transcribe what the instructor writes on a board or says. This student used the highlighting feature to emphasize some points of importance about the topic at hand. CP can also be used to give students the opportunity to put to practice a concept or skill just learned, as shown in Fig. 1(b). In this case, the students were asked to write the equilibrium equations governing a particular truss problem. The student's work, which was done first, is shown on the right side of Fig. 1(b) and the instructor's solutions (in the box) were provided to the students thereafter.

KD

Trusses are one of the most useful structures in engineering, and are found in roofs of buildings, antenna towers, aircraft frames and bridges of all sizes

Before we start to analyze trusses, we need to discuss four assumptions or idealizations about trusses:

- Truss members are connected at their ends only
- Truss members are connected by frictionless pins
- Trusses are loaded (forces are present) only at their joints
- The weights of each truss member may be neglected

In problems involving truss structures, we are always trying to find (1) the reaction forces at the supports, and (2) the forces (tensile and compressive) that are internal to the truss members

(a)

Fall 2005

Example: [6-23] The lawn mower weighs 35 lb and has a center of gravity at G. Determine (a) the magnitude of the force P required to push the mower at a constant velocity, and (b) the forces exerted on the front and rear wheels by the inclined surface.

FIGURE 2
EXAMPLE OF A FREE-FORM SOLUTION SUBMITTED BY A STUDENT DURING CLASS.

The usefulness of this technology is in its ability to elicit student misconceptions in a just-in-time fashion and to provide the opportunity to discuss and correct them. Figures 3 and 4 show two examples of this. In Fig. 3, the student's critical misconception is in representing the internal force exerted by another frame member (part CF). With CP, when students submit their free-form solution to the instructor, he can quickly scan through the collection of images and select certain ones to display publicly (and anonymously). This provides the opportunity for all students to see common mistakes and misconceptions and to correct them as they are formed.

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(b)

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FIGURE 1
TWO TYPICAL PAGES FROM A STUDENT'S CP NOTES SHOWING THE INFORMATION PROVIDED TO THE STUDENT AND HIS ANNOTATIONS.

As alluded to earlier, some concept problems are difficult to pose as multiple-choice problems and Fig. 2 shows an example. Here the student is asked to draw the free-body diagram of the forces acting on the body, the lawn mower. It is obvious that the possible combinations of mistakes or misconceptions that a student may commit would render this problem nearly impossible to be posed as a multiple-choice question, but it is readily handled if the student can submit a free-form solution, as he did in this example. (There is in fact an error in the student's work; the forces labeled " F_N " are incorrect.)

FIGURE 3
EXAMPLE OF A MISCONCEPTION BY A STUDENT. THE STUDENT'S ORIGINAL WORK IS SHOWN IN BLACK INK WITH THE MISTAKE BEING THE HORIZONTAL FORCE LABELED " F_x " ON PART ABC. THE CORRECT FORCE REPRESENTATION AT THAT LOCATION IS SHOWN WITHIN THE CIRCLE AND LABELED " F_{cf} ".

Figure 4 is a good demonstration of the importance of rapid feedback for correcting misconceptions. In the first part (Fig. 4(a)) of the problem involving the determination of the

forces acting at the various connection points in the frame, the student correctly draws a free-body diagram of frame member ABE. In the second part (Fig. 4(b)), however, the student commits a common mistake and incorrectly shows the directions of the forces (labeled “ B_x ” and “ B_y ”) on a connecting member (BCD). If this misconception were not identified and corrected immediately, it is possible to continue through this problem with the mistakes in the free-body diagram and arrive at plausible solutions. The student would have no idea that he had made a critical conceptual error until he received the usual feedback much later through a homework set or quiz. With CP, he was able to identify the error immediately, as he highlighted with a circle and notes in Fig. 4(b).

SUMMARY

The project design described creates an environment in which transformative learning can occur, as demonstrated by preliminary results from a different course. It provides an activating event as well as for opportunities for the student to identify his or her current knowledge and to critically self-reflect (through conceptual questioning). It further allows for critical discourse with other students (through peer-assisted learning) and the instructor. Finally, it affords students the chance to test and apply new perspectives after a new paradigm is adopted (through more conceptual questioning). After full implementation of this project, we expect to find that students will gain a deeper conceptual understanding of thermodynamics concepts and will be more satisfied with the learning experience as a result.

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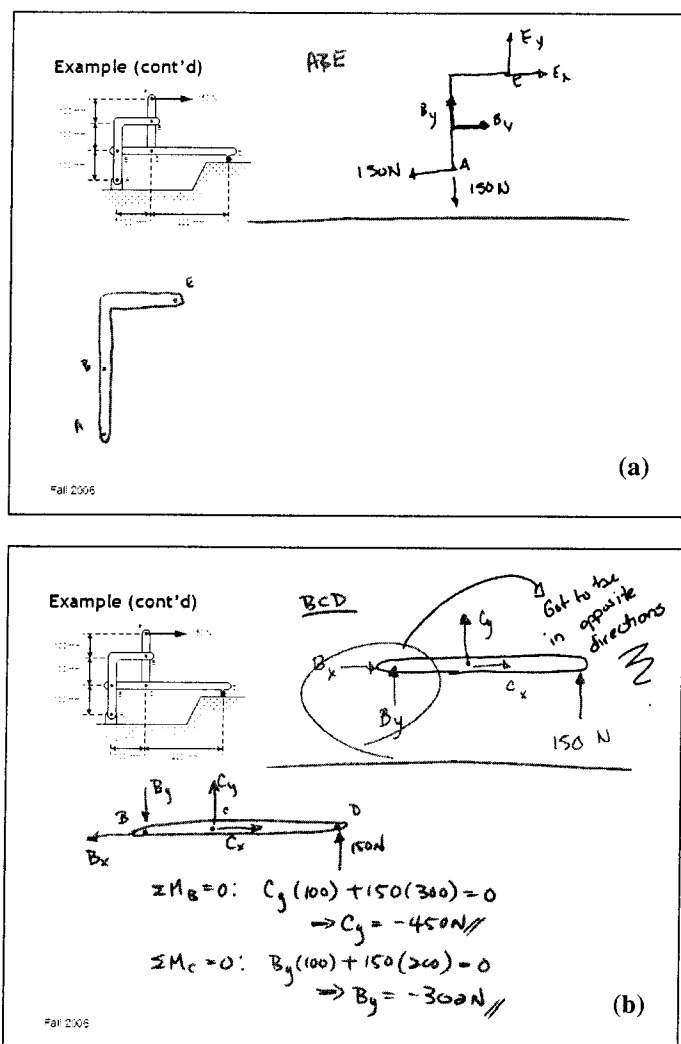


FIGURE 4

TWO CONSECUTIVE PAGES FROM A STUDENT'S NOTEBOOK IN CP. THE INSTRUCTOR'S WORK (DONE AFTER THE STUDENT COMPLETED HIS WORK) IS SHOWN IN THE BOX ON FIG. 4(B).

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