Session 2566

Integrated Design, Experimentation, Analysis and Life Skills (IDEALS) Courses

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Abstract

A number of teaching/learning reforms are underway in the College of Engineering at Penn State to enhance student learning with a special focus on providing opportunities for students to apply and integrate their knowledge and skills, and to develop lifelong learning skills. All of the reforms use problem-based, collaborative learning approaches to achieve the simultaneous development of professional and technical skills by requiring students to practice these skills in an integrated fashion, within a realistic context. In the reform effort underway in Mechanical Engineering, courses are being developed in an IDEALS format, where IDEALS refers to Integrated Design, Experimentation, Analysis, and Life Skills. Here "life skills" are professional skills such as communication skills, team skills, and lifelong learning. To date, two different approaches to the IDEALS courses have been piloted, a one-credit course, which links to core courses the students are taking concurrently, and an IDEALS version of a three-credit required course. In this paper, the two pilot courses are described along with student evaluations of the courses and faculty assessment of the effectiveness of the approaches.

Introduction

Industry, academia, professional societies, and the federal government have been calling for enhancement of engineering education to properly prepare students for success in the highly competitive, global marketplace. The NSF report, Shaping the Future,[1] points out that "too many graduates go out into the workplace ill-prepared to solve real problems in a cooperative way, lacking the skills and motivation to continue learning." The NRC report, Engineering Education: Designing an Adaptive System,[2] asks many questions about engineering education including: "Does engineering education integrate the fundamentals well enough with design and experimentation?" The ABET EC2000 criteria emphasize the importance of <u>both</u> technical and professional skills through the outcomes common to all engineering programs, with six of eleven of these outcomes relating to professional skills such as communication skills, team skills, and lifelong learning.

One very difficult challenge facing engineering programs today is how to meet the escalating expectations for engineering education without increasing credit hours or burdening students

Proceedings of the 2001 American Society for Engineering Education Annual Conference & Exposition

with unrealistic workloads. Currently five departments in the College of Engineering at Penn State are instituting reforms in teaching/learning methods and curricula to address this challenge. All of the reforms use problem-based, collaborative learning approaches to achieve the simultaneous development of professional and technical skills by requiring students to practice these skills in an integrated fashion, within a realistic context. In the reform effort underway in Mechanical Engineering, courses are being developed in an "IDEALS" format, where IDEALS refers to Integrated Design, Experimentation, Analysis, and Life Skills with "life skills" indicating professional skills such as communication, team skills, and lifelong learning. The ultimate goal of the reform effort is to have students take at least one such course each semester during the junior year and first semester of the senior year; the second semester of the senior year is when most students take the industry-driven capstone course, which already uses the IDEALS approach.

The core of the IDEALS courses is collaborative, problem-based learning; however, critical to the approach are explicit objectives related to communication, team skills, consideration of and application of engineering fundamentals in design, experimentation, or computer modeling. In the design of the courses, the various assignments were specifically chosen to draw upon prior knowledge and to have students use it along with their newly acquired knowledge in working on meaningful tasks, following Novak's recommendations for promoting meaningful learning.[3] In this case, problem-based learning was used to provide the meaningful tasks. It was also hoped that the problem-based learning would motivate the students to learn meaningfully, and the tasks were designed so that rote learning would not be sufficient to accomplish them. Teams were an integral part of the approach used not only to provide an opportunity to allow students to develop their team skills, but also to provide a vehicle for discussion and "constructing" of knowledge, consistent with the constructivist approach to learning.[4]

The literature on lifelong learning indicates that learning occurs in both formal and informal modes.[5] Formal learning occurs in traditional classes where learning is typically directed by instructor; whereas informal learning often occurs through the process of inquiry that is required to complete a challenging task. The literature on self-directed learning shows that giving students opportunities to engage in this type of learning, along with appropriate support, will improve their attitudes and skills in this mode of learning.[6] Because lifelong learning was an explicit focus in the learning objectives in the two courses, the students were required to engage in self-directed learning, i.e., they had to decide what they needed or wanted to know, choose appropriate resources, and set about learning.

Two different approaches to the IDEALS courses have been piloted, a one-credit course which links to required courses that students are taking concurrently, and an IDEALS version of a three-credit core course, which is a second, required course in Thermodynamics (Thermodynamics II). In the one-credit course, students were presented with the objectives related to integration and lifelong learning, and they were asked to decide what type of project they would like to undertake to achieve these objectives. The three-credit course taught in the IDEALS format emphasized integration of writing and lifelong learning as well as the creation of engineering models of actual energy systems using computers, *ala* the "mindtools" approach described by Jonassen.[7] In this paper, the two pilot courses are described along with student evaluations of the courses and faculty assessment of the effectiveness of the approaches.

IDEALS "Linking" Class

Two sections of the one-credit class were offered in spring semester of 1999. Students were recruited into the classes by advertising in required junior level courses to which the IDEALS class was intended to link. In this case, the majority of the students were enrolled in machine design, vibrations, heat transfer, and an instrumentation lab. The two sections had a total of 28 students, 12 in one and 16 in the other. Each section met once per week for 3 hours and the course was designed so that most of the work was accomplished in class; this was an intentional aspect of the design to avoid overloading already busy students.

At the beginning of the semester, students were presented with the learning objectives for the course, which were:

- Students will apply theoretical knowledge from core Mechanical Engineering courses to an engineering system.
- Students will demonstrate effective professional skills, including communication, team, and lifelong learning, in conducting their team project, in design reports, and presentations.

The students were asked to decide what type of project they would like to undertake to achieve these objectives. After some deliberation and negotiation between the two sections, the students decided to use radio-controlled cars as the engineering system that they would analyze and re-design. With the radio-controlled cars as the focus for the class, the IDEALS instructional approach integrated design, experimentation, analysis, and life skills in the following ways:

- **D**esign: students dissected the original vehicles and re-designed them to maximize performance in the race events.
- **E**xperimentation: students designed and conducted experiments on subsystems.
- **A**nalysis: students performed analysis of subsystems in order to optimize them.
- **L**ife **S**kills: students applied their team, written and oral communication, self-directed learning, and time management skills in conducting their work for the class.

After the project was selected, each class was divided into teams around four major subsystems of the radio-controlled cars: chassis, suspension, drivetrain, and powerplant. Each team was charged with developing a comprehensive engineering understanding of their subsystem, performing an analysis of the characteristics of their subsystem, designing and conducting experiments to verify their analysis, and finally proposing modifications to the car to optimize their chances of winning the race against the other section. Each class was organized so that the major portion of the time was spent working in teams, but the last portion of the class time was used for team status reports to assess progress and to ensure that the teams were communicating with each other. Early in the semester each class was charged with preparing time lines for their work with key deliverables.

The students were provided with two identical cars – one fully assembled and one to be assembled. The assembled car was dissected. Each team set about studying its subsystem and devising experiments to determine key characteristics. For example, the powerplant team decided that they needed to know the torque and power characteristics of their engine. This need for information motivated them to build a small friction brake; they started the design process for the brake by going to the library to do research on the topic. The chassis team needed to determine the moment of inertia of the chassis, and they designed an experimental rig that suspended the chassis and allowed it to swing to estimate its moment of inertia. The students learned a good deal about the challenges of designing and conducting experiments, including the frustration that is sometimes involved.

At about mid-semester, the teams were asked to prepare for a design review at which they would present the results of their analyses and experiments. They were also asked to make recommendations for the modifications of the car to optimize it based upon their analyses and measurements. A Penn State alumnus, with thirty years of experience, participated in the design reviews. At the beginning of the design review, the instructor and the alumnus discussed the objectives of a design review and its importance in industry. The rate of progress in the analyses and experiments was a little slower than anticipated, so the students had only one week to prepare for the design review. As a result, their ideas were largely in the formative stage, and the design review turned into a brainstorming session. However, it proved to be very fruitful in giving the students experience in presenting and defending their ideas.

In the remainder of the semester, each team set about redesigning and reconstructing cars for the race. The race had three events: flat course speed, hill-climb, and obstacle course. The speed event was timed with a start at zero velocity with the distance reached in the allowed time measured for three heats. In the incline event the vehicle had to carry another vehicle up the incline, and the incline was increased incrementally until the vehicle could no longer climb. The obstacle had three segments: equally spaced bumps, randomly spaced ½" PVC pipe, and an "S" style obstacle course. All three courses were available prior to race day for testing and practice.

Each team was permitted to modify two cars for the races, so that they had to make trade-offs in their design choices. For the speed event, changes were made to increase the maximum speed; they included changing the gear ratio, minimizing weight by removing the front suspension, and locking the friction clutch. The last modification was ultimately detrimental as it caused the tires to slip. In this event, traction and the skill of the drivers proved to be the determining factors. For the hill-climb event, the goal was to maximize traction. Design modifications included changing tires and using a traction enhancing compound, redistributing weight to maximize weight over drive wheels, and the use of an electronic speed controller for improved traction management. Both teams approached the obstacle course as their "compromise" event and simply used the better of their two vehicles for it. In the end, driver skill was the determining factor in the obstacle course.

At mid-semester and the end of the semester, the students were asked to reflect on the major objectives of the class and offer their thoughts on how well they were achieved. In the end of semester evaluation, the students were asked to reflect on whether the courses objectives had been met and what aspect of the course was most valuable to them. With respect to the objective of application of theoretical knowledge from core courses to an engineering system, the students were overwhelmingly positive in evaluating the course; 25 of the 26 who responded felt that this objective had been met. All of the students who responded to the question on professional skills felt that they had been improved in the course; skills most commonly noted by the students were team and communication skills. In response to the question of what was most valuable aspect of the course, the students mentioned working in a team most frequently (11/26); the second most common response was applying theoretical concepts to an actual system (7/26). Other things mentioned by the students were the importance of communication in engineering, project management skills, the role of cost in design, and the challenges of doing experiments.

From the instructor's perspective, the course largely achieved the goals of having the students apply theoretical concepts and methods that were being learned in their core courses, and in improving professional skills. The student teams demonstrated the ability to apply their knowledge from other courses to their subsystem during the design reviews. They also demonstrated an enhanced appreciation for the difficulty of designing and conducting experiments, and interpreting the results. There was a noticeable improvement in their team skills and presentation skills throughout the course. One aspect that will need to be enhanced in future offerings of this course is the direct application of the results from the analysis and measurements made during the first half of the course to the design modifications that were made in the cars. But, overall, the students achieved the major course objectives.

IDEALS Version of Thermodynamics II

The IDEALS pilot of Thermodynamics II, the second required course in Thermodynamics, had 30 students, most of whom were juniors. To some extent, the students in the class were "self-selected" because they could have transferred to other sections of Thermodynamics II that were offered in a more traditional format. In terms of the IDEALS approach, this course emphasized the following:

- **E**xperimentation: students compared results of thermodynamic engine models to experimental data from a single-cylinder, spark ignition engine.
- **A**nalysis: students built theoretical models of energy systems, including a numerical model of a spark-ignition engine.
- **L**ife **S**kills: students applied their team, communication, and self-directed learning skills.

At the beginning of the course, the students were presented with the following major learning objectives, which made explicit the IDEALS aspects of the class:

- Students will apply the laws of thermodynamics to model energy systems, both analytically and numerically, including refrigerators, heat pumps, gas turbines, and internal combustion engines.
- Students will engage in self-directed learning in preparing their term paper.
- Students will demonstrate effective team and communication skills through in-class discussion, active problem solving in teams, and their term paper.

The motivation for the new format of the class and the selection of the learning objectives were discussed with the students on the first day of class.

As designed, the class focused on modeling, especially the process of constructing engineering models of actual energy systems and the role of approximations in that process. A major homework project was the construction and solution of a numerical model of a spark ignition engine cycle, which required the students to draw upon previous knowledge and computer skills. Self-directed learning and written communication were combined into a term paper, described in more detail later in this section. Both the modeling assignment and the course paper were done in teams. In-class problem solving in small groups was also used to promote meaningful learning and to give further experience in working with others.

In order to emphasize the modeling of energy systems, the content of the class was reorganized from its traditional flow following the textbook to focus on different types of energy systems. All new content was introduced on a "just-in-time" basis to model and analyze a given energy system. Combustion and chemical equilibrium were introduced as part of the process of modeling the processes that occur in a spark-ignition engine; psychrometry was introduced in design considerations for heat recovery steam generators; and compressible flow was introduced in order to model gas turbine cycles for aircraft propulsion. Thus, in the design of the course, the energy systems were the "problems" for the problem-based learning.

Much of the computer modeling of the spark-ignition engine cycle was done in-class based upon the expectation that the students would find this a very challenging task. The process of modeling began with a discussion of actual pressure-volume curves and processes of spark-ignition engines. The next step in the process was to formulate the necessary governing equations and to make engineering approximations to model the actual processes. The students were given an empirical model for the energy release rate from combustion to use in their models. Their first task was to create a model and to run it using the approximation of constant specific heats, so that they could verify their solutions against the air-standard cycle. The student teams built their models in EXCEL or MATLAB, based upon their preference. After completing this part of the task, they were required to determine appropriate properties for the mixtures of gases undergoing the various processes and to determine the energy added per mass of mixture for stoichiometric combustion. These two tasks required them to apply new concepts and calculation procedures related to properties of ideal gas mixtures and combustion. Using the completed model, the students were to compare their predictions to results from a small single cylinder engine. Unfortunately, only four teams managed to get their models to work for the air-standard case, and none were able to make comparisons to the experimental results. (Changes to this part of the course to allow learning objectives to be better met are discussed at the end of this section.)

The integration of lifelong learning and writing into the course was accomplished through a term paper. The motivation for this assignment in terms of self-directed learning was explicitly discussed with the students. In the initial part of the task, the students wrote a short essay on the relationship between an area of personal interest and thermodynamics or energy. Topics of the essays ranged from artificial hearts to rocket propulsion. Based upon these essays, student teams were formed around common interests, which set the general area of their papers. The selection of themes based upon students' interests was aimed at increasing the students' motivation to engage in the task, and the use of teams was intended to provide a supportive environment for undertaking. The teams were charged with selecting a paper topic and writing a single term paper based upon independent research. One class period was used to allow the team members to exchange drafts of their sections of the paper and to do constructive critiques of each other's work. Upon completion of the paper, they were asked to reflect on their experience and discuss what was most valuable to them and why it was valuable.

One measure of the impact of the IDEALS tasks was feedback from the students at the end of the computer modeling project and the term paper. Also the students were given an end-of-semester survey. The students' reflective comments on the self-directed learning assignment indicated that the assignment had positive impacts in skills and attitudes, including confidence in their abilities. In describing what was most valuable aspect of the assignment, nine students mentioned that the assignment improved their information retrieval/selection skills, eight students mentioned that the assignment provided strong motivation to learn; three mentioned practice of self-management, and two mentioned that it had improved their confidence in their abilities. Four students indicated that they were already accomplished at self-directed learning, so the assignment had little impact on them. The end of semester survey asked about the effect of the assignment on ability to engage in self-directed learning and confidence in their abilities. 21 of 29 responding to the survey indicated that the assignment improved their ability to engage in self-directed learning and 24 of 29 indicated that it had increased their confidence. The students' responses and their performance on the assignment were consistent with the instructor's assessment that the assignment was successful. The student teams all managed to select a topic, locate appropriate materials, and integrate them into good papers.

Student feedback on the computer modeling assignment was also positive, in general, in spite of the fact that many failed to complete it. When asked what was most valuable about the project, nine students noted that the experience was valuable because it helped them to see physical meaning in the thermodynamics and to make abstract concepts more concrete. Others noted that the experience of working in a team was most valuable or learning MATLAB. 26 of 27 students responding to the survey indicated that the experience had improved their understanding of the process of modeling. Several noted explicitly the effectiveness of the project in pulling together various aspects of thermodynamics and their computer skills. When evaluated against the learning objectives for the course, this project was only partially successful because only 4 of 8 teams got their models to work with air standard assumptions, and none of them were able to model the actual experimental data. It appears that some of the difficulty that the students had can be reduced with a re-design of the tasks involved. One change that will be implemented in future offerings of this course was suggested by a student; it was that a working model using air standard assumptions be made available to those teams who fail to complete this part of the task, so that all teams can attempt to model the experimental results.

Next Steps

During spring semester of 2001, additional sections of the two versions of IDEALS classes will be offered. The Thermodynamics II class will be scaled up to a typical section size of approximately 60 students. Two sections of the one credit "Linking" class will be offered, and they will be linked more explicitly to the instrumentation class, to that extent that some of the subsystems of the vehicles will be used in labs in the measurement class. The ultimate challenge for the IDEALS initiative lies lie in extending the array of IDEALS classes to handle 220 students per semester for both semesters of the junior year and the first semester of the senior year. Currently efforts are being made to engage more faculty members in the project so that they can use the summer to prepare additional IDEALS classes for the following academic year.

Acknowledgement

This work was conducted with support from NSF through the Action Agenda Initiative under Grant No. EEC-9973002 and from the Leonhard Center for the Enhancement of Engineering Education.

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