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Discovery Learning in Mechanical Engineering Design: Case-based Learning or Learning by Exploring?

For the United States to maintain its economic leadership and sustain its share of high-tech jobs, it must create new and better products and industries: innovative engineering design will be essential to this task. Engineering design must continue to adapt to new trends and to educate the next generation of workers.

NSF Workshop on Engineering Design in Year 2030

Abstract

Relative to traditional deductive teaching, inductive methods impose more logistical problems and require much more planning. Inductive teaching and learning techniques are more likely to trigger student resistance and interpersonal conflicts. Moreover, instructional methods that call for the use of team-based learning pose additional problems, such as the needs to assess individual student performance in a team environment and to prepare students to deal with communication problems that arise in cooperative work. Discovery Learning is an extreme form of inductive teaching where students are presented with a challenge and left to work out the solution mainly on their own. The instructor may provide feedback in response to students’ efforts but offers little direction. This form of inductive teaching has rarely been used in undergraduate classes. There is little empirical evidence for its effectiveness in that setting.

This paper discusses two different challenges, presented in two consecutive semesters as part of the Mechanical Design Applications II class at Texas A&M University, using the discovery learning approach. We compare the effectiveness of the discovery learning approach in the two undergraduate classes, based on empirical evidence and students’ perceptions. In the end, the paper summarizes some of the lessons learned and plans for future activities using the discovery teaching/learning approach.

Introduction

To facilitate learning in a time demanding environment, authors and educators have proposed inductive teaching and learning techniques. Discovery learning is an approach to learning that can be facilitated by particular teaching methods and guided learning strategies. For the purpose of this paper, the term discovery learning will refer to the learning taking place within the individual, and the teaching and instructional strategies designed by the faculty and the environment created when such strategies are used. Discovery learning encompasses an instructional model and strategies that focus on active, hands on learning opportunities for students [1], [2], [3]. Bicknell-Holmes and Hoffman [4] describe the three main attributes of discovery learning as: (1) exploring and problem solving to create, integrate and generalize knowledge, (2) student-driven, interest-based activities in which the student determines the sequence and frequency, (3) activities to encourage integration of new knowledge into the learner’s existing knowledge base. These three main attributes combine to make discovery learning different from traditional forms, yielding to the following fundamental differences (1) learning is active rather than passive [5], (2) learning is process-oriented rather than content-oriented, (3) failure is important part [6], (4) feedback is necessary [7], (5) understanding is
deeper [8]. Discovery learning allows for deeper understanding by encouraging natural investigation through active process-oriented methods of teaching [9].

There are five main architectures, categorizing discovery learning [6]: (1) case-based learning, (2) incidental learning, (3) learning by exploring, (4) learning by reflection, (5) simulation-based learning. In case-based learning students examine cases and discuss how to solve problems. Incidental learning is characterized by game-like activities, learning by exploring and learning by reflection teach students to ask questions, encourage thinking of multiple ways to categorize and build analysis skills. Last, the simulation-based learning allows for experimenting in an artificial environment and trials without the fear of failing.

Motivation

During the semester long Mechanical Design Applications II course of Fall 2010, a new learning strategy environment was created, by introducing the students to a team challenge where they were asked to design an assistive device for a particular person who is disabled. The students were introduced to local non-profit agencies that train and find employment opportunities for disabled people. During the semester, the students worked in teams and in collaboration with a specific disabled person, with physical therapists at the local hospitals, as well as with the disability services at Texas A&M University to better understand the barriers faced by the disabled on a daily basis. Based on lessons learned, in the Fall of 2010, the students in the Mechanical Design Applications II class were presented with a new challenge.

The current paper compares the student perception, as well as the instructor’s involvement and planning in both semesters. Preparing students to actively participate in the learning process, be more responsible for their own learning in order to become lifelong learners [10] were the main goals of both projects. Since students who are capable of self-learning are better prepared to become lifelong learners, the teams were provided with limited guidance. To guarantee success, their work was assessed three times during the semester.

Student’s Prior Knowledge in the Subject Matter

Students, who take the Mechanical Design Applications II course have a prior knowledge in mechanical design and it’s applications from the following classes:

- Solid Modeling, which introduces design processes and methodologies, materials and process selection, design for manufacturing and assembly, fundamentals of modeling part geometry and mechanical assembly using parametric CAD software.
- Computer-aided Manufacturing, in which students evaluate and analyze production systems, learn about automation and material handling technologies, as well as learn the computer-aided manufacturing program FeatureCam.
- Mechanical Design Applications I, which introduces theories of failures, fatigue and fracture design criteria, materials and their selection and simple machine elements.

Course Description ‘Fall 2010

The Mechanical Design Applications II is a senior course, which introduces the applications of principles of analysis and design of machine elements, machines and mechanisms, including
linkages, cam and follower systems, shafts, gears, clutches, belt and chain drives. The course presents the mathematical tools for analysis and design. Course specific material related to the design of technologies to aid people with disabilities were identified and included in the curriculum. The course specific activities and materials were then mapped to the desired course development and outcomes. The case based learning approach was utilized through the use of disabled individual’s cases that contain the information the faculty wanted the students to learn. Students were divided in teams and were asked to examine the cases (each team working on one particular case) and attempt to make decisions based on their knowledge of the content area \cite{6}. Case-based learning takes the advantage of having “teachable moments”, where students discuss how they are making decisions regarding their case. To increase the quality of learning and writing skills \cite{11}, the students were asked to submit and present three design overview reports during the semester. By the end of the first month, teams formally presented their design ideas, based on customer needs and functional requirements. In the mid semester, the teams discussed their progress on the projects, by presenting their conceptual designs. In the end of the semester, the students presented their final assistive device design documents. They were reviewed by engineering technology professors and health-care professionals. The review criteria consisted of overall solution, cost, ease of use and implementation, safety features, quality and accuracy, function, plans for testing and evaluation, as well as innovation. Interactions of each team with the customer/user of the assistive device and with the collaborators were also taken into account. Feedback from the collaborators, regarding the teams development, experiences, as well as the industry-defined competency of the developed assistive device were also extremely important during the semester. This provided a partial summative evaluation of the project and the students’ learning. The projects were evaluated at the end of the semester. Students were asked for a detailed feedback and recommendations for improvements. The survey was anonymous and the students had to grade their answers on a scale from 1 (low/poor) to 5 (high/excellent). The questions of the survey are given in Appendix A. The survey was completed by twenty two students. The average was 3.558. Questions, regarding the student skills necessary to develop system and component requirements, identify real-world engineering problems, write and clearly present ideas, as well as communicate effectively with team members and collaborators received high scores. These areas were part of the curriculum for the mechanical engineering design course and, as such, were skills students were able to utilize towards the project. Despite the success of the students learning outcomes, this extreme form of inductive teaching was clearly calling for some changes.

Lessons Learned

Based on the student’s survey answers, in order for the course and the students to progress to the next level, it was clear that:

1. The lack of time and limited guidance, made it hard for students. Below are some of the negative student comments, regarding the project: “students don’t have the time for another project”, “took a lot of time, which could have been used for solving more examples similar to the material we are covering, or examples similar to the homework”, “takes away valuable time from senior design project”;
2. The absence of direct relevance to the class material arose student resistance at times: “the project is not relevant to class material”, “this is not a senior design class”, “did not understood what the project has to do with the class”;
3. Each team was involved in solving their particular challenge. This did not allow for more group interactions, such as debates and team design critiques at the three presentations during the semester. These interactions are very important for the collective experiences of the group that assist in the creation of new knowledge;

4. Projects like that, i.e. wide scope and many different original cases, need a great amount of preliminary work by the faculty.

Course Description ‘Spring 2011

In the ‘Spring 2011 a new team challenge was presented to the students, using learning by exploring architecture. This type of discovery learning is based on a collection of answers to questions students ask about the particular topic. Students were given a hands-on problem from a particular company and they were supposed to solve it by interacting with the company’s experts by asking questions. In this architecture, curiosity is intended to serve as a dramatic motivational tool. With the lessons learned from the previous semester, this challenge had the following main characteristics:

1. Use of only one design problem for the whole class, instead of number of different problems;
2. The design problem was specifically chosen, so that it allowed for a number of different design solutions;
3. The design problem was directly related to the class curriculum;
4. The design challenge was presented to the class by two industry personnel, who were responsible for providing a structured feedback/answers to teams questions throughout the semester.

Specifically, students were asked to develop an automated system for inserting specimen cups in a carbon analyzer for commercial applications. The students were introduced to the machines that analyze the carbon content of organic and inorganic samples. The current process is characterized by manually loading the specimen cup into the furnace of the analyzers for carbon acquisition (see Figure 1a). Along with other design requirements, the company requested that the system be constructed within a reasonable budget, with the goal of being under a $1,000. The company also requested that the new system design should be different from complicated solutions that will require a substantial number of design changes in the already existing parts and machines. In the mid semester, the teams presented their progress on the projects, by discussing their conceptual designs in front of two industry personnel (see Figure 1b). The industry personnel provided the teams with written comments. Examples of the company’s feedback are presented in Appendix B. In the end of the semester, the students presented their final design documents, which were reviewed by the faculty and the company. The review criteria consisted of overall solution, cost, ease of use and implementation, safety features, quality and accuracy, function, plans for testing and evaluation, as well as innovation. Evidence for constant interactions of each team with the company was also taken into account.

Effectiveness of the Two Learning Strategies

Both projects, presented in Fall 2010 and Spring 2011, aim to take the study of mechanical design to the next level by using different discovery learning methods in order to motivate the students with real-world challenges and prepare them for the development of innovative engineering design ideas. The students take the theoretical ideas of mechanical design and implement them with limited guidance.
Survey questions (see Table 1), regarding the effectiveness of the discovery learning approaches were given in the two undergraduate classes. About twenty students completed the survey each semester. While the average value from the survey for the first semester was 3.558 (between good and very good), the second semester student learning outcomes were higher at 4.317 (between very good and excellent). The first semester the survey revealed areas that the students did not feel comfortable with, such as knowledge in the development of a schedule for manufacturing, plans for testing, as well as identification of features that distinguish their design from the competition. These areas were not part of the curriculum for the mechanical engineering design course, but were areas that the senior students, taking the course, had to have previous knowledge in and as such to be able to utilize towards the challenge. The second semester these issues were taken into account by the faculty and included in the curriculum. Questions regarding student’s ability to identify features that distinguish their team idea from the competition as well as ability to interact with and provide feedback from the customer were substantially improved in the second semester. This implies the faculty’s efforts in emphasizing design innovation rather than design analysis in the class.

![Figure 1](image1.png)

Figure 1. a) Total Organic Carbon Analyzer (TOC), Model 1030 S. b) Examples of student’s work for developing of an automated system for inserting specimen cups in a carbon analyzer: from rack and pinion traversing design, through belt and chain drives, drum assembly with a swing arm to using a robotic arm and four bar linkages.
Table 1 shows the top and bottom three scored questions (see Appendix A), based on student perception. The table also shows the average learning outcomes for the two semesters, based on student perception on a scale from 1 to 5. The survey questions are shown in Appendix A.

Table 1.

<table>
<thead>
<tr>
<th>Semester</th>
<th>Top three scored questions, based on student perception</th>
<th>Lowest three scored questions, based on student perception</th>
<th>Average learning outcomes, based on student perception</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall 2010</td>
<td>9, 3, 1</td>
<td>7, 4, 10</td>
<td>3.558 (good/very good)</td>
</tr>
<tr>
<td>Spring 2011</td>
<td>10, 7, 4 and 1</td>
<td>5, 3, 6</td>
<td>4.317 (very good/excellent)</td>
</tr>
</tbody>
</table>

Table 2 compares the effectiveness and instructional demands imposed by the two learning approaches from faculty viewpoint, on a scale from 1 (minimal), 2 (small), 3 (moderate), 4 (considerable) to 5 (major).

Table 2.

<table>
<thead>
<tr>
<th>Method</th>
<th>Resources available to students</th>
<th>Planning time</th>
<th>Instructor’s involvement</th>
<th>Student Learning Outcomes</th>
<th>Student Resistance</th>
<th>Direct Relation of the Challenge to the class curriculum</th>
<th>Social Aspect of the Challenge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case-based Learning</td>
<td>Cases</td>
<td>Substantial (finding original cases and/or approving team’s cases)</td>
<td>Major (team management, collaborators, customers, including challenge specific material in the course)</td>
<td>Considerable</td>
<td>Considerable</td>
<td>Moderate</td>
<td>Major</td>
</tr>
<tr>
<td>Learning by Exploring</td>
<td>Company facilities</td>
<td>Moderate</td>
<td>Considerable (team management)</td>
<td>Major</td>
<td>Moderate</td>
<td>Substantial</td>
<td>Moderate</td>
</tr>
</tbody>
</table>

A comparison between Table 2 and Table 3 shows that despite the social aspect of the first challenge, the learning by exploring method revealed more positive qualities from student, as well as from faculty perspective.

Impacts

There has not been a great deal of research done in the area of presenting discovery learning techniques in undergraduate classes or even in terms of its effectiveness in engineering design classes. A significant advantage of the method is its capacity to motivate students. Discovery
learning provides the opportunity for students to explore and seek information that satisfy their natural curiosity and consequently creates a more engaging learning environment. The mathematical tools in the analysis and design the students must understand are at times overwhelming, but when students are given a chance to design devices that have an immediate real-world application, they are motivated to progress in unimaginable ways.

Despite the high resistance from both students and educators, the ideas behind discovery learning are getting more and more accepted, as industry begins seeking employees who are better problem-solvers and independent workers. Producing graduates capable of designing high-quality products is the ultimate goal of engineering education. However, the resources necessary to support good design education are underestimated by schools and universities. This leads to weak design curriculum and ill-prepared engineering graduates. The design curriculum should be radically changed, emphasizing design innovation, rather than design analysis. The students should spend sufficient time on problem definition and concept generation and innovation instead of rushing into detailed design. Discovery learning is an active learning process where students develop high level skills to build a deep understanding of major concepts. The challenges provided by inductive methods are a great way to motivate students, encourage them to adopt a deep approach to learning and serve as precursors to intellectual development.

References
11. P.C. Wankat, The Effective Efficient Professor, Allyn and Bacon Co.
Appendix A: Survey Questions

<table>
<thead>
<tr>
<th>Survey Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Identify real world engineering design problems and formulate possible solutions</td>
</tr>
<tr>
<td>2. Develop system and component requirements and responsibilities to meet the desired needs</td>
</tr>
<tr>
<td>3. Write and clearly present team ideas in project document files</td>
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<tr>
<td>4. Develop a concept for the design of the system and subsystems</td>
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<td>5. Develop a bill of materials for the project</td>
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<td>6. Develop a schedule for manufacturing and plans for testing within a given period of time</td>
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<tr>
<td>7. Identify the features that distinguish our team’s project idea from the competition</td>
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<tr>
<td>8. Interact with and provide feedback from the customer</td>
</tr>
<tr>
<td>9. Communicate effectively with the team members and collaborators</td>
</tr>
<tr>
<td>10. Understand the impact of engineering solutions in a societal context</td>
</tr>
</tbody>
</table>

Appendix B: Samples of company’s feedback to students

Here are a few comments regarding the project proposals. These suggestions are merely for consideration and in no way should be viewed as mandates.

Team 1: This racetrack design presents a small footprint and a large number of samples. There are, however, a few practical operational problems that will preclude the implementation of this project. It appears to be hard to load and service to the main instrument will be obscured by the presence of a racetrack that goes all the way around the instrument. There is a door on the left side of the instrument that requires service access. If the racetrack was formed in a corkscrew, for example, and placed in the front of the instrument, it would not interfere with access to the instrument. You might consider a chain drive, where each pin held a cup. That might help prevent binding of the cups at the corners.

Team 2: The most pressing problem with this design is that it takes a large amount of counter-top space. True, the samples are stored above the instrument, and the loading is simple and straightforward, the mechanism for loading the samples appears to take almost as much room as another whole instrument. If the loading mechanism could be positioned tucked along the side of the instrument, instead of sticking out at a right angle, the design might be workable. Consider a width of an inch or two, the entire length of the instrument, and anything in front, as acceptable real-estate.

Team 3: This design is really clever, and, with just a few changes and some thought, might be a really attractive design. First, the loader has to travel all the way to the furnace, and the sealing mechanism is quite large. If the cup holder had a slice out of the side of it, it would allow the rod to ascend, lift the cup an inch or so, then allow the tray to swing out of the way to allow the arm and sealing mechanism to clear the tray on its way up. The swing could be activated by the motion of the arm in some sort of cam mechanism. As the arm descended, the cam would operate in reverse, moving the tray around the rod to catch the spent vial on its way down. Second, it is
possible that this design could be a purely mechanical design, with no electronics, motors or anything. If, as the arm continued down, it activated some sort of ratchet, the sample would advance automatically.

Team 4: This design also has some attractive points and would be a design that could be implemented into a practical product. Consider simplifying the advancement mechanism. The design you have is clever, but appears to be expensive. A simple friction drive and an indexer might be cheaper. I like the pick & place arm. It could be driven by compressed air (which is available) and it could in-fact activate a cam to advance the tray, thereby removing the need for that expensive stepper.

Team 5: This is a very interesting design. If the tray were removable it would allow for quick loading of the samples, a high priority. With a little work, the samples could zigzag back & forth thereby increasing the sample size. That would preclude the sample arm coming up through the middle. The loading arm needs some thought. It would be advantageous if the sample did not have to move up and down in order to get the cup, let the loading arm retract, and then continue on up into the furnace.