



Can Student Questions Help in Assessing Inductive Techniques in Mechanical Engineering Design Classes?

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Abstract

The paper discusses two different challenges, presented in the form of two projects, as a part of the Introduction to Mechanical Design class at California State University Fullerton, using inductive techniques. The students take the theoretical ideas of mechanical design and implement them with moderate guidance for the first project and limited faculty involvement in the second project. We use techniques to uncover what the students are asking themselves as they try to solve each challenge, in order to assess the approach and get ideas for possible enhancement. Based on these questions, the main project objectives: critical thinking, responsibility for students' own learning and intellectual growth, are discussed. The approach itself is tested, based on two main criteria: students' success in learning new tasks and in transferring skills to tasks of greater difficulty.

Introduction

There is a very deep viewpoint from students, educators and parents that inquiry learning takes too much time and that it is much more efficient for students simply to be given the information they need to know. This point of view is strongly reinforced by the kinds of things that K-12 students and later college students are expected to know to pass the majority of tests they are given. However, workforce skills are not specific job skills but rather more broad understandings that provide one the abilities to quickly adapt to new job-skill demands. An instructional strategy that comes close to emulating the constantly changing demands of our society is inductive teaching^[1]. In this approach, the students are first presented with a challenge and they attempt to solve it. Learning takes place while students are trying to understand what they need to know to address that challenge. Students tackling these challenges quickly recognize the need for facts, skills, and a conceptual understanding of the task at hand. At that point, the faculty provides minimal instruction to help students learn on their own. Bransford, Brown, and Cocking^[2] survey extensive neurological and psychological research that provides strong support for inductive teaching methods. Ramsden^[3], Norman and Schmidt^[4] and Coles^[5] also demonstrate that inductive methods encourage students to adopt a deep approach to learning. Felder and Brent^[6] show that the challenges provided by inductive methods serve as precursors to intellectual development. Prince and Felder^[7] review applications of inductive methods in engineering education, and state the roles of other student-centered approaches, such as active and cooperative learning, in inductive teaching.

Inquiry learning is one form of inductive methods and begins when students are presented with questions to be answered, problems to be solved, or a set of observations to be explained^[8]. If the method is implemented effectively, the students should learn to “formulate good questions, identify and collect appropriate evidence, present results systematically, analyze and interpret results, formulate conclusions, and evaluate the worth and importance of those conclusions^[9].” The same statements could also be made about problem-based learning, project-based learning, discovery learning, certain forms

of case based instruction, and student research, however, so that inquiry learning may be considered an umbrella category that encompasses several other inductive teaching methods. Lee makes this point, observing that inquiry is also consistent with interactive lecture, discussion, simulation, service learning, and independent study, and in fact “probably the only strategy that is not consistent with inquiry-guided learning is the exclusive use of traditional lecturing ^[9].” In what follows, we briefly discuss the motivation and course objectives.

Motivation

The main goal of both challenges was to let each student experience being an engineer by introducing a problem and encouraging the students to link engineering theory to real-world applications. As faculty, we engage ourselves in inquiry throughout our academic careers when we explore questions and try to make sense out of what is going on in our area. I particularly chose my field of study because one circumstance, somewhere along the way motivated me to seek for answers. So “How do I get my students excited about Mechanical Engineering Design?”. A good way to do this is to present them with inquiry-based learning (IBL) activities that are relevant to their future careers and give them the opportunity to engage in course concepts and tasks.

Other than increasing student motivation, preparing students to actively participate in the learning process, by exercising original thinking, evaluating alternative solutions, making decisions and defending them, was my ultimate goal. With the trend in higher education to move away from teacher-centered instruction to a more student-centered approach, IBL gives the opportunity to help students learn the content and course concepts by having them explore a question and develop and research a hypothesis. Thus, giving students more opportunity to reflect on their own learning, gain a deeper understanding of the course concepts in an integrated fashion, and become better critical thinkers.

Course Description and Objectives

The Introduction to Mechanical Design is a junior course, which introduces kinematics and dynamics of mechanisms and their applications. The course covers design and analysis of linkages, gears and cam and follower systems. Course specific material related to both projects, described below, were identified and included in the curriculum. The course specific activities were then mapped to the desired course development and outcomes.

Specifically, the process for integrating inquiry techniques into the course, contained the following phases:

- Determine faculty goals and objectives; analysis of potential students (students, who take the course are juniors and do not have a prior knowledge in the field of mechanical design and it’s applications);
- Determine faculty role in the learning process;
- Develop an instructional plan;

- Design activities, assignments, and assessments that are congruent with the four desired student outcomes: (a) improved critical thinking skills, (b) greater capacity for independent work, (c) taking more responsibility for one's own learning, (d) intellectual growth, congruent with the above mentioned goals and objectives.

In what follows, we briefly discuss the two projects, Device Analysis and Design Challenge, both presented in the 'Fall 2012 as a part of the Introduction to Mechanical Design class at California State University, Fullerton. For more details, please refer to Robson ^[10].

Scope of the Two Projects

In the first part of the 'Fall 2012 semester, a project activity was presented to the students, *using guided inquiry learning* architecture. Students were given a hands-on problem to find a real-world mechanical device, disassemble it and analyze it. The activity was designed such that students work either individually or in groups of two for two weeks. In the end of the two-week period, the students were asked to present their device analysis projects. On average, the amount of faculty involvement in the project was moderate. For this project the students mainly had to use the theoretical knowledge they had gained from the first part of the class.

A month later, after the completion of the first project, the students were presented with a second challenge, using *project based learning* approach. The overall goal of the open-ended challenge was to propose a design for a passive suspension for wheeled robotic platform suited for operation on rough terrain. The students had to be able to develop selection criteria considering all relevant issues, develop and evaluate alternative solutions and chose a solution. As a part of the learning process, the students had to work in teams of two. The goal of the project was to give the engineering undergraduates understand and apply design tools and skills such as sketching and drawing, kinematics, evaluate alternative solutions, communication, as well as ability to take decisions and defend them. The students were notified that the faculty involvement in the project will be minimal.

Effectiveness of the Learning Environment with Regard to the Three Main Project Objectives

Both projects, presented in the 'Fall 2012 semester, aim to take the study of mechanical engineering design to the next level by using inductive teaching techniques 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 moderate guidance in the first and minimal faculty involvement in the second project.

Survey questions regarding the effectiveness of the two approaches were performed, based on the main course objectives (see Robson ^[10] for details). Despite the fact that the second project, Design Challenge, was more complicated and the

students worked without direct faculty assistance, the results regarding students' learning outcomes were higher at 4.38 out of 5 versus 4.1 out of 5 (see Robson ^[10] for details). The first project revealed areas that the students did not feel comfortable with, such as ability to take decisions and defend them, as well as ability to analyze a real-world mechanism. These issues were taken into account by the faculty and were substantially improved in the second project, which implies the faculty's efforts in emphasizing critical thinking and intellectual growth throughout the semester.

In an effort to get possible ideas on enhancing the inductive teaching methods, as a part of each survey, the students were asked to identify three questions that they were asking themselves, while solving each project. Later, the students' questions were classified into three major groups, according to the desired outcome goals: critical thinking, responsibility for one's own learning and intellectual growth. The results from the two projects are compared in Table 1. Given the difficulty (if not impossibility) of carrying out a clean and conclusive comparative study, the best we could do is to look at the results to see if any robust generalizations can be inferred. In what follows we summarize our results.

Table 1. Comparison in Critical Thinking, Responsibility for One's Own Learning and Intellectual Growth between the two Challenges, Based on Student's Questions.

	Number of Questions, related to Critical Thinking	Number of Questions, related to Responsibility to one's own learning	Number of Questions related to Intellectual Growth
Inquiry/Discovery Learning (Device Analysis)	29	7	21
Project-Based Learning (Design Challenge)	41	26	35

The critical thinking, was assessed by the number of students' questions with regard to their interest in analyzing data, evaluating alternative solutions, taking critical decisions, and communicating design ideas. Below are examples of some of the students' questions with regard to that:

- *Since it did not fall into a clear-cut category of the devices we went through in class, what research do I need to do to move forward?*
- *How does geometry affect the wheel travel?*
- *How can we minimize overall mass and keep the rover stable?*
- *How can we increase the range of motion of the suspension?*
- *Can shock absorbers be implemented into the design?*
- *At what point would too much range of motion of the rover create instability?*
- *Are these design objectives the correct ones for solving this specific problem?*
- *Will the time invested in additional experimentation yield a professional gain in the final design and performance?*
- *How can I design the suspension, so that I reach a maximum vertical movement of the wheels, while still keeping the platform size close to 14"x14"x14"?*

- *Are my calculations with regard to the design parameters right? How do I double-check?*

The comparison in students' responsibility of their own learning was assessed by the number of student's questions regarding their desire to learn more, be successful and look for additional sources, out of the class. Below are some of the examples of students' questions, concerning their own learning:

- *Are there any additional examples I can look at?*
- *How can I be most successful in choosing a device, analyzing it and presenting the results?*
- *Is there any way I can improve my skills, i.e. read more on-line, books, etc. to be able to do successfully my project?*
- *How can make sure that I am following the right procedure to solve the problem?*
- *Where can I find additional sources to help me better understand the project?*
- *How do I mathematically prove this is a good design?*

The comparison in intellectual growth between the two projects was assessed by the number of student's questions regarding their ability/desire to propose improvements to a design, to find out the relationships between different concepts and to defend their design decisions. Below are examples of some of the students' questions with regard to that:

- *Are the improvements I will suggest reasonable?*
- *How can I suggest improvements to an already professionally made design?*
- *What is the most effective way to solve this problem?*
- *How to solve for the fixed and moving pivots, so that the performance is improved?*
- *How may I get a good performance out of my design?*
- *How will our model compare to real world models that are constructed to achieve similar design constraints?*
- *How can I make my design better?*
- *How do I layout my design and what alternatives do I have?*
- *How can I maximize the climbing ability of the rover?*
- *How important is the accuracy of design calculations, in order to maximize its mechanical advantage?*
- *How would my suspension design work in different terrains?*
- *How can I propose something new and original?*
- *Should I make a computer model as well as a physical model of my design in order to justify it?*
- *What variables can I manipulate, in order to improve the performance of my design?*

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

Table 2. Instructional Demands Imposed by the Two Approaches, based on Faculty Viewpoint.

Method	Resources Available to Students	Planning Time	Instructor's Involvement	Student Resistance	Direct Relation of the Project to the Class Curriculum
Inquiry/Discovery Learning (Device Analysis)	Different real-world devices	Moderate	Moderate (team management)	Moderate	Major
Project-Based Learning (Design Challenge)	Internet	Moderate (challenge could be part of faculty on-going research)	Minimal	Small	Moderate

It can be seen from the table that the project-based learning requires less instructional demands than the inquiry learning techniques, especially, in the cases where these two techniques are designed to complement each other. Overall, the results from Table 1 and Table 2 show that a combined guided inquiry learning and project based learning presented in a conventional teaching environment brings to positive learning and teaching outcomes.

Assessment of the Approach and Conclusion

Both projects, presented to the students aim to take the study of engineering design to the next level by incorporating inductive teaching techniques into the educational process and motivating the undergraduates with real-world challenges. The students work in small teams, take the theoretical ideas and implement them with limited guidance. As students explore the topic, they ask questions, draw conclusions, and, as exploration continues, they revisit those conclusions. Exploration of questions leads to more questions and knowledge construction.

Based on comparison between the average students' grades and the average learning outcomes, for the limited time between the first and second challenge, Table 3 reveals a certain *transfer of knowledge* from the first to the second project. Therefore, it seems that guided inquiry is efficient not only *for learning new tasks*, but also in *transferring learned skills to tasks of greater difficulty*.

Table 3. Learning Outcomes, from both Projects Reveal Transfer of Knowledge.

Project	Average Learning Outcomes (from 1 to 5)	Students' Grades on Project Content and Presentation (out of 100)
Device Analysis	4.1	94.59
Design Challenge	4.38	95.85

It is not quite easy to make a comparison in order to get conclusion as to which of the two methods revealed more positive qualities from students' and faculty perspective. However it can be seen that presenting two different projects using two different

inductive approaches, which complement each other in one semester, brings to successful results. For the limited time of about a month between the two challenges, the results show students' improved critical thinking, taking more responsibility for their own learning, as well as intellectual maturity. Our preliminary results show that guided inquiry seems to be efficient not only for learning new tasks, but also for transferring learned skills to tasks of a greater difficulty.

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