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# Transitioning Students from Analysis to Design with an Active Incremental Learning Approach

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# Transitioning Students from Analysis to Design with an Active Incremental Learning Approach


## Abstract

In a typical mechanical engineering technology curriculum, a mechanical design course is preceded by physics, mechanics, and mechanics of materials courses that focus on developing students' analytical skills. While strong analytical skills are required in mechanical design, the open-ended nature of design problems often prevents students from making a smooth transition. Students are used to problems with a unique, standard solution. Introducing the concept of multiple unknown parameters that lead to plurality of design solutions can be a challenging task. Given the critical need in developing students' competence and confidence in design, an effective approach to guiding students to transition from analysis to design thinking is of significant interest.

The present work examines the effects of active learning activities on students' progression in applying their analytical skills to solve design problems. In the beginning of the semester, a survey is first conducted to evaluate students' aptitude for design with questions such as if they are comfortable dealing with problems that has no standard solution and if they enjoy creative activities involving synthesis. The survey gives an indication regarding the level of readiness for students to tackle mechanical design problems. Through the semester, in-class exercises, quizzes, and homework assignments are given in the formats of both analysis and design. Students are initially given the freedom of selecting the types of problems they prefer, and then are encouraged to work on design problems as the semester progresses. The transition is characterized by the types of the problems the students select and the performance of the students in design problems. A final exam consisting of only design problems and a summative survey, similar to the initial survey, are administrated at the end of the semester.

This paper presents the methodology of the study, the survey questionnaires, the design course outline, and examples of the analysis and design problems. Data comprising students' initial survey response, selection of problem types and the competence with the design skills are reported.


## Introduction

Mechanical design and machine elements is one of the most critical courses in a typical mechanical engineering technology program. The course is preceded by physics, mechanics, and mechanics of materials courses that focus on developing students' analytical skills. While strong analytical skills are required in design, the open-ended nature of design problems often prevents students from making a smooth transition. Students are used to problems with a unique, standard solution. Introducing the concept of multiple unknown parameters that lead to plurality of design solutions can be a challenging task. Given the critical need in developing students' competence and confidence in design, an effective approach to guiding students to transition from analysis to design thinking is of significant interest. Successful transition from analysis to design will enhance students' ability to perform well in the capstone course where integration of knowledge and skills is required in solve design problems.

Students' analytical skills and disciplinary knowledge play an important role in innovation in the context of mechanical design education.[1] Efforts have been made to investigate the type of knowledge, acquired across the undergraduate time span, students use when making design decisions. The open-end nature of mechanical design problem requires students to "think out of the box," deal with multiple choices and make trade-offs according to requirements. It was reported that design teams in the capstone courses offer a higher number of decisions per project than the teams in the freshman course, indicating the need of a transition to engage students in design decision making.

Project based learning (PBL), which strongly motivates students, is a well-known pedagogical approach.[6] In PBL, open-ended problems are provided in courses. As there are multiple feasible solutions, students need to evaluate each option, make decisions, and deliver a solution. This process guides students to use their analytical skills to solve real problems. Previous endeavors include incorporating an open-ended project (delivering a prototype at the end of the semester), into a junior level course to prepare students for the capstone project.[7] The outcomes showed that students appreciated this experience with positive feedback. Wilmann et al. motivated students' desire to design by assigning students a project on designing adapted physical activity devices for people with disabilities.[8] This challenge forces students to consider a user centered design approach with few existing references or standard solutions that students could refer to. Other PBL efforts include conducting a common design-build-test project to integrate the analytical and design skills[9] and incorporating PBL into courses while redesigning a mechanical engineering curriculum.[10]

In order to help students to enhance their analytical skills without limiting their experience in exploring open-ended design problems, efforts were made to provide active learning environments. Active learning activities refer to students' exploration of concepts, principles, and solutions, and reflection about what/why they are doing.[2,3] Students' knowledge retention and problem-solving skills can be enhanced when they learn what they care about. [4,5] To facilitate student learning in mechanics of materials and finite element analysis, a novel portable pen-and-tablet-based system was developed.[11, 12] The software platform, which bridges the gap between engineering design and analysis, helps students to study their own design and to seek various design options before a detailed design is achieved.

It can be observed that the previous efforts mostly provided opportunities for students to engage in design. The need of a mechanism to incrementally guide students to transition from analysis to design has not been well addressed. This paper presents an incremental approach to making such a transition.

## Course Description

The *Mechanical Design Application I* is the first of two mechanical design and machine element courses in the Manufacturing and Mechanical Engineering Technology Program at Texas A&M University. The course covers principles of design of mechanical components, engineering materials and their selection to engineering applications, theories of failures/failure criteria, fatigue and fatigue failure criteria, and a number of machine elements such as columns, fasteners and springs. The course objectives are:

1. To provide students with a clear understanding of the theory of the fundamentals of mechanical design. Students will develop the ability to select and apply failure theories/criteria for mechanical design.
2. To provide the procedures and decision making techniques required to design and analyze mechanical components. Students will develop the ability to design part geometry, identify loads, calculate stresses, and use failure theories to select materials.
3. To provide students with a clear understanding of the critical concerns in the design and selection of common machine elements. Students will be able to design and select machine elements such as fasteners and springs to meet the performance requirements.

The prerequisite of the course is *Mechanics of Materials*, which has a material and a mechanics (statics) courses as its prerequisite. The *Machine Elements in Mechanical Design* (by R. Mott) is adopted as the textbook. Table 1 shows the course contents listed in the syllabus. Since analysis is a critical component in design, the course could be taught with emphasis on analytical (stress analysis) skills. It is, however, of significant interest to gradually introduce students the concept of plurality and the decision making process in design.

Table 1. Course contents in *Mechanical Design Application I*

| **Lecture (Chapters)** |
|---|
| Design Process (1), Engineering Materials (2) |
| Material Selection (2), Stress Analysis (3) |
| Stress Analysis, Combined Stress (3) |
| Stress Transformation (4), Static Failure Theories (5) |
| Static Failure Theories (5), **Exam #1** |
| Endurance Strength (5) |
| Fatigue Failure Theories (5) |
| Review of Failure Theories, Damage Accumulation Method (5) |
| Surface Failure, Column Design (6) |
| Stress in Cylinders (13), **Exam #2** |
| Stress in Cylinders (13), Fasteners (19) |
| Fasteners (19) |
| Springs (18), Design Project |
| Springs, Design Examples |

**Active Incremental Learning Methodology**

The active incremental learning methodology used in this study can be shown in Figure 1. In the beginning of the semester, a survey is first conducted to evaluate students' aptitude for design with questions such as if they are comfortable dealing with problems that has no standard solution and if they enjoy creative activities involving synthesis. The survey gives an indication regarding the level of readiness for student to tackle mechanical design problems. In the course, in-class exercises, quizzes, and homework assignments are given in the formats of both analysis and design to gradually expose student to design. Students are initially given the freedom of selecting the types of problems they prefer, and then are encouraged to work on design problems as the semester progresses. The transition is characterized by the types of the problems the students select and the performance of the students in design problems. A final exam consisting of only design problems and a summative survey, the same as the initial survey, are administrated at the end of the semester.

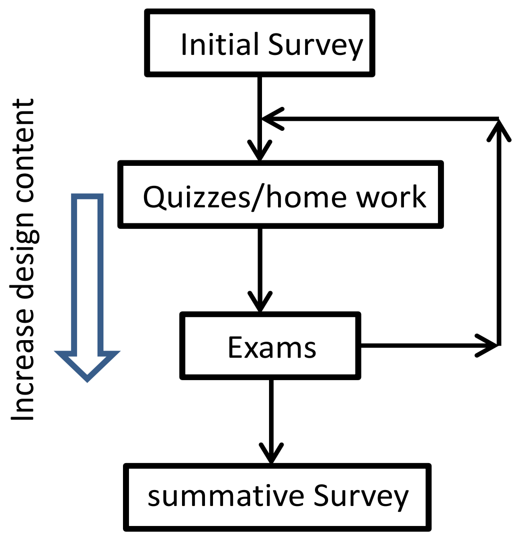



Figure 1. An active incremental learning methodology

<u>Survey Questionnaire</u>

The survey questionnaire is shown in Table 2 below. For each question, students are asked to mark their preference in the scale from 1, agreeing to Statement A, to 5, agreeing to Statement B while marking "3" indicates the student is neutral towards the two statements. To avoid bias, the survey is designed such that for Questions 1, 3 and 5, the selection of "1" indicates that the student prefers analysis over design. Similarly, for question 2 and 4, the selection of "5" indicates that the student prefers analysis over design. In determining the students' aptitude, the rating of Questions 2 and 4 are reversed. As such, a student's preference can be identified from analysis at a rating of "1" to design at a rating of "5." The rating shown in Table 2 indicates that the student has a relatively strong "analysis" preference.

Table 2. Survey questionnaire on students' aptitude for design

| | Statements | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Q1 | A. In a test, I prefer problems with only one correct answer. [1]<br>B. Problems with multiple correct answers do not bother me. [5] | | x | | | |
| Q2 | A. I like to guess (educated guess) and check different potential solutions. [1]<br>B. I like to analyze problems to get exact solutions. [5] | | | | x | |
| Q3 | A. I prefer to use fixed procedures to solve problems. [1]<br>B. I like to use learned concepts to come up with solutions. [5] | | x | | | |
| Q4 | A. Choosing among various factors and use a procedure to determine the viability of a solution is something I enjoy. [1]<br>B. When solving a problem, I like to follow a methodical procedure to come up with a solution. [5] | | | | | x |
| Q5 | A. I consider myself an analytical person. [1]<br>B. I enjoy being "creative." [5] | x | | | | |

<u>Analysis versus Design Problems</u>

A set of quizzes, homework assignments, and exam problems are designed to provide the contrast between design and analysis. As shown in Figure 2, the topic of "rule of mixtures" in composite material is taught and tested in Week #2. The students are asked to select one of the problems to solve. In this example, Problem A, while can be solved analytically, has some "design" flavor and Problem B is a typical analysis problem.

<u>Select/circle and solve Problem A **or** Problem B</u>

The "rule of mixtures" is commonly used to predict various properties of a composite material. For elastic modulus, the "upper bound modulus" corresponds to the composite property in the direction parallel to the fibers:

$$E_c = fE_f + (1 - f)E_m$$

where $E_c$ is the "upper bound" elastic modulus of composite, $f = \frac{V_f}{V_f + V_m}$ is the volume fraction, $E_f$ is the modulus of the fiber, and $E_m$ is the modulus of matrix. The moduli of carbon-PAN fiber and epoxy matrix are 231 GPa and 3.86 GPa, respectively.

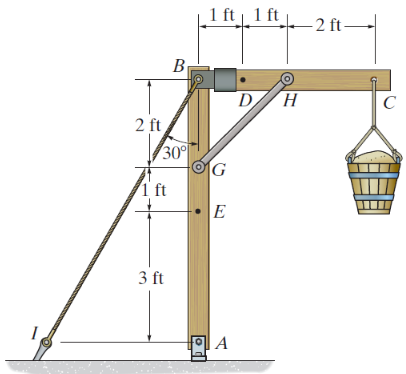
A. Determine the volume fractions of the fiber and matrix to obtain $E_c$ = 100 GPa.

B. The volume fraction of the fiber is 40% and that of the matrix is 60%, determine $E_c$.

Figure 2. An example of quiz problem

Another example demonstrating the difference between design and analysis problem is shown in Figure 3. To meet the requirement of sustaining 150 lb. load at the specified location C, Member GH can be designed with different combinations of cross section size and material property (Problem A). An analytical form of the problem is to determine the maximum load at C for a given cross section and material property. Again, students are given the choice of selecting one of the problems.

Select/circle and solve Problem A **or** Problem B




A. The bucket is loaded with 150 lb load. Determine the cross section and material required for member GH.

B. Given the member GH has a cross section of 2.0 in$^2$ and the yield strength of the material is 30 ksi. Determine the max. allowable load for the bucket.

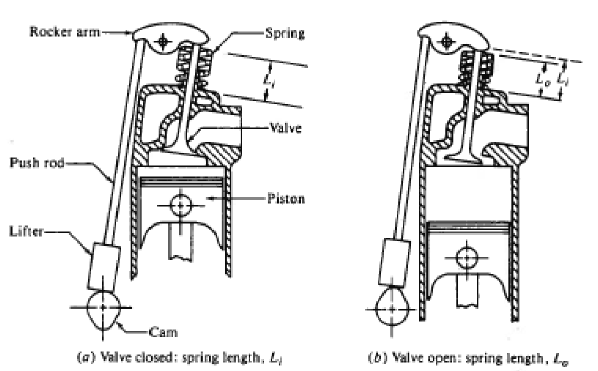
Figure 3. An example of exam problem

As the semester progresses, fewer analytical problems are given. Toward the end of the semester, quizzes and homework assignment are mostly presented in the form of design problems. Figure 4 shows two take-home final exam problems. It can be observed that the problems are open-ended with multiple solutions. In Problem #1, students are asked to specify design requirements and state the assumptions. While the members can be in various cross section geometries with different materials, application of the analytical skills (statics, mechanics of materials, and static failure theories) is required to come up with a feasible solution. Similarly, Problem #2 includes the design of column (push rod), beam (rocker arm) and spring while considering fatigue failure.

Final Exam Problem 1

Design a scissor jack for a typical vehicle. Assume **Static Loading.**

- Specify design considerations/requirements (weight to be lifted, initial position, final position, safety factor, etc.)
- Specify dimensions and select materials for all members (including the threaded rod).




Provide a preliminary design of the spring, rocker arm, and pushing rod based on the following spring information:

- Installed force: 50 lb, Installed length: 2.15”,
- Operating force: 130 lb, Operating length/height: 1.75”

(figures from Mott, *Machine Elements in Mechanical Design*)

Figure 4. Examples of final exam problems

## Results and Discussions

The active incremental learning methodology was implemented for one semester. Fifty nine students participated in the *Mechanical Design Applications I* course. Four in-class quizzes were given with the choices of attempting analysis or design problems (some student attempted both). Table 3 is a summary of the students' preference and performance. It was found that regardless the type of problem, there is no significant difference in the student performance. The selection of the problem type, however, fluctuated. Due to the concern of their grades, students often selected a problem that is perceived "easy." (This is seen in Quiz#3.) It is evident that close to the end of the semester, 60% of the students were willing to select a design problem that is often more time-consuming to accomplish.

Table 3 Student preference and performance in analysis versus design

| Quiz | Preference (% student)* | | Performance | |
|---|---|---|---|---|
| | Analysis | Design | Analysis | Design |
| #1 | 70 | 21 | 90.0 | 93.75 |
| #2 | 59 | 41 | 79.5 | 79.35 |
| #3 | 82 | 16 | 76.5 | 75.00 |
| #4 | 40 | 60 | 100.0 | 93.50 |

* Students attempted both analysis and design problems were not shown in the percentages.

The pre- and post-survey questionnaires also demonstrated a slight improvement of students' preference towards design. In the beginning of the semester, the average rating was 2.31 (where "1" indicating a preference of *analysis*, "3" indicating *neutral*, and "5" indicating a preference of *design*). At the end of the semester post-survey, the rating increased to 2.45.

Another indicator of students' transition from analysis to design is their performance in the final exam with respect to their overall semester grade. It was found that the class average of the semester grade, including quizzes, homework assignment, two mid-term exams (with analysis and design problems), and the final take-home exam, was 75.75. In comparison, the class average of the final exam, consisting only design problems, was 83.19.

## Conclusions

This work examined a methodology of transitioning mechanical engineering technology students from an analysis-focused mindset to a design-thinking for solving open-ended design problems. Through active problem solving activities, students were incrementally exposed to the concept and skills of design decision making. While the number of assessment instrument such as quizzes, homework, exams is limited, it was shown that students can be guided to attempt more challenging design problems. As this course is followed by a capstone design course where integration of knowledge and skills is required, it is of interest to further study effectiveness of the methodology. Student feedback and comments on the various analysis and design exercises will be collected to improve the implementation of the methodology.

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