Session 2625

Design-Based Engineering Mechanics

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Abstract

Engineering Mechanics at the FAMU-FSU College of Engineering is a four credit hours course offered every semester for chemical, electrical, environmental and industrial engineering students. The course covers the mechanics concepts in both statics and dynamics. Students classify the course as one of the most difficult core courses in their curriculum. Several educational approaches were examined to identify the best tool of delivery. Some of these tools that have been used by the author are cooperative learning, computer based instruction and design based instruction. This paper describes the design-based instructions in the engineering mechanics class. In the design based instruction, students are required to build a product that will require the engineering mechanics concepts while performing the analysis and optimization stage in the design process. Because the collaborative group learning is used for the all course assignments including the product design, students are placed in design teams. The assessment is based on competition between the design groups. By virtue of the nature of the course and the time limitation, the design process is taught through one-on-one interaction. Detailed requirements are given in the project statement. Design groups perform limited market analysis before their first meeting with the instructor who acts as a consultant. Functional analysis, idea generation and evaluation of the alternatives are done by one-on-one interaction between the consultant and the design groups. The systematic design approach is emphasizes. Upon completion the selection of one design alternative, the design group performs a complete statics and dynamics analysis of their design. Software such working model is used in the analysis. Through the three semesters where this approach was applied, students have showed higher participation, enhancement in their analysis skills and better understanding of the mechanical concepts.

I. Introduction

The FAMU-FSU College of Engineering serves two universities, Florida A & M University (http://www.fsmu.edu) and Florida State University (http://www.fsu.edu), with a total enrollment of approximately 2,000 students. Engineering students from the chemical, electrical, environmental and industrial majors are required to take the engineering mechanics class. The average student enrollment is around 70 students each semester. The course is offered three times a year. Conventionally, mechanics is taught into two consecutive segments; statics and dynamics. In this class both statics and dynamics concepts are covered. The course is considered one of the hard obstacles they need overcome to achieve their career goals. The course is a four credit hour course. Its meeting schedule is set for two two-hour sessions per week. The class usually has a mixture of sophomores, juniors and seniors.

The variation in the academic achievement between students and in the students' background makes it difficult to use one method of delivery to achieve the learning objectives. Thus, variety of teaching and learning strategies for the engineering mechanics class at the FAMU-FSU College of Engineering has been developed and used. These strategies include:
1. Integrated lecture notes: Conventionally the material for the engineering mechanics is presented into two distinctive sections: Statics and Dynamics. Commercially available textbooks are usually come into two parts. One part deals with the statics concepts and the other deals with the dynamics concepts. These concepts are covered into two distinctive classes for the mechanical and civil engineering majors, whereas for the other majors these concepts are covered into one class. If the class is taught by covering the statics concepts then merge to cover the dynamics concepts then students feel lost and there is no relation between the two areas. For this class the author developed lecture notes that integrate the two subjects in a coherent manner. The material is divided into four units: (a) Mechanics of particles include statics and dynamics of particles (b) Mechanics of rigid bodies include statics and dynamics of rigid bodies. The concepts of centroids and moment of inertia are included into this unit. (c) Energy and Momentum methods for particles and rigid bodies. (d) Special topics which include structures, frames and vibration. This approach allow the instructor to cover both statics and dynamics and allow students to make the connection between the two subjects. Furthermore, students need both statics and dynamics concepts to build there design project. The author was able to include open-ended problems, computer simulation problems and real world engineering problems as homework using this coherent approach. The notes are made available to students and other instructors through the internet at (http://www.eng.fsu.edu/~haik/EGM3512)

2. Multimedia learning: In recent years, multimedia learning becomes an important tool of instruction. Web page for the engineering mechanics class was designed to offer an interactive synchronous and asynchronous communications and mechanism to dispense the course outlines, lecture notes, exercise, worked example and grades. Asynchronous communication was accomplished through the use f personal and group email. Synchronous dialog was implemented through the use of news groups, on-line conferences and chat groups.

Two multimedia packages, Multimedia Statics [1] and Multimedia Dynamics [2], obtained by Addison-Wesley through a partnership agreement are incorporated into the course. These two multimedia packages contain real-world problems and exercises that explore concepts covered in typical engineering statics and dynamics courses. The problems in dynamics lend themselves naturally to the use of animation and motion pictures. The dynamics concepts are much easier to demonstrate with movies and animation than stationary picture. Students were assigned homework problems that extend on the available demonstrations in these two packages.

3. Commercially available math tools: Mathcad [3], Maple [4] and Matlab [5] are some tools which are used to teach linear algebra, integration, differentiation and plotting of results. On line help via the course web page on how to use these tools was provided to students. At the start of the semester a survey showed that the number of students who were familiar with these tools was

less than 2%. By the end of the semester almost 100% of students where able to show capability of using the software. The use of these software helped students in mastering the solution steps.

4. Active Cooperative learning: In class activities to engage students in the learning process through the lecture are performed in each class period. After introducing a concept through lecturing, students are placed into teams of three or four. A problem that emphasizes the concept that was covered is given to students to be worked out in about 2-3 minutes. All students are involved in the solution. Once the time is up a randomly selected student will be called upon to share with the class his approach to the solution. The approach will represent his group approach. This interaction is carefully structured to provide individual accountability, positive interdependence and use of interpersonal skills such as communication and teamwork [6,7,8].

5. Designed based: This paper is devoted to present the use of designed based teaching and learning strategy that is also used in teaching the engineering mechanics course. The designed based strategy will be discussed in more details in the subsequent sections.

II. Project-Based vs. Designed Based Learning

A study by Tobias [9] has found that a complete passive instructional strategy and focus on algorithmic problem solving as opposed to conceptual understanding are some of the reasons behind the students dropouts from science majors. The use of a variety of learning strategies such as those listed in the introduction enhances students understanding of the concepts covered in the lecture. Furthermore, they cover the variety of the learning style [10] that students may possess. However, a hand on experience that an engineer must have is not well emphasized in the cooperative learning.

Two learning styles that link the hand on experience to the theoretical learning are usually appear in the education literature: project-based learning where students are assigned many small projects through out the semester. These projects emphasize the different major concepts the instructor trying to communicate to students. In the design-based learning strategy, students are following a systematic design procedure to build a product. The systematic design procedure help students be systematic in presenting their solution methodology. It enhances the systematic approach in solving problems.

Project based instruction was implemented by the author for the engineering mechanics course in previous years. Initial assessment showed that students could extend their capabilities to achieve a higher goal. Examples of the project based include building small systems that are illustrated in textbook problems. Students are divided into groups of three or four. Each group is assigned a multiple of three different projects, one of these projects concentrates on the statics concepts and two other projects concentrates on the dynamics section. Students were required to build mechanisms as illustrated in the textbook problems then extend their analysis to include full mechanical analysis. Computer programs were usually used to perform the plotting of the results. Interpretation of the obtained results was required in a report. The student assessment of this method was encouraging. Many students started with a frustrated attitude. Toward the end of the semester the attitude was changing to a positive attitude after accomplishing the tasks. It was well demonstrated through the students' presentation that they master the concepts, which were emphasized through their projects. One of the disadvantages in this approach is that students are copying a mechanism from a textbook, which kills the creativity and finding the different possible solutions for the same problem. In a sense this method is also emphasizing the textbook approach to the engineering problem. Systematic solving skills and design methods are not well emphasized in this approach. Figure 1 shows a picture of students with one of their design projects. The design project represents an energy conservation problem in a rotational mode.

Figure 1: Project based instructions

III. Design Process

In early 1900s it was common in American industry for products to be synthesized experimentally by a master mechanic. The value of synthesizing on paper was soon realized since it was less costly and more efficient to erase rather than to remake parts in the shop. This approach was adopted in engineering education. The science and the hand on experience were essential ingredients in the engineering education until the period that followed the Second World War. Following the Second World War the trends in engineering education emphasized the science portion more than the applied side in engineering. Recently, and with the ABET 2000 criteria more engineering schools are readjusting there curriculum to implement the design as an essential part in the engineering education.

A successful design is achieved when a logical procedure is followed to meet a specific need. The procedure, called the design process, is similar to the scientific method with respect to a step-by-step routine. In the engineering mechanics course the design process encompasses the following activities, all of which must be completed [11]:
(a) Problem definition and understanding the objectives. By this step students need to understand the required tasks without any misinterpretations. Students usually spend a week after posting the design problem studying the objectives they need to achieve.
(b) Market analysis and literature search. Students must perform a market and literature search before their first meeting with the instructor who acts as consultant for all groups. The objective of the market analysis is to explore the available solutions. Usually the market analysis is done by web search.
(c) Function analysis of the problem: The solution of the problem starts at this stage. Students need to define the functions that may be required to answer the design requirements. This stage adds to the understanding of the different mechanisms and how they work. It allows students to explore many different mechanical systems that may perform the required function. A matrix that show all the functions needed to perform the required task along with the different mechanisms that achieve these functions must be first accomplished before the students are allowed to proceed to the generate different alternatives that may achieve the design requirements.
(d) Generating ideas within the limit of the constraints: Students now are combining the different functions that were generated in the previous step. This combination allows students to generate many solutions for the same problem. The alternatives that may not meet the requirement constraints are dropped out. Sketches of the other alternatives are then developed to illustrate the level of manufacturing requirement.
(e) Evaluating and choosing a suitable alternative: The different possible solution are then evaluated against each other based on manufacturing limitations, part availability, time to build,

cost, assembly and other engineering constraints. One of these alternatives will be chosen by students to build.
(f) Analysis of the solution and match with the constraints: Complete mechanical analysis is performed. The analysis include structural analysis, centroids, moment of inertia, force balance, moment balance, acceleration, etc. The mechanics concepts taught in the class are highly emphasized during this period. Students will not be allowed to build before the complete analysis is performed.
(g) Building and testing the product: The last stage in the design is to use the machine shop to produce the required parts. This step has shown many students that what may work on paper may not be made in the machine shop. This real life experience will not be achieved in a conventional class room settings.

The design process holds within its structure an iterative procedure, as the students proceeds through the step, new information may be discovered and new objectives may be specified then the steps need to be revisited again. Similar design process is taught for the mechanical engineering students in the introductory and advanced design courses. The process is introduced to the chemical, industrial, electrical and environmental engineering students through the engineering mechanics class. It should be emphasized here that when this process is taught, students were able to show completely different possible solutions for the same problem. Building a product through a systematic way help students build a systematic learning skills. Communication and teamwork are also implied when building a product.

Examples of the use of the design process for the engineering mechanics course can be found at http://www.eng.fsu.edu/~haik/EGM3512. One of the examples that will be illustrated in the following section is the cable car project.

IV Cable Car Project

Students during the summer 1998 semester were given to design and build a cable car. The cable car must be able to carry a minimum weight of 10 lbs (weight of the car not included) and travel down a cable that will be set up between the second and third floors of the college of engineering building. The cable will be fixed at both ends and span diagonally from second floor to the third floor. The car must be self-driven (i.e. no external drum and pulley mechanism). The drive mechanism must be within the unit. The overall dimensions of the unit should not exceed 1 x 1 x 1 feet. The cable will be fixed at both ends and cannot be removed. The car must be installed onto it. The unit must not damage the cable in any way. The competition will be based on the time that the unit takes to travel the length of the cable. The cable must be controlled to travel the distance in 2 minutes. Penalties will be assigned if the car travels faster or slower than two minutes. If the car travel without any control, the project will be rejected and assigned a zero for performance. If the car takes longer than 2 minutes a decreasing grade scale will be considered. The device must be a stand-alone unit. No assistance from the operator will be allowed after actuation. Any device that is available through a retailer will be disqualified. The device must be designed and constructed from simple component level, by team members.

Students were assembled in-groups of three or four students. The group set meeting time with the instructor. The instructor acted as a neutral consultant for all groups. Because of the nature of the engineering mechanics course and time limitation the design process was taught through the consulting times with the groups. This provided one-on-one instruction for all groups.

The instructor working as a consultant for all groups open a much-needed channel of communication between students and instructors. Through these meeting the author was able to identify the learning styles of each group then compile it to the whole class. This helped the instructor to identify the suitable method of delivery that suite the whole class. Furthermore, these meetings built a communication channel to identify the problems among students who needed help the most. The teaching assistant reported that many students turned into them for help after the beginning of this procedure. Scheduling of events and time management was enforced during the design phase.

The mechanics concepts played role in the setting up the requirement in the whole design process. Students were required to perform the following analysis
(a) Force analysis for the frame and structure of design body
(b) Kinematics of the cable car to choose the motion control
(d) Kinetics of the cable car to produce the sufficient torque and force to move to overcome friction and to break overcomes gravity.
(e) Centroid calculation for the moment balance
(f) Moment of inertia calculation for the moving parts
(g) Justification of the performance of particle or rigid body calculation
(h) Use of energy methods
(i) Use of working model to simulate the design
(k) Cost analysis and engineering drawings

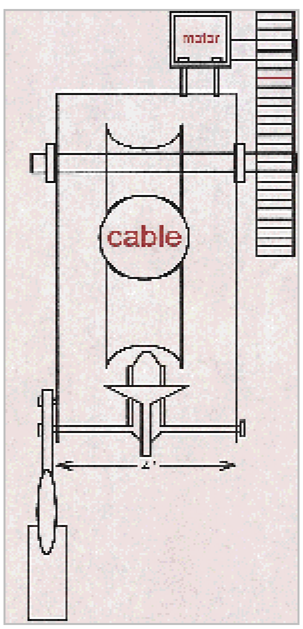

Figure 2: Schematic of cable Car


Figure 3: Design team

Figure 2 shows a schematic of one design for a cable car that students were able to achieve. The schematic shows two wheels that fit on top of the cable, one wheel is three inches in diameter while the other is three and one half inches in diameter. A six inches in diameter steel gear was welded to the shaft that the wheel sets on. This gear was placed outside the box. This gear was meshed wit a two inch in diameter steel gear, which was set on the shaft of the motor. Figure 3 shows two students holding their design, which was shown in figure 2.

V Outcome Assessment

The author utilized surveys to measure the assessment of the student experience using the designed based learning for a class such as engineering mechanics. The summery of the survey shows the following
(1) Students like to work in-groups: Over 95% of the surveyed students showed that group work helped them in learning material. The peer interaction helped them in building communication skills and enhanced their teamwork abilities.
(2) Student like hand on experience: Over 90% of the surveyed student showed that they learned the material and understood the physical meanings of concepts better when they built a product. Abstract concepts such as moment of inertia and centroids start to have physical meaning when they are implemented in the building of the project.
(3) Students like to work on real life problems: Over 95% of surveyed students liked working on the project despite its time and effort requirement.
(4) Students' friends and family become involved in the students learning which gave the students a moral support and encouragement through the semester.
(5) Other class material became a part of the design. Industrial students developed schemes to reduce cost. Electrical students applied digital circuit on their product to show the time and distance as their product move.
(6) Overall assessment is positive with a positive student attitude.

The author has noticed the following, which was not surveyed:
(1) Experimental methods to measure centroids and moment of inertia were applied for the different shapes
(2) Student enthusiasm increases as the new material is introduced when the students see how they can apply it in their design
(3) Student involvement in the class activities and the consulting meeting showed the higher level of student evolvement
(4) Class is not boring anymore to students or to the instructor. The class period of 2 hours is well spent by both the students and the instructor.
(5) Systematic design process helped students in building better product
(6) Non of the design products is symmetrical. This illustrated to student the vast variety of engineering solutions for the same problem

VI. Conclusions

This paper presents the author experience in using a designed based instruction in the engineering mechanics class. The design-based instruction uses the systematic design process as a tool to enhance the learning objectives of students. It further involves students in designing and building a product the emphasized the concepts utilized in the engineering mechanics. The assessment of this method showed preference by students and instructor. It should be emphasized that the used of design-based instruction can be implemented in many other engineering courses.

VII. References

1. Gramoll, K. and Abbanat, R. *Multimedia Engineering Statics*, Addison-Wesley Interactive, http://www.aw.com
2. Gramoll, K. and Abbanat, R. *Multimedia Engineering Dynamics*, Addison-Wesley Interactive, http://www.aw.com
3. Matsoft Co., Mathcad, http://www.mathsoft.com
4. Maplesoft Co., Maple, Release V, http://www.maplesoft.com
5. Mathworks Co., Matlab, http://www.mathworks.com
6. Felder, R. M., *How students learn: Adapting Teaching Styles to Learning Styles*, Proceedings of the Frontiers in Education Conference, Santa Barbara, CA, 1988.
7. Haik, Y., Chen, C. J. and Kuncicky, D., *Development of Multimedia Instructional Tools for Engineering Mechanics*, Proceedings of the International Conference on Engineering Education, Vol. 1, pp. 696-702, Chicago-IL, 1997.
8. Haik, Y., *Collaborative Learning in Engineering Mechanics*, Proceedings of the 13th National Congress in applied Mechanics, Gainesville, FL, June 21-26, 1998.
9. Tobias, S., *They 're Not Dumb, They 're Different: Stalking the second Tier*, Tucson Research Cooperation, 1990.
10. Felder, R. M., *Reaching the Second Tier-Learning and Teaching Styles in College Science Education*, Journal of College Science Teaching, Vol. 23, No. 5, pp. 286-290, 1993.
11. Haik, Y. and Chandra, N., *Engineering Design Process*, Lecture notes, FAMU-FSU College of Engineering, Tallahassee, FL, 1998.

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