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Teaching Mechanical Design for Mechatronics Engineering Students Using a Project-based Sequential Learning Approach

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Abstract

In this work, we described project-based multi-objective sequential learning modules and the teaching strategy of the machine design subject for undergraduate mechatronics engineering students. The suggested approach introduced the design procedures and concepts using a single multi-level design problem as a semester-long project. The students worked in teams to complete design modifications using new and enhanced design concepts and tools during the semester. An Excel spreadsheet for the design analysis was created by each team and was upgraded repetitively during the course to achieve new design specifications and criteria. In addition, the students built a numerical model for the same project using Finite Elements method and gradually updated the model during the semester using evaluation tools and design libraries in SolidWorks. The students compared and discussed results of the numerical simulation and the traditional design equations and formulas through two midterm projects, final project reports, and several classwork assignments.

The Machine Design course had been implemented and evaluated at Engineering Department at Colorado State University - Pueblo. The students' participation rate was high during the implementation of this advanced subject in mechanical engineering. They gained skills in critical thinking, teamwork, and engineering design. The main challenge from the students' perspective was their variable skill level in using the software and from the instructor's perspective was keeping the students involved in a long-term project problem as well as introducing new theoretical concepts in a single design problem. This paper describes learning modules and provides information on how the modules are integrated into a cohesive system at the end of the project.

Introduction and background:

Mechatronics Engineering is a flexible, broad degree that prepares graduates to work in many branches of industry. Mechatronics combines mechanical and electrical engineering with computer technology and computer science to create smart devices that improve the quality of our lives. Electrical and mechanical systems, controlled by computers, are at the core of a wide range of processes and products. Robots, the Mars Rover, a heart-lung machine, a 3D printer, a computer controlled telescope, and an atomic force microscope are all examples of mechatronics devices. Philosophy and structure of a mechatronics engineering program "divert from the classical single-discipline engineering programs and induce a challenge for the higher education institutions. Different institutions in various countries are reacting differently to this challenge but, all aiming at educating mechatronics engineers [1].” Constructing a high level undergraduate mechatronics course, therefore, poses a clear challenge in selecting the appropriate content, methodology, and course structure. Moreover, specific curricula vary among institutions, depending on the specific strengths of their faculty.

Machine design is a cornerstone foundation course in any mechanical engineering program and has the same importance in any multidisciplinary engineering field like mechatronics and bioengineering. The traditional objective of this course is to engage students with analysis techniques to guard against specific failure modes or to predict a product’s life cycle based on a loading scenario. Generally, the course is taught by introduction of a topic first, e.g. stress analysis; then examples are presented and homework problem-sets are assigned to allow students to practice and sharpen their problem solving skills [2]. The traditional approach is relatively hard for multidisciplinary engineering students because of the rich and condensed study program that makes them hardly involved with advanced level specialized course, like Machine Design, even if they have the basic knowledge required for this course.

Okojie [3] claims that “in a highly competitive manufacturing industry, the total cost of design and manufacturing can be reduced and hence increase the competitiveness of the products if computers can integrate the whole working procedures. Computer-aided integration has, therefore, become an inevitable trend. Many industries have achieved a great deal of success between non-integrated and integrated systems.”

Egelhoff et al. [4] described “a structured problem-solving approach which uses the students' understanding of free-body-diagrams, shear and moment equations, and energy methods. With the development of note-taking handouts supplied to the students, the structured analysis is led by the instructor using Castigliano's theory of internal energy. The problem formulation is kept general until the last step. The numerical integration can be performed by using the software of the students' choice.” The researchers [4] “found that using this approach accomplishes a richer, deeper understanding of design among our students and increases their confidence as indicated by our pre- and post-activity assessment.”

In general most millennium students entering engineering programs with a background in computing, video games, computer graphics and other ‘virtual’ experiences and skills are ready to interact positively with any advanced topic using software packages and tools. The software skills and knowledge can be used to support teaching and learning of traditional engineering courses like machine design.

This paper shares the authors’ experience in introducing the machine design subject to the third-year mechatronics engineering students via a single regular course, Virtual Machine Design. The objective is to introduce the machine design concepts in a systematic and easy way that improves the students' involvement in the course topics and helps them use their ‘virtual’ skills in programming and engineering graphics as complementary tools for machine design subject. In addition, the proposed teaching style will help improve critical thinking and teamwork which is important in the design process and product development in industry.

Course Description

The Virtual Machine Design course is a three credit-hour course offered to junior students (2 hr lecture and 2hr lab) and it is focused on the analysis of stresses due to applied loads, static failure theories for ductile and brittle materials, fatigue, and analysis of mechanical components, such as shafts, fasteners, gears, etc. [5].

Prior to this course, the students had freshman and sophomore level courses. We expect the following prerequisites by topic:

1. Basic physical concepts: force, torque, energy, power
2. Working knowledge of calculating 3D forces and torques
3. Working knowledge of dynamics
4. Basic understanding of stress, strain, bending load, torsion, failure mechanisms
5. Working knowledge of mechanical properties of engineering materials
6. Programming skills: variable assignments, loops, and logarithmic problem-solving skills (MATLAB or MS-Excel).
7. Graphing 3D objects and system assemblies using SolidWorks,

Course Implementation:

The course is taught by first introducing each topic then presenting examples and finally assigning homework. The class assignment problem-sets are assigned to allow students to practice and sharpen their problem solving skills. In addition, the students are allowed to work in teams to solve in-class assignments during lab time. Each student is required to develop from scratch an MS-Excel sheet to complete the analysis of a countershaft carrying two V-belt pulleys as shown in Figure 1, and to submit a standard design report.

During the semester the students need to work on three sequential design projects. Each project has specific design specifications for the required system which are related to the topics covered during the previous course period. Project#1 and Project#2 include several assumptions to make sure that the students have the adequate scientific knowledge and skills to work on the assigned project. Project#3 is more related to professional design specifications and no assumptions were given in the project description (i.e. the student needs to figure out if any of the assumptions are applicable to the given design specifications).

Also, each student is asked to design a 3D part assembly model for the countershaft carrying two V-belt pulleys system using SolidWorks. A static study and dynamic study need to be implemented using Finite Element (FE) simulation tools in SolidWorks for Project#2 and Project#3. After each project, the instructor initiates scientific and technical discussion with each student to identify the errors and weak points in the design report so that the students can avoid them in the next project assignment.

Note: the values X1, X2, X3 and X4 are assigned differently for each student

Project#1: (Shaft Layout, Forces, Reactions, Torque, Shear, and Moments, Shaft Design for Static load),

Figure 1 shows the design work sheet for Project#1 for student A. The pertinent design specifications for the required system are:

- The power is transmitted through the shaft and delivered to the belt on pulley *B.* Assume the belt tension on the loose side at *B* is **X1** percent of the tension on the tight side.
- The loads are acting in the yz plane
- Assume that the bearings act as simple supports for the shaft and
- The weight of the system can be ignored

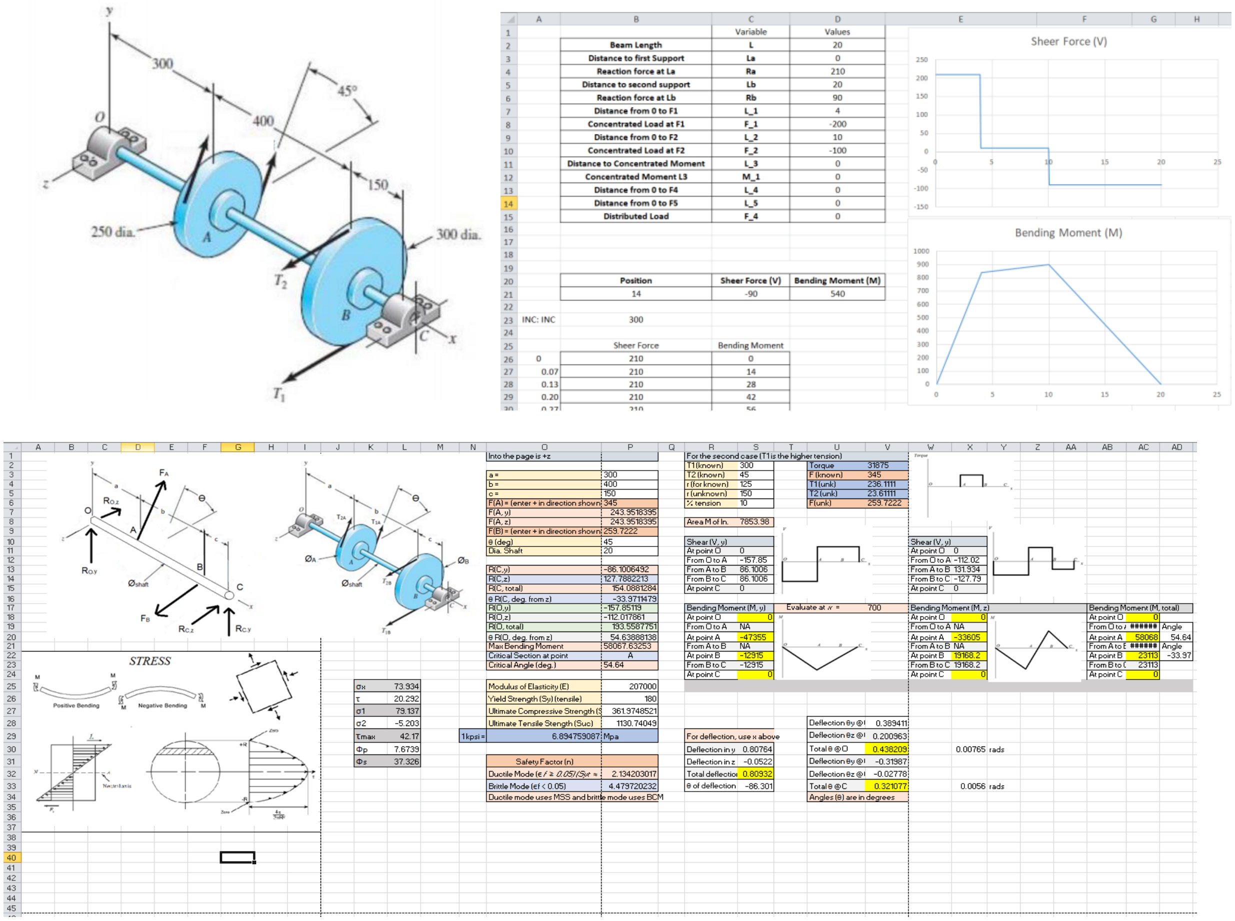
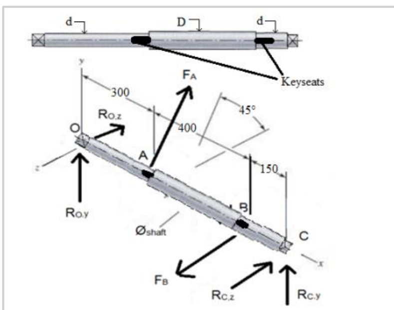


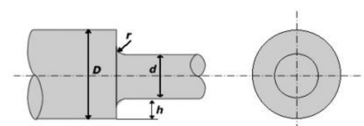
Figure 1 Design Work Sheet for Project#1

Project#2: (Shaft Layout, Forces, Reactions, Torque, Shear, and Moments, Shaft Design for Static load, Keyway and the Key, Shaft Design for Dynamic load (Fatigue), Critical Speed analysis, 3D model and Static and Dynamic study)

Figure 2 shows the design work sheet for project#2 for student A. The pertinent design specifications for the required system are:

- The power is transmitted through the shaft and delivered to the belt on pulley *B.* Assume the belt tension on the loose side at *B* is **X1** percent of the tension on the tight side
- Keyseats are cut with standard end mills.
- Minimum factor of safety for the design is 2
- The bearings are press-fit against the shoulders with combined reliability of 95 percent.
- The pulleys seat against the shoulders and have a hub with screws to lock them in place
- The loads are acting in the yz plane
- Bearings act as simple supports for the shaft, and
- The weight of the system can be ignored.





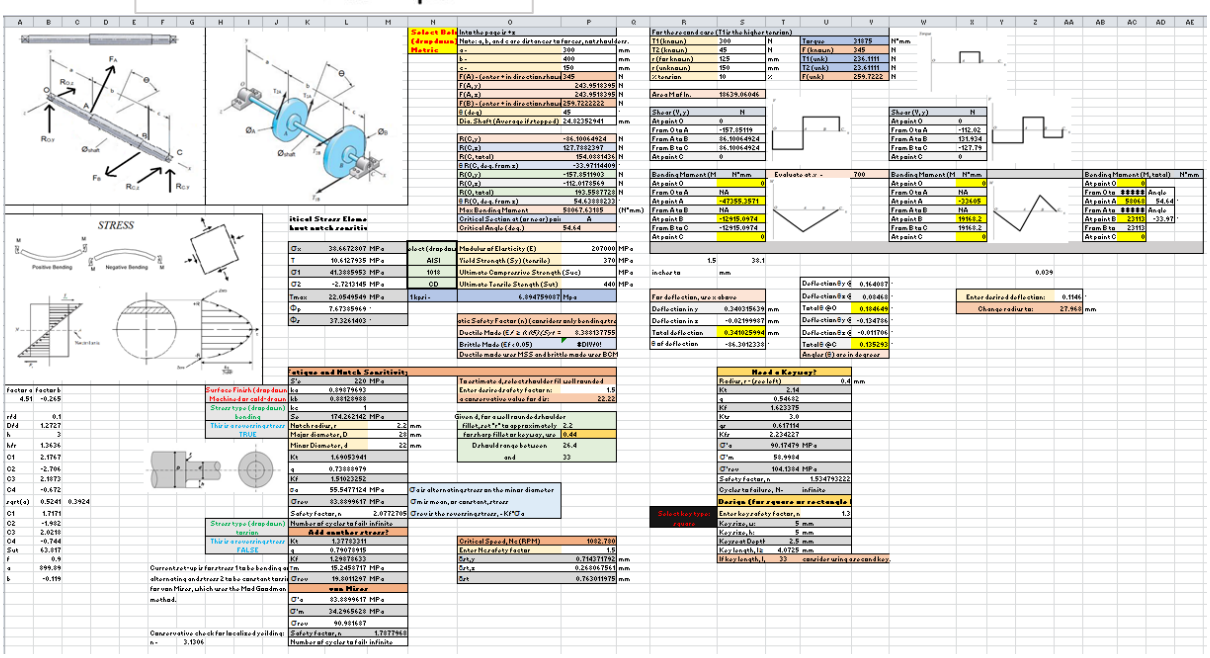


Figure 2. Design Work Sheet for Project#2

Project#3: (Shaft Layout, Forces, Reactions, Torque, Shear, and Moments, Shaft Design for static load, Keyway and the Key, Shaft Design for Dynamic load (Fatigue), Critical Speed analysis, Bearing selection, Design Mounting and Bearing Housing, 3D model and Static and Dynamic study)

Figure 3 shows the design work sheet for Project#2 for student A. The pertinent design specifications for the required system are:

- Power to be delivered: **X1** hp
- Shaft speed **X2** rpm
- Low shock levels
- Bearings life > **X3** hours, infinite shaft life
- The belt tension on the loose side at *A* is **20** percent of the tension on the tight side
- The belt tension on the loose side at *B* is **15** percent of the tension on the tight side
- Width of Pulley A and B is 30 mm
- Keyseats are cut with standard end mills
- Minimum factor of safety for the design is 2
- The bearings are press-fit against the shoulders with combined reliability of 95 percent
- The pulleys seat against the shoulders and have a hub with screws to lock them in place
- The guiding block at C and O need to be fixed to a horizantal 20 mm thickness Alloy steel base plate using for bolts.
- The loads are acting in the yz plane

The design work sheet is implemented using Microsoft-Excel. The user enters the required information about the design parameters of the shaft. Once the data is entered, the design work sheet computes all the parameters required in analyzing the design parameters of the shaft using formulas and codes given in the textbook. After running the FE simulation for the same design case the students need to compare the differences in results and try to explain the source of difference (Figure 3.)

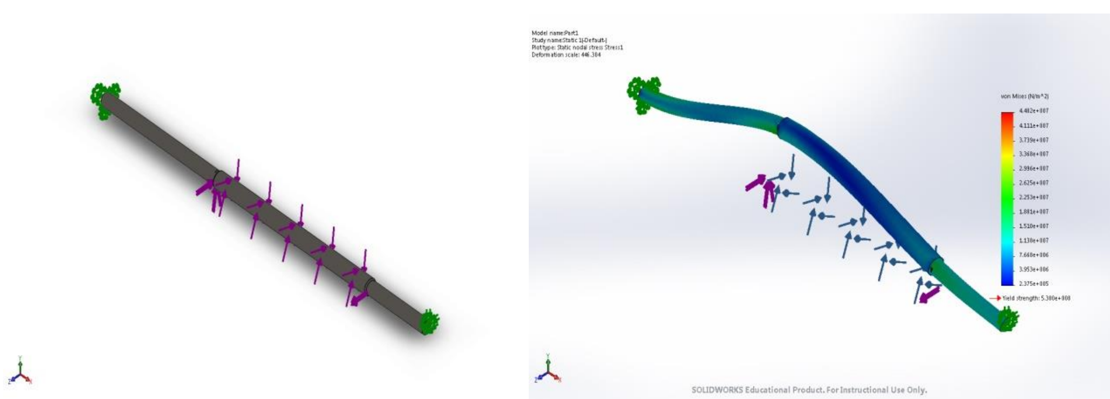


Figure 3 Simulation Study Configuration and Static Stresses

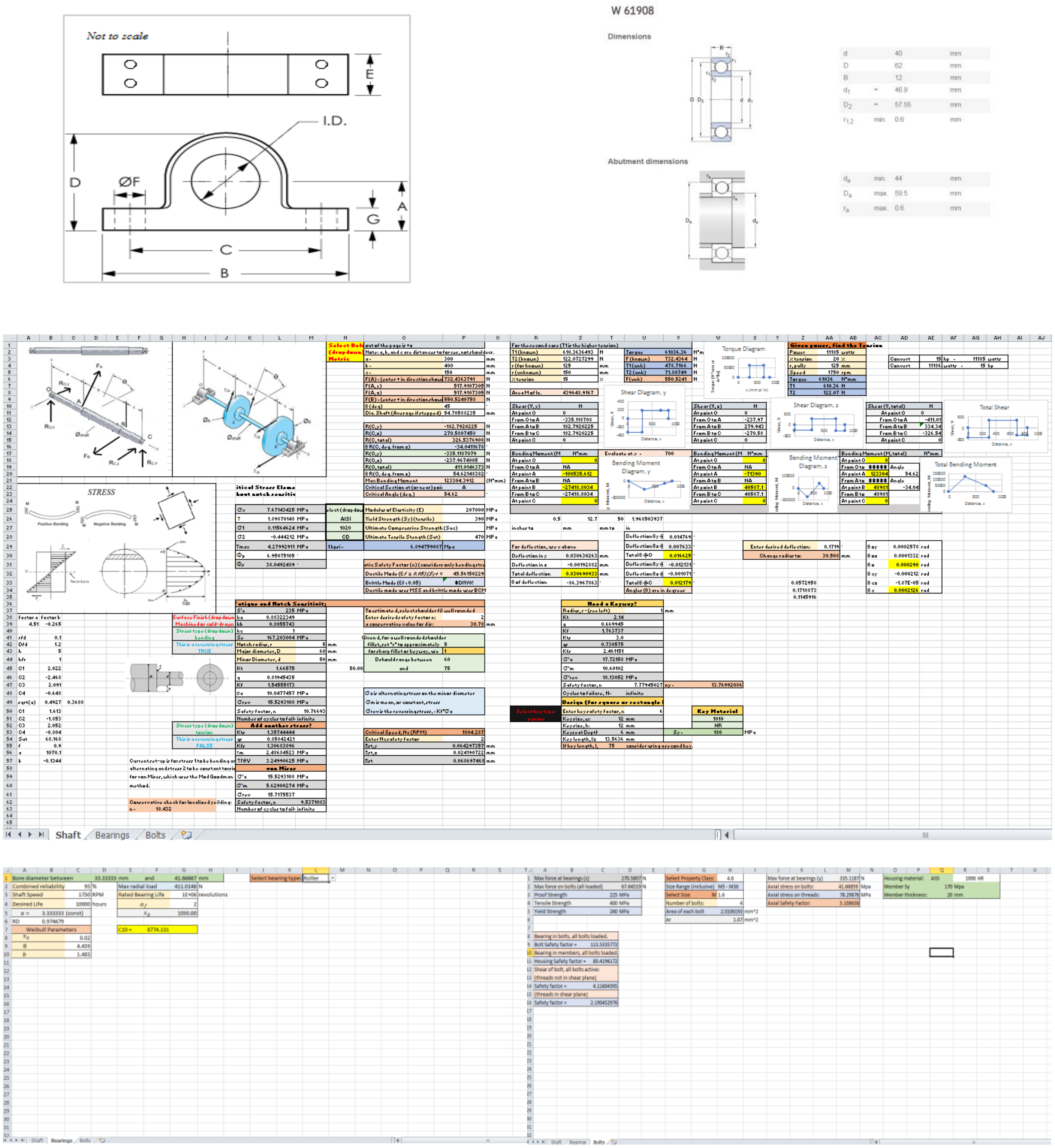


Figure 4 Design Work Sheets for Project#3

Assessment of Student Attitudes

At the close of the semester, the authors used standard university survey to gauge the opinion of the students concerning the course. The class had a total of 12 students at the outset, and one student did not complete the semester. Of the 11 remaining, a total of 9 students responded to the survey. Table (1) shows students' responses to some critical questions about learning and teaching styles. In general, the students show positive attitudes for the course and teaching approach.

Table (1) students’ responses to selected questions in the end of semester survey.

Question Text	Weighted Students response
Instructor encouraged critical thinking and analysis	5/5
Instructor encouraged class participation	4.8/5
Instructor communicated enthusiasm for the course	4.8/5
I learned from the course	4.3/5
Teaching strategies enhanced learning	4.4/5

The following are students' responses to Question: **What works well?**

- Projects and lectures
- The projects were much better than a standard test
- The involvement that us students have on the labs. He knows his material and wants us to know it as well.
- Take home projects were very good way to work on what we learned in class.
- Labs and examples in class
- Working on labs together was good. Pace of the class at beginning of semester was very good. Instructor new material very well and showed passion in teaching it. Was able to answer questions well.
- The various examples we did in class
- The writing on the boards was helpful.

Conclusions and Lessons Learned

First, the students showed high enthusiasm while going through multilevel projects’ sequence to develop the design work sheet as shown in Figures 1-3. **Second**, the one to one design report discussion and repeating analysis helped students to overcome their weaknesses in understanding basic design concepts and procedures, and additionally, to improve the critical thinking skills related to the design problem and design methodology in general. **Third**, even the students with different skill levels (MS-Excel and SolidWorks), showed high interest for learning new skills required to complete their project assignments. **Fourth**, introducing a numerical methods (finite elements) topic in the course helped the students to interact with new design approach and tools. This interaction between traditional design approach and design toolbox and libraries in SolidWorks is useful in gaining more in-depth understanding of design concepts. Also, this multi-approach experience challenged the students and provided an advanced level experience in the course better related to the contemporary work field. **Fifth**, due to large differences in students' computer skills, it is important to integrate computer skills training in the sophomore and junior level courses with advanced level courses. This can be done by designing new cross-level related assignments and projects. **Sixth**, this course experience is coming from a relatively small class size, thus it is important to analyze learning course outcomes with medium or large class size in the future.

The above observations and conclusions come from direct notes from the students or indirectly from the standard end-of-course surveys, in addition to discussions with other faculty in the Engineering Department.

As a general note from the authors, the suggested systematic instructional approach that emphasizes the software skills of the students can be implemented for any course in a multidisciplinary program. The required skills and expertise of the instructors (and students) need to be evaluated carefully before course implementation.

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