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Towards a More Hands-on, Design-oriented Course on Mechanisms

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Abstract

Traditional approaches to teaching mechanism design have tended to emphasize analysis over design. Both are important for complete coverage of the subject, but there is a current need to improve the balance of design with analysis-oriented aspects of the subject. Several innovations toward this end have been incorporated into an undergraduate course in mechanisms at San José State University and have been favorably received by the students.

Introduction

A critical challenge facing those teaching undergraduate mechanical design is how to provide students with the proper balance of engineering science and design so that graduates are fully grounded in theoretical fundamentals and can apply their knowledge practically. Many would agree with Smith, 1994, that design education is not as well off as it was fifty years ago, because abstract engineering science has been emphasized at the expense of concrete engineering practice. A common complaint from employers of engineering undergraduates is that "they don't have any practical experience." Additionally, and more seriously, "lack of motivating engineering relevance in lower division courses has been hypothesized as a major factor for undergraduates deselecting engineering as a career." (Agogino, et. al., 1992). The Accreditation Board for Engineering and Technology (ABET) has responded to the need for more balance in the last five years by becoming more specific with regard to the design content in undergraduate programs, however, there is still a long way to go to integrate design and concrete engineering practice into the curriculum.

A case in point is the teaching of mechanism design. The traditional approach in teaching mechanisms tends to emphasize kinematic and dynamic analysis over design. The usual order is to plow through displacement, velocity, acceleration, and force *analysis* before any mechanism *synthesis* or *design*. Following this approach, it is easy for students to lose interest or get lost in kinematics, because they have no sense of origin or application of the mechanisms they are analyzing. Additionally, by emphasizing analysis over design, students end up lacking the practical facility to design a mechanism to accomplish a specific task.

We have successfully introduced several innovations into a one semester, undergraduate course in mechanisms at San José State University that address the need to improve the balance of analysis with design. The course, ME 155, is a required three-unit, lecture/laboratory course, normally taken by junior level students. The innovations follow six major thrusts:

- Order of presentation of the subject areas
- Use of cardboard models
- Mechanism sketching assignment
- Hardware dissection laboratory exercise
- Term design project

The following sections will explain the innovations in more detail and discuss the results of their introduction into ME 155.

Order of presentation of the subject areas

We changed the traditional order of presentation of topics, so that synthesis is introduced toward the beginning rather than toward the end of the course. (A current course outline is included as Appendix A). This approach follows that of Norton, 1992, who argues that "one cannot analyze anything until it has been synthesized into existence."

We present graphical synthesis in approximately the second week, immediately after sufficient terminology and kinematic fundamentals have been introduced. Here, the students begin to synthesize fourbar mechanisms for simple tasks such as two-position rocker output motion, three position coupler motion generation, etc.

We then cover displacement analysis, both graphical and analytical beginning in the fourth week. Here, students are introduced to complex numbers applied to describe link vectors in loop equations.

From displacement analysis, the students have enough familiarity with vector loop equations that we can then cover analytical synthesis starting about the sixth week.

The balance of the course presents velocity, acceleration, and force analysis, and finally, cam design beginning in approximately the eighth, tenth, thirteenth, and fifteenth weeks respectively.

We have found that introducing synthesis early in the course has several benefits:

- It helps pique students' curiosity and interest in mechanism design and maintain their enthusiasm throughout the course.
- It provides context for kinematic and dynamic analysis covered later in the course.
- It equips the students early enough in the course that they can tackle a practical design term project where they must create a device involving a mechanism to solve a particular problem.

Use of cardboard models

In homework problems where students have synthesized a linkage, we require that they build movable cardboard models to verify that their designs can achieve the desired motions. Models provide a rapid means to investigate the results of linkage synthesis. For example, the student can readily observe a minimum transmission angle or verify that no limiting toggle condition is encountered by articulating a linkage model.

Models are easily constructed using strips cut from the cardboard backing of a pad of paper or light posterboard for links, such as described by Hartenberg and Denavit (1964). Revolute and sliding pair joints can be constructed using thumbtacks, brad clasps, etc. We have experimented with a variety of methods to create revolute joints, and have found that soft, steel wire, such as that used to hang picture frames works best. A length long enough to allow a few millimeters to grasp the link when the ends are bent over is sufficient. These simple clasps are easy to work with and are inherently safer than thumbtacks!

We have found that construction of cardboard models:

- Provides an enjoyable and motivating design experience.
- Helps the student gain insight into the quality of their linkage designs.
- Introduces the concept of prototyping in design.

For many students, model building is a highlight of the course. Combined with synthesis, model building provides a simple, but complete design experience. It allows the students to go from a need (the problem statement) through conceptual design (synthesis) all the way to implementation and testing (cardboard model) in a relatively short time.

The concept and discipline of rapid prototyping are very important for mechanical design students to grasp. Simple models can be extremely effective tools to elucidate unforeseen problems and stimulate new ideas. Linkage model building provides a natural context to introduce the concept of prototyping in design.

Mechanism sketching assignment

The mechanism sketching assignment is an ongoing assignment in which students are asked to <u>find</u> mechanisms in their everyday experiences, <u>sketch</u> their form and basic function, and <u>determine</u> their material makeup and nature of construction. They record this work in a sketchbook, which is periodically reviewed and graded.

There are several purposes for the sketching assignment:

- To give the students hands-on exposure to a variety of mechanisms used in common products
- To motivate the students to observe and investigate mechanisms around them
- To have the students understand joint types and how mechanisms are commonly assembled
- To help the students gain familiarity with materials used to construct mechanisms
- To improve the students' ability to communicate graphically through quick sketches
- To introduce the students to the idea of keeping a design notebook

The sketching assignment aims at improving the students' skill at graphical communication and helping them build a knowledge base of how mechanisms are practically applied. Both goals are vitally important for the mechanical design engineer.

One sketching assignment is comprised of the following elements:

- A perspective sketch of the device that contains the mechanism
- A sketch of the mechanism showing key features roughly to scale
- A kinematic diagram of the mechanism (that is, a simplified diagram showing the essential elements of the mechanism: joint types and link arrangement) sketched roughly to scale
- A description of the link materials
- A description of the joint construction (that answers, "How are the links held together?")
- Measurements of key dimensions (between joints, etc.)
- A description of the purpose of the mechanism

Figures B1, B2, and B3 in Appendix B give an example of a sketching assignment.

Students have reacted positively to the sketching assignments. The students seem to enjoy discovering how mechanisms are applied in devices that they had previously taken for granted. Many have difficulty initially with hand sketches, particularly the overall device sketch in perspective. The students have had some introduction to orthographic constructions and Computer-Aided Design (CAD) prior to the course, but little freehand sketching. Most improve markedly after several assignments.

Hardware dissection laboratory exercise

Hardware "dissection" refers to a hands-on learning experience consisting of disassembly and reassembly of a mechanical artifact. We have adapted ideas for a laboratory exercise from a course called Mechanical Dissection developed by Professor Sheri Sheppard at Stanford University (Sheppard, 1992). The exercise gives students an in-class opportunity to explore how mechanisms are incorporated in common consumer devices. The specimen dissected is a 3.5 inch floppy disk drive.

The goals of the exercise are manifold:

- To give the students a hands-on experience investigating the application of mechanisms in a common consumer product
- To expose the students to the design process in getting them to think about how design function is mapped into hardware
- To provide the students with another significant cooperative learning experience
- To help the students practice their written and oral communication skills

We give the students a handout several days in advance of the dissection which directs them in the procedure for disassembly and asks questions regarding the mechanisms and devices inside. On the day of the dissection, the students are divided into teams of two. Each team is given a disk drive and screwdriver. They have about two hours to complete the dissection and return a properly reassembled drive. A week or two later, the teams turn in a written report based on information recorded during the dissection and make a five minute oral presentation about a kinematic analysis of one of the mechanisms they discovered inside.

Course evaluations and informal surveys indicate that the dissection laboratory is immensely popular among the students. The common sentiment after finishing the laboratory is, "I wish we could do more of this!" The students appreciate the hands-on nature of the laboratory and the chance to explore the inner workings of a device they commonly use. The written report and oral presentation are excellent opportunities for the students to sharpen their communication skills in the context of learning about mechanisms.

Term design project

The term design project provides students with an open-ended, hands-on, and practical opportunity to design, analyze, and construct a mechanism to solve a particular problem.

The overall organization of the term design project is as follows:

- The project assignment is presented to the students on the first day of class.
- The students are given three options from which to choose their project.
- The students are assigned into groups of three unless prior arrangements are made with the course instructor.
- The groups turn in milestone assignments throughout the term.
- The groups present their results in a poster session during the second half of the final examination and turn in a final report.

The project assignment takes the form of a memo from the project director to the course engineers. The memo clearly explains the options, deliverables and schedule. The presentation of the results and final report determine 25% of each student's course grade.

Three options are given to allow the students maximum flexibility in deciding what they will devote themselves to. The first option is to define their own problem. Students are encouraged to find a problem from work, home, hobby, etc. This option is highly recommended, because students learn the most and produce the best results by working on something they are personally interested in. The second option is a broad problem statement to give the student with no burning passions at least a general direction from which a problem can be formulated. The third option specifically defines a problem within the general area outlined by the second option. This last option gives the student who needs more structure a well defined task to carry out.

Examples of the range of projects we have seen from groups who have defined their own problem are shown in Table 1. An example of problems we have given for options 2 is, "Design a device to aid a handicapped student at San Jose State University, and for option 3, "Design a device to enable quadriplegic to load and unload a floppy disk from a personal computer."

In the spirit of cooperative learning (Ercolano, 1994), the term project is intended to be a group effort to give students an experience carrying out a design project with others. For most students, the term project is their first design experience and their first group design project. We allow the students to select the members of their group with the hope of minimizing personal conflicts. The students who do not choose their own groups are assigned to groups by the instructor.

• prosthetic knee joint • fixed rope ascender • animation model for an oblique wing supersonic transport • rear-wheel suspension for a mountain bike • self-feeding aluminum can crusher • solar panel tracking device • hands-on exhibit for the San Jose Children's Discovery Museum

Table 1. Examples of term projects from groups who have defined their own problem

There are four milestone assignments that project teams must turn in at specified dates:

- Background of the problem and project goal statement (week 5)
- Functional specification (week 7)
- Design concepts (week 9)
- Analysis of selected design (week 13)
- Final report and presentation of the device (week 16)

The objectives of the milestone assignments are to:

- Guide the teams through the design process through structured assignments
- Force the students not to procrastinate and leave the project to the last minute

The final report compiles the milestone assignments in a coherent form.

The presentation consists of poster session and demonstration of the device, which is held during the second hour of the final examination. We have found that students don't mind a short final exam! The poster session is a low-stress, fun way to end the course. It gives the students a chance to learn from their peers and show off the fruit of their labor.

Course evaluations show that for most of the students, the term project is the best part of the course. The students get very enthusiastic about the hands-on aspect of the project. The project gives them extreme freedom to conceive and bring into existence a device using the concepts and methods developed in the course.

Conclusions and Future Directions

The innovations we have introduced into ME 155 have substantially improved the balance of analysis and design. By introducing mechanism synthesis before analysis, we provide the context necessary to understand and apply methods of kinematic and dynamic analysis. Use of cardboard models gives students a complete experience of the design process, and introduces the idea of prototyping in design. The sketching assignment helps students develop competency in graphical communication and expand their knowledge base of how mechanisms are practically applied. Hardware dissection provides students with an opportunity to explore how mechanisms are incorporated in familiar consumer products and to practice technical communication skills. A term design project gives students an in-depth, cooperative experience to practically integrate concepts and skills gained through the course. In summary, we have modified flow of the course and introduced design-oriented experiences that contextualize the analytical aspects of the subject.

Most importantly, the innovations have generated enthusiasm in the students for the subject. By and large the students have reacted positively to the changes we have made. Feedback from course evaluations praised the hands-on nature of the assignments. Based on the results we see from the term projects, the students come through the course with a practical ability to design and analyze a mechanism for a particular task.

We have, however, received criticism from the students that the class requires too much work. Consequently, we are making continuous improvements, such as reducing the length of homework assignments and eliminating some laboratory assignments to balance their workload.

Further innovations are planned for coming semesters:

- Additional dissection laboratory
- Integration of computers into classroom instruction

Since the disk drive dissection has been so well received, we would like to add another dissection assignment. The second dissection will allow students another opportunity to practice written and oral communication having received feedback from the instructor after the first assignment.

We would like to develop several computer assisted classroom instructional modules using commercially available authoring and mechanism simulation software. The standard technique of blackboard lecture is inadequate for demonstrating and modeling mechanisms (Nisbett, et. al., 1993). There is tremendous opportunity to pioneer new paradigms involving computer assisted curriculum delivery in the classroom.

A course on mechanisms should be one of the most interesting and practical courses a mechanical engineer takes. By improving the balance of design to analysis we believe this can be a reality.

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Appendix A - Kinematics and Dynamics of Machinery Course Outline

1. Introduction to Kinematics and Mechanisms
   - Important definitions
   - Classification by task
   - Links, joints, and kinematic chains
   - Degrees of Freedom (DOF) and mobility
2. The Fourbar Linkage
   - Grashof condition
   - Types of fourbars, inversion
   - Transmission and deviation angles
3. Graphical Synthesis
   - Motion generation
     – Two prescribed positions
     – Three prescribed positions
   - Path generation
     – Three prescribed positions
   - Function generation
     – Three precision points, Chebyschev spacing
   - Quick-return mechanisms
4. Displacement Analysis
   - Graphical method (Computer-Aided Drawing (CAD) application)
   - Analytical methods using complex numbers
5. Velocity Analysis
   - Graphical method - vector polygon (CAD application)
   - Analytical methods using complex numbers
   - Instant centers and their application to velocity analysis
   - Mechanical advantage
6. Acceleration Analysis
   - Graphical method - vector polygon (CAD application)
   - Analytical methods using complex numbers
   - Coriolis acceleration
7. Dynamics of Mechanisms
   - Inertia forces
   - Graphical method - vector polygon (CAD application)
   - Analytical methods using complex numbers
8. Analytical Synthesis
   - Two, three, and four prescribed positions
9. Cams
   - Cam and follower types
   - Displacement diagram – types of follower motions
   - Velocity and acceleration profiles
   - Cam design

Appendix B - Example of Sketching Assignment

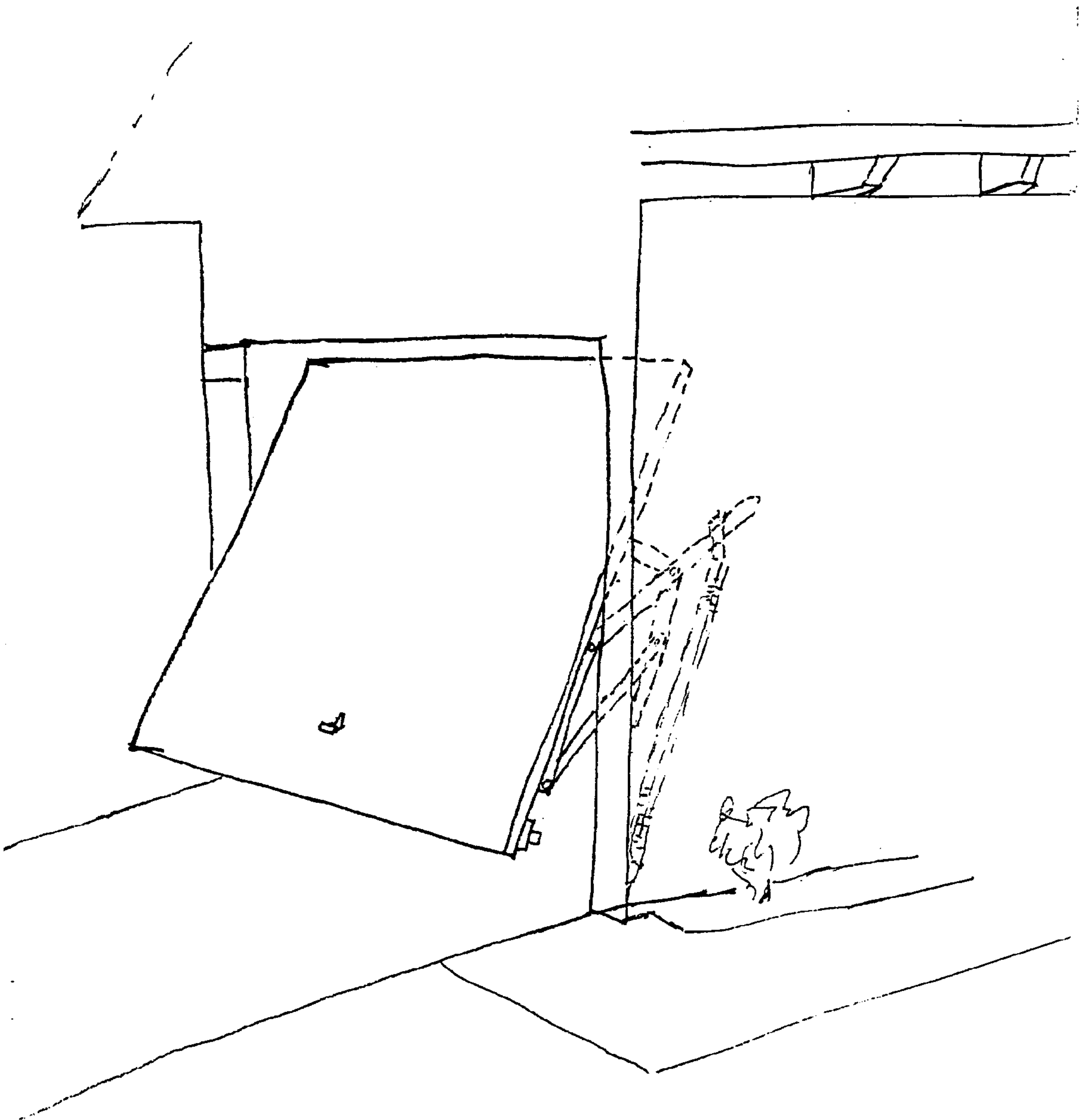

Figure B1. Overall sketch of a garage door mechanism

Figure B2. Sketch of a garage door mechanism

Figure B3. Sketch of kinematic diagram and key dimensions for a garage door mechanism