AC 2011-615: TEACHING DYNAMICS WITH A DESIGN PROJECTS

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Teaching Dynamics with a Design Project

Introduction

For over a decade, Dynamics students at Ohio Northern University (ONU) have been required to complete a design project. This project intentionally incorporates several key principles from the list of those covered in the course. All students are required to submit a project, which includes a problem description, sketches of several design concepts with a clear decision process for selecting the optimal design, detailed CAD drawings of all manufactured parts required for the design, calculations supporting the key parameters for the chosen design, as well as other velocity and acceleration plots which may be applicable to a given project. Students are also given the option of constructing a physical prototype of their design for extra credit. Each prototype is evaluated for functionality and compliance with design criteria.

Motivation

Dynamics is a difficult subject, assert Jolley *et al.*[1] in discussing their own Lego®-based design project. It brings together many concepts from math and physics that students have previously seen often only in isolation. Further complicating the subject, many of the results and concepts of Dynamics are non-intuitive. These authors suggest students' difficulty with this subject is because the course is taught in chalkboard-based theory without the benefits of observing a physical model.

Another study[2] describes a bridge design project used in Statics and Strength of Materials courses to improve student "involvement in their learning process." Citing their activity as an example of project-based learning, they list several benefits: the students "learn more material, retain the information longer, and enjoy the class activities more."

Project-based learning (PBL) has taken root not only in specific courses, but throughout the entire curriculum at a number of universities. Hadim and Esche[3] describe how their institution is "enhancing the engineering curriculum" with PBL, saying it improves student participation in the learning process, improves communication skills, addresses a wider set of learning styles, and better promotes critical and proactive thinking in comparison to traditional lecture-based pedagogy.

The PBL trend has its roots in studies into various learning styles, such as those of Felder[4]. These studies typically agree that the traditional lecture-based teaching approach best suits only students with certain learning styles, whereas the use of design projects engages a significantly wider variety of styles and improves comprehension and retention for all students, especially those students not effectively reached with lecture.

Some authors apply a more rigorous definition to PBL[5] and would not consider the Dynamics project presented here as a true example. This project runs parallel to the course topics, but is neither a regular focus of class activity nor the tool by which many principles are illustrated. However, under a looser definition (one obviously used by a number of the cited papers), this design project qualifies as project-based learning.

The project described herein is intended to take advantage of the project learning benefits cited by these authors, as well as other factors. Engineering students at ONU are introduced to the design process in the full year Freshman Engineering sequence through several small projects, as well as one quarter-long project. Unfortunately these students have little engineering background to apply to the solutions. At the other end of their college program, all ONU seniors will complete an intensive design process as part of their year-long capstone course. But building skill and experience in the design process, item "c" of the ABET list of critical engineering program outcomes,[6] is best achieved when continually reinforced throughout the curriculum. Thus the design project in Dynamics, a course currently taken by all engineering students, provides an important bridge of continuity in the heart of the four year curriculum (typically the sophomore year) to keep the design process fresh.

Project Description

The Dynamics design project has taken many forms over the years. Many projects, at least conceptually, have been drawn from the design problems included in the Hibbeler Dynamics text.[7] This textbook, through the eleventh edition, described one or more open-ended problems at the end of each chapter. (Unfortunately such problems were omitted in the twelfth edition.) Sample project descriptions, as conceived by Hibbeler and implemented at ONU, may be found in the appendix. Complete details and grading rubrics are provided for one project.

Students are typically given eight weeks to complete the project, though the principles required to complete it are often learned later in the quarter. Though a certain amount of class time is required for introducing the project, it does not reduce the number of topics covered in the rather aggressive syllabus.

Each project, completed by teams of two students, comprises two phases. First is the preliminary report, in which students must study the problem and generate at least three concepts for a potential solution. Each concept must be supported by any calculations necessary to describe its key dimensions or parameters, as appropriate to the problem. No format is prescribed for the preliminary report except a standard page header in MS Word.

The final report is a formal document describing the problem and presenting many details of the solution. Students must describe how the best design was chosen from among the initial concepts, generally by use of a decision matrix or similar tool. Designs are rated on cost, manufacturability, reliability, and other practical considerations.

The final report also includes a verbal description of how the chosen design works, as well as an assembly drawing and detail drawings for each component. Students are expected to show all dimensions and views required for another person to be able to manufacture the parts. In addition to these requirements, each project typically requires calculations describing the kinematics (such as plotting the velocity and acceleration of an output link vs. the rotational position of the input shaft) or other dynamics principles central to the problem.

Students have the option of building a prototype of their design for extra credit. Typically the maximum extra credit amounts to 3% of the total course grade. The percentage of student groups choosing to build the prototype tends to depend on the project's difficulty. For instance, 82% of students built a prototype cranberry sorter (Example 3 in the appendix), but only 36% built a reciprocating saw (Example 1).

Another factor is the class makeup: the cranberry sorter project was given during winter quarter, when the class is over 90% mechanical engineers; the saw project was given during spring quarter, when electrical, computer, and civil engineers dominate the roster. Examining data from five Dynamics sections, roughly 77% of mechanical engineers built a prototype compared to 44% of students from other engineering majors. Once all survey data was processed, however, this particular imbalance disappeared; the difference was determined to be a matter of project difficulty and appeal rather than the student's major.

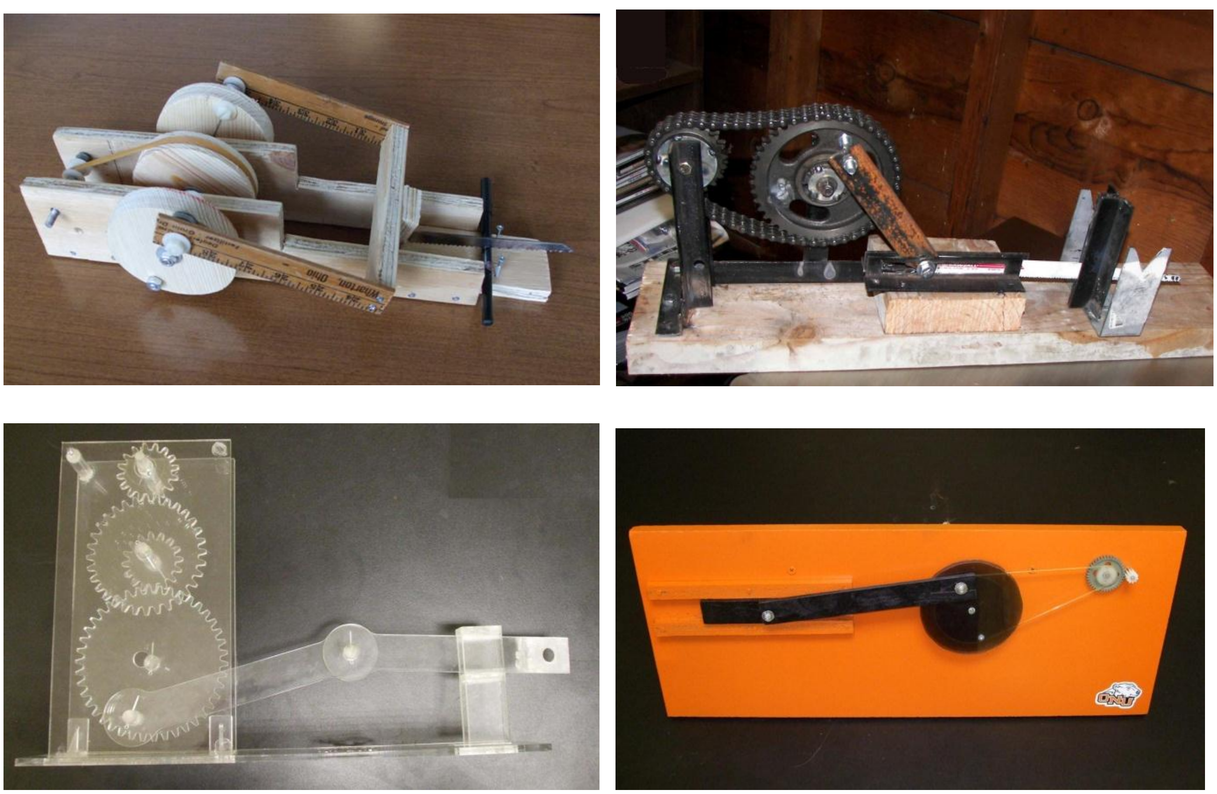


Figure 1: Reciprocating Saw with Rotary Input – Examples from Four Student Teams

Project Examples

One project is the concept and design of a rotary to reciprocal transducer to convert the rapid rotational input from some power source into the slow back-and-forth motion of a saw blade (Example 1 in the appendix). Figure 1 shows examples of project prototypes.

Various construction materials and full tool resources (mill, lathe, hand tools, welder) are made available in the machine shop. The prototypes were tested with a variable speed drill input, the speed of which was calibrated using an optical tachometer to match the rate specified in the problem.

Another project was the design of a retractable landing gear mechanism. The two mechanical engineering sophomores who constructed the prototype shown in Figure 2 won the engineering college's annual Remsburg Creativity Award for their effort. The Lexan frame was produced on the laser engraver available in the Technology Department.

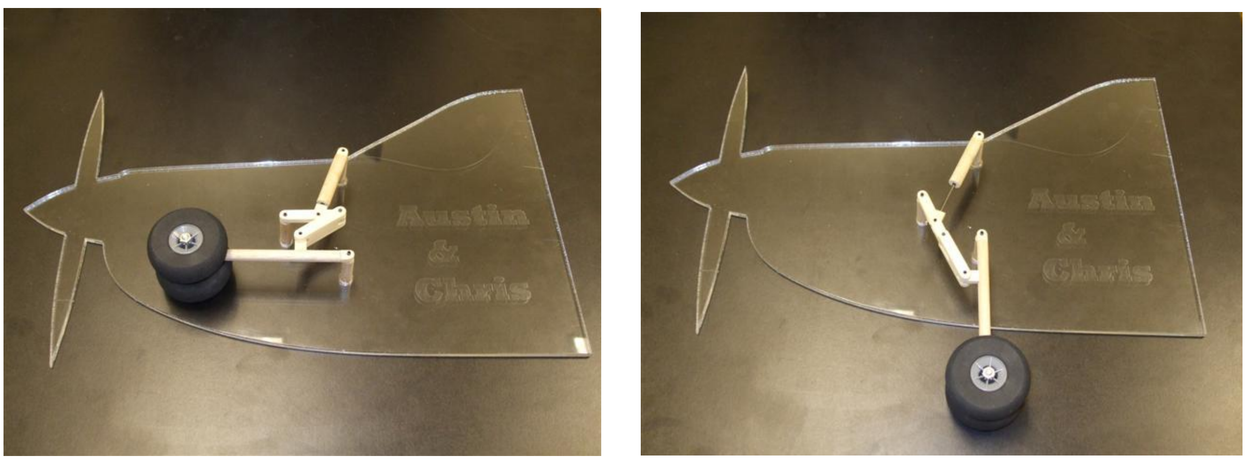


Figure 2: Retracting Landing Gear Mechanism (retracted, extended)

Results

In order to evaluate the effectiveness of the Dynamics design project in accomplishing the authors' goals as well as the benefits cited by other authors in the introduction, 116 engineering students were surveyed using the instrument shown at the end of the appendix. These students are two or three years removed from their Dynamics class, depending on whether or not an extra co-op year was taken (~20%).

Full survey results are tabulated at the end of the appendix. Some differences were observed between responses from mechanical engineering students as compared with students from other engineering majors, thus the table breaks down the results accordingly. 79 of the 116 students surveyed were mechanical engineers, and 37 were civil, computer, or electrical engineers.

The pie charts which follow show the combined results for all surveyed engineering students. Figure 3 displays results for survey questions 1 and 6, both of which relate to the question of active vs. passive learning. 44% of students either agree or strongly agree that they "learn material just as well from a normal lecture / homework / exam class format as (they) do with a design project." Under one-third of the respondents are neutral, and 27% disagree.

But over half (61%) of the students agree that they "learn better with active tasks than in a normal lecture setting." One-third was neutral, and only seven students disagreed.

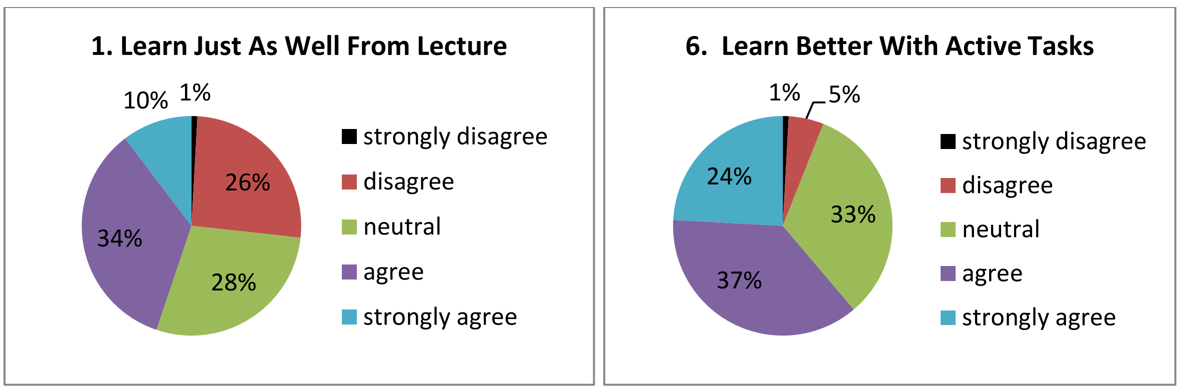


Figure 3: Results from Survey Questions 1 (left) and 6 (right)

Questions 3 and 4 evaluated other claims for project-based learning (Figure 4). Over 75% of students agreed that the project gave them "an opportunity to exercise creativity," though the impact of that creative experience is not investigated. Similarly, a large portion of students (64%) agreed that the dynamics project gave them "a better understanding of the dynamics principles it employed." 6% disagreed with this statement, but none strongly so.

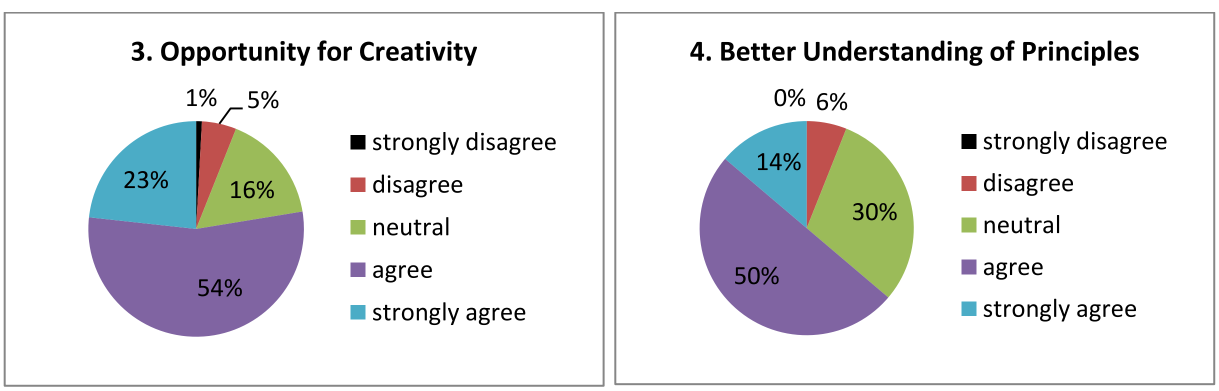


Figure 4: Results from Survey Questions 3 (left) and 4 (right)

The surveyed students were evenly divided as to whether the design project helped them "remember how to use the dynamics principles used in the project better than (they) remember other principles from this class," according to the results at left in Figure 5. Interestingly, the response of mechanical engineering seniors to this question was much different: only 18% agreed, and nearly half disagreed. Conversations with several students left the impression that the particular project assigned to (most of) this class was not as effective as other dynamics projects.

Students overwhelmingly agreed that they learn better when they "can observe a physical model of the principle," question 7. Only one respondent disagreed, and17% were neutral on the topic.

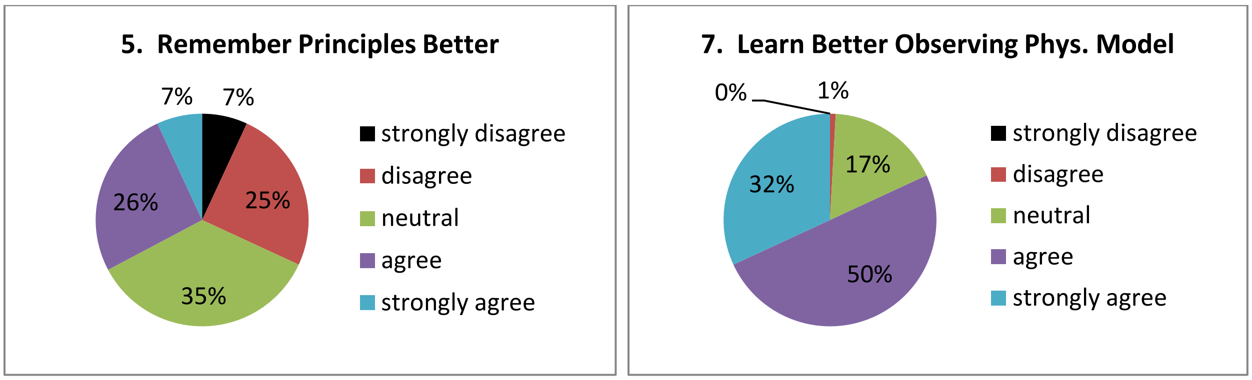


Figure 5: Results from Survey Questions 5 (left) and 7 (right)

Nearly half the students (49%) reported enjoying Dynamics more as a result of the design project, as shown on the left in Figure 6. Again ME seniors were not as enthusiastic, with only one-third sharing the same sentiment. Overall, one-third of students were neutral and 20% disagreed.

Survey question 8, at right in Figure 6, asked whether students felt the dynamics project helped them "remember the design process and decision-making tools learned in Freshman Engineering." This project goal was somewhat successful, at least in the minds of the students, as 43% agreed and only 19% disagreed.

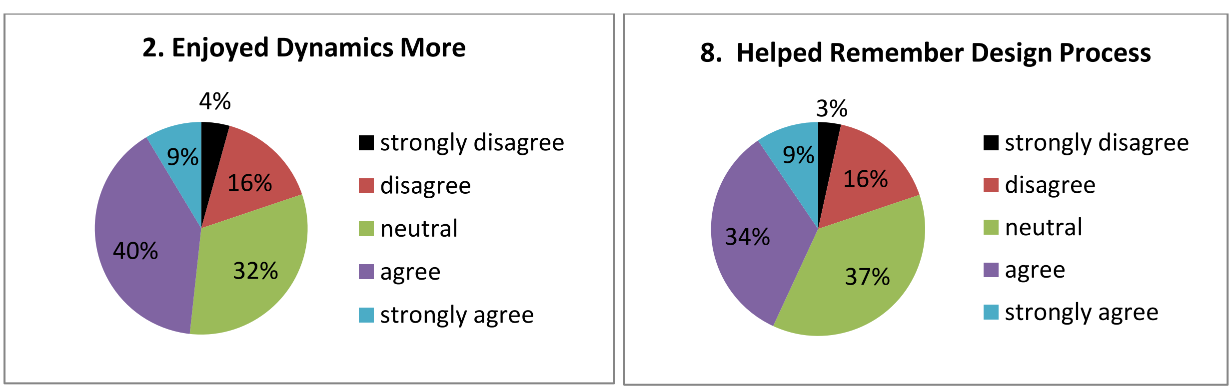


Figure 6: Results from Survey Questions 2 (left) and 8 (right)

The final survey question asked whether students could cite any of the dynamics principles used two or three years ago to complete their design project. Well over half (68%) were able to list at least one specific principle, and a number of students listed more than one principle. Whether their memory was correct, however, was not evaluated. Mechanical engineering students much more readily recalled specific principles (72%) than other engineers (59%).

Students were also given the opportunity to provide additional comments and suggestions. One comment received, which has also been observed by Dynamics instructors, is that the success of some prototypes was more a function of guess and check than of proper design. This frustrating result was most common in those projects where sliding friction was present.

Several students requested a choice of projects, rather than the same project for everyone. Two students complained that the project was difficult due to their ignorance in manufacturing methods and tools.

Four ME juniors gave very positive overall comments about the project, indicating that the "Cranberry Sorter" outlined in the appendix was a rewarding exercise. This correlated to significantly higher numeric scores than the ME seniors gave in the metrics reviewed above. One junior, however, specifically said not to repeat the cranberry project.

Students gave several suggestions to increase participation in the prototype construction. One said to increase the grade weighting, one suggested making it a competitive exercise with a reward for the best project, and two students thought that the prototype should be *required* of all students rather than only an extra credit opportunity.

Conclusions

Based on survey results, students seem generally to favor project-based learning, at least as it is embodied in the Dynamics design project at Ohio Northern University. Only one of 116 surveyed students disagreed with the notion that being able to observe some sort of physical model improves their learning in Dynamics. Over half of students report learning better with active tasks, but less than half will go so far as to say that they learn better via the "active learning" of a hands-on physical model as compared to a traditional lecture format. Nearly all are helped by *seeing* a model, but fewer claim to benefit from the hands-on aspect.

In the students' minds, the design project succeeds at providing an opportunity to express creativity, better learning of dynamics principles, and to a lesser extent, remembering and reinforcing the design process. The project does not appear to help students remember the principles, however, nor is it clear whether they enjoyed the class more as a result.

The widely varying responses to survey question 5 and the variety of enthusiasm communicated in student comments show that not all projects are equally effective at achieving intended goals.

An instructor must rotate the design projects each quarter to encourage original thought, but he or she must be careful to select tasks which provide interesting challenges.

Those interested in other examples of incorporation of design projects in engineering mechanics can view papers from Carroll[8], Hennessey[9], and Cottrell *et al.*[10]. For design projects used in other courses, Armstrong[11] (Control Systems), Johnson[12] (Microcontrollers), and Elger *et al.*[13] (a variety of engineering topics) provide useful references.

Bibliography

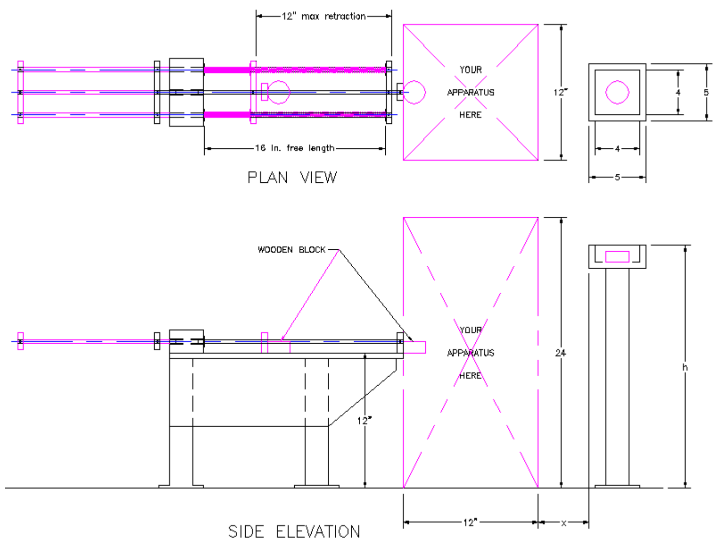
1. Jolley, W., Rencis, J., Hagglund, R., and Cobb, E., "A Fun and Challenging Engineering Dynamics Project Using a Lego Construction Set," in Proc. ASEE Annual Conf. & Expo., Nashville, 2003.
2. Chang, G., and Peterson, W., "Bridge Design Project: A Hands-on Approach to Statics and Strength of Materials Learning," in Proc. ASEE Annual Conf. & Expo., Austin, 2009.
3. Hadim, H., and Esche, S., "Enhancing the Engineering Curriculum through Project-Based Learning," in Proc. of Frontiers in Educ., Boston, 2002.
4. Felder, R., Woods, D., Stice, J., and Rugarda, A., "The Future of Engineering Education II: Teaching Methods That Work," *Chem. Engr. Educ.*, **34**(1), pp.26-39, 2001.
5. Buck Institute for Education, "What is PBL?" http://www.bie.org/about/what_is_pbl, Mar. 3, 2011.
6. ABET, "Criteria for Accrediting Engineering Programs," http://www.abet.org/Linked%20 Documents-UPDATE/Criteria%20and%20PP/E001%2007-08%20EAC%20Criteria%2011-15-06.pdf, Jan. 2011.
7. Hibbeler, R., "Engineering Mechanics – Dynamics," 11ed., Pearson Prentice Hall, New Jersey, ISBN 0-13-221504-7: 2007.
8. Carroll, D., *Integrating Design into the Sophomore and Junior Level Mechanics Courses*, J. Eng. Educ., 1997, **86**: pp. 227-231.
9. Hennessey, M., "Statics and Dynamics Projects Emphasizing Introductory Design and Manufacturing," in Proc. ASEE Annual Conf. & Expo., Pittsburgh, 2008.
10. Cottrell, D., and Ressler, S., "Integrating Design Projects into an Introductory Course in Mechanics of Materials," in Proc. ASEE Annual Conf. & Expo., Milwaukee, 1997.
11. Armstrong, B., "A Design Project for a Second Course in Controls," in Proc. ASEE Annual Conf. & Expo., Milwaukee, 1997.
12. Johnson, P., "A Design Project Approach to Microcontrollers," in Proc. ASEE Annual Conf. & Expo., Washington, D.C., 1996.
13. Elger, D., Beyerlein, S., and Budwig, R., "Using Design, Build, and Test Projects to Teach Engineering," in Proc. of Frontiers in Educ., Kansas City, 2000.

Appendix

Note: Project concepts, descriptions, and figures for examples 2-4 must be credited to Hibbeler[5]. Some details have been changed. The assignments shown were somewhat condensed.

EXAMPLE 1: Direct the Puck

Your design team will design a device to fit in the space shown on the figure on the back of this page. The goal will be to 'shoot' a 2" diameter x 1" high round puck of pine into the 'basket' at the right. The springs will generate 1.5 lbf/inch when they are compressed, and you can specify how far they should be compressed to the nearest 0.5". The material used on our portion of the device will be wood. For this project, assume x=4" and h=22".

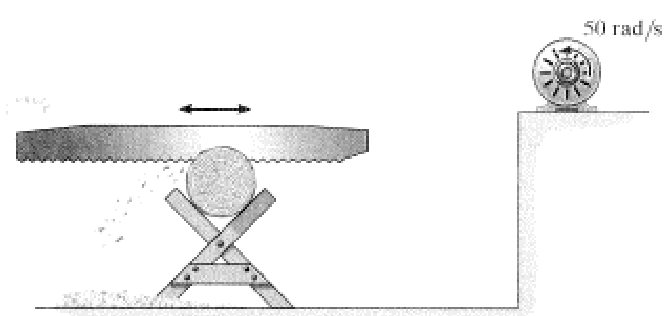


EXAMPLE 2: Design of a Saw Link Mechanism

Project Description

The saw blade in a lumber mill is required to remain in the horizontal position and undergo a complete back-and-forth motion in 2 seconds. An electric motor, having a shaft rotation of 50 rad/s, is available to power the saw and can be located anywhere.

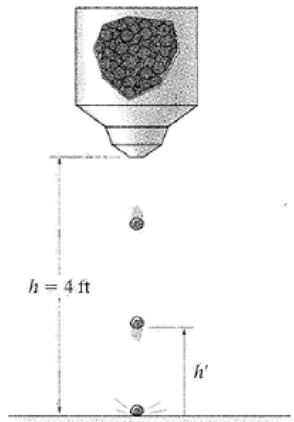
Design a mechanism that will transfer the rotation of the motor's shaft to the saw blade. Submit drawings of your design and calculations of the kinematics of the saw blade. Include a plot of the velocity and acceleration of the saw blade as a function of its horizontal position. Note that to cut through the log, the blade must be allowed to move freely downward as well as back and forth.



EXAMPLE 3: Design of a Cranberry Sorter

The quality of a cranberry depends on its firmness, which in turn is related to its bounce. Through experiment, it is found that berries that bounce to a height of $65 \leq h' \leq 85$cm, when dropped from a height of h = 150 cm, are appropriate for processing. Using this information, determine the range of allowable coefficient of restitution for a cranberry, and then design a manner in which good and bad berries can be separated. Submit drawings of your proposed designs, and show calculations as to how the selection and collection of berries is made from your established geometry.

Note: Should you decide to make a working model, the device will be tested with rubber balls approximately 39mm in diameter. The balls have the correct value of e for a cranberry.

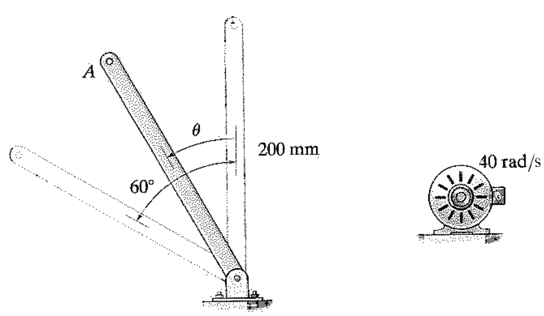


EXAMPLE 4: Design of an Oscillating Link Mechanism

Note: Though this project is quite similar to Example 1, it does not appear so to most students.

The operation of a sewing machine requires the 200-mm long bar to oscillate back and forth through an angle of 60° every 0.2 seconds (five cycles per second). A motor having a drive shaft that turns at 40 rad/s is available to provide the necessary power. Specify the location of the motor, and design a mechanism required to perform the motion. Submit a drawing of your design, showing the placement of the motor. Compute and plot the velocity and acceleration of link end A as a function of its angle of rotation 0°≤θ≤60°. See the reverse for a more detailed listing of project requirements.

Should you decide to make a working model, the device will be tested with a motor turning at 8 rad/s. Then your prototype will actually only have to oscillate once per second, should you desire to construct a less robust prototype. More rugged designs can be tested at the design speed. Your device's input shaft should be 0.5" or less in diameter.



More details for Example 4, including report descriptions and grading rubrics, are on the following pages.

EXAMPLE 4: Report descriptions and grading rubrics.

PRELIMINARY REPORT must include:

- Header (see *Preliminary report header.docx*)
- Introduction (description of the problem to be solved)
- At least three different design ideas:
  - Sketches
  - Any necessary calculations to justify design dimensions
- Percent contribution of group members

FINAL REPORT must include

- Title page
- Table of contents including page numbers
- Introduction (description of the problem to be solved)
- Results:
  - How was best design chosen?
  - How does it work?
  - Final design including:
    - Overall drawing
    - Detailed drawing of any parts that will need to be made for this design. Include all dimensions and views needed to manufacture the part.
    - All calculations required to justify the selection of this design.
    - Graphs of point A velocity and acceleration as a function of its angle of rotation for $0° \leq \theta \leq 60°$.
- Appendix:
  - Preliminary report
  - Worksheets, notes, etc.

Prototype Evaluation (30 pts. max)

1. Does it work? 20 pts
   a. At all?
   b. Like the report calculations said it would?
2. Does it match report design? 5 pts
3. Finishing touches (aesthetics, etc.) 5 pts

Preliminary Report Grading (30 pts. total)

1. Format / Grammar / Appearance 5 pts
2. Introduction 10 pts
3. Design Ideas (handwritten is acceptable)
    a. Sketches 5 pts
    b. Calculations 10 pts

	poor	acceptable	good
Format/Grammar/App.	(0pts) illegible scrawl	(3pts) few grammar or spelling errors, or sloppy calculations	(5pts) neat appearance, no spelling or grammatical mistakes
Introduction	(1pt) one-line introduction	(5pts) cut and paste of assignment project description	(10pts) clear, concise, thorough description of problem and explanation of your approach
Design Sketches	(1pt) one or two quick sketches	(3pts) three sketches hastily-drawn or all minor variations of the same concept	(5pts) four or more neatly-drawn sketches showing some variety and imagination, key dimensions shown
Design Calculations	(2pts) confusing or inaccurate calculations for one sketch	(6pts) clear, accurate dynamics calculations supporting key dimens. & parameters for one sketch OR inaccurate calculations for each sketch	(10pts) clear, accurate dynamics calculations supporting key dimensions and parameters for all sketches

Final Report Grading (70 pts. total)

1.	Title page / table of contents	5 pts
2.	Introduction	10
3.	How was best design chosen	10
4.	How does chosen design work	5
5.	Drawings	10
6.	Calculations	10
7.	Graphs of velocity & acceleration	10
8.	Writing	10

	poor	acceptable	good
Title page / TOC	(1pt) one or other missing, many errors	(3pts) few grammar or spelling errors, wrong page numbers	(5pts) neat appearance, no spelling or grammatical mistakes, accurate pg nrs.
Introduction	(1pt) one-line introduction	(5pts) cut and paste of assignment project description, or confusing introduction	(10pts) clear, concise, thorough description of problem and explanation of your approach
Design Choice	(3pts) conclusion with no justification	(7pts) conclusion based on general discussion	(10pts) merits & limitations of each approach, decision matrix
Design Function	(0pts) none	(2pts) confusing description	(5pts) good, brief description
Design Drawings	(3pts) one assembly drawing with no part drawings	(6pts) hand-drawn part drawings, views or dims. missing, some required parts missing	(10pts) detailed CAD drawings of all manufactured parts; preliminary design sketches in appendix
Design Calculations	(2pts) confusing or inaccurate calculations with gross conceptual errors	(7pts) clear dynamics calculations supporting key dimensions and vel./accel. plots; few small errors	(10pts) clear, accurate dynamics calculations supporting key parameters for chosen design and velocity/accel. plots
Velocity / Accel. Graphs	(3pts) plotted vs. time instead of θ OR other gross conceptual error	(7pts) accurate plots missing axes labels etc. OR well-labeled plots with minor inaccuracy	(10pts) clear, accurate plots of the bar tip velocity and acceleration with appropriate axes labels, title, legend, etc.
Writing	(3pts) many grammatical errors, unclear wording, spelling mistakes	(8pts) clear prose, few grammar or spelling errors	(10pts) clear and concise writing, no spelling or grammatical mistakes

Dynamics Project Survey

For the statements below, please circle one number.

1 = "strongly disagree"	2 = "disagree"	3 = "neutral"	4 = "agree"	5 = "strongly agree"

1. I learn material just as well from a normal lecture / homework / exam class format as I do with a design project.

   1 2 3 4 5

2. I enjoyed the dynamics class more because of the design project.

   1 2 3 4 5

3. The dynamics project gave me an opportunity to exercise creativity.

   1 2 3 4 5

4. The dynamics project gave me a better understanding of the dynamics principles it employed.

   1 2 3 4 5

5. I remember how to use the dynamics principles used in the project better than I remember other principles from this class.

   1 2 3 4 5

6. I learn better with active tasks than in a normal lecture setting.

   1 2 3 4 5

7. I learn dynamics principles better when I can observe a physical model of the principle.

   1 2 3 4 5

8. The dynamics project helped me remember the design process and decision-making tools I learned in Freshman Engineering.

   1 2 3 4 5

9. My team built a physical prototype for our project.

   Yes No

10. Can you remember what principle(s) were used to complete the project? If so, please list it/them:

Any additional comments on the usefulness of the dynamics design project?

Any suggestions for improvement?

1 I learn material just as well from a normal lecture / homework / exam class format as I do with a design project.

	strongly disagree	disagree	neutral	agree	strongly agree
ME	1%	22%	29%	38%	10%
CE / CPE / EE	0%	35%	27%	27%	11%
All	1%	26%	28%	34%	10%

2 I enjoyed Dynamics class more because of the design project.

	strongly disagree	disagree	neutral	agree	strongly agree
ME	5%	16%	32%	37%	10%
CE / CPE / EE	3%	14%	32%	46%	5%
All	4%	16%	32%	40%	9%

3 The dynamics project gave me an opportunity to exercise creativity.

	strongly disagree	disagree	neutral	agree	strongly agree
ME	1%	5%	16%	49%	28%
CE / CPE / EE	0%	5%	16%	65%	14%
All	1%	5%	16%	54%	23%

4 The dynamics project gave me a better understanding of the dynamics principles it employed.

	strongly disagree	disagree	neutral	agree	strongly agree
ME	0%	8%	33%	44%	15%
CE / CPE / EE	0%	3%	24%	62%	11%
All	0%	6%	30%	50%	14%

5 I remember how to use the dynamics principles used in the project better than ... other principles from this class.

	strongly disagree	disagree	neutral	agree	strongly agree
ME	8%	24%	35%	24%	9%
CE / CPE / EE	5%	27%	35%	30%	3%
All	7%	25%	35%	26%	7%

6 I learn better with active tasks than in a normal lecture setting.

	strongly disagree	disagree	neutral	agree	strongly agree
ME	1%	5%	33%	39%	22%
CE / CPE / EE	0%	5%	32%	32%	30%
All	1%	5%	33%	37%	24%

7 I learn dynamics principles better when I can observe a physical model of the principle.

	strongly disagree	disagree	neutral	agree	strongly agree
ME	0%	1%	16%	51%	32%
CE / CPE / EE	0%	0%	19%	49%	32%
All	0%	1%	17%	50%	32%

8 The … project helped me remember design process and decision-making tools I learned in Freshman Engineering.

	strongly disagree	disagree	neutral	agree	strongly agree
ME	5%	19%	37%	30%	9%
CE / CPE / EE	0%	11%	38%	41%	11%
All	3%	16%	37%	34%	9%

9 My team built a physical prototype for our project.

	yes	no
ME	71%	29%
CE / CPE / EE	70%	30%
All	71%	29%

10 Can you remember what principle(s) were used to complete the project?*

	yes	no
ME	72%	28%
CE / CPE / EE	59%	41%
All	68%	32%

* Answer was scored “yes” if the student was able to list at least one principle.