



Use of Process-oriented Approaches in Content-Intensive Courses: Some Insight in Teaching / Learning of Machine Design

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Introduction and Literature:

The idea of learning in contexts that promote real-life applications of knowledge extend backward more than two decades. Resnick's bridging apprenticeships [1] connected theoretical learning in the classroom to the application of knowledge in the work environment. Also, Collins's idea of situated learning, "learning knowledge and skills in contexts that reflect the way the knowledge will be useful in real life" [2], addressed knowledge applied in authentic contexts [3]. Process-oriented teaching [4] is aimed at the integrated teaching of learning and thinking, on one hand, and domain-specific knowledge on the other. It is an instructional model in which learners are taught to employ suitable learning and thinking activities to construct, change and utilize their knowledge of a particular subject domain. The main teacher tasks are initiating and supporting the thinking activities that students employ in their learning [5]. Teaching / Learning methodologies have traditionally seen content and process as competing priorities. Integrating content and process together in the teaching/ learning activities offers the opportunity to increase students' experience with authentic activities while also achieving deeper content understanding [6]. Prior knowledge activation also has strong facilitative effects on learning. Prior knowledge provides learners with a relevant context in which new information can be integrated [7].

The undergraduate "Machine Design" course taught in many engineering universities is primarily focused on teaching the fundamentals of designing mechanical elements for meeting engineering specifications, functionality and failure. It is a content-intensive course in general and traditionally taught with information based lectures and textbook problem solving, and student's learning is tested with time-bound tests and exams. Teaching the Machine Design course using some hands-on activities, projects and case-studies have been reported in the literature [8-12].

In this paper, prior knowledge supported process oriented approaches on students learning in the "Machine Design" course are presented. Traditional content-centered teaching approaches with a focus on textbook problem solving skills is compared to process oriented approaches using prior knowledge of CAD and analytical tools. Students' performance in the course is quantified in a content-centered approach, a process-oriented approach and an integrated approach combining content and process. Qualitative and quantitative results with insight on the effect of various approaches on students' learning and meeting course outcomes are presented.

Course description and prerequisites:

The Machine Design course (ME 3180) at the Woodruff school of Mechanical Engineering, Georgia Tech is taken by mostly senior level Mechanical engineering students as a design

elective. This course is focused on teaching the fundamentals of various mechanical components in terms of their functionality, design and failure analysis. The course is content intensive with many definitions and empirical relations for calculating the functional behavior of various mechanical elements and their static and fatigue failures. As the amount of material to be covered is large, it is traditionally taught with a content-centered teaching approach and a focus on textbook problem solving skills and time-bound exams to test students' learning of subject matter. The course catalog description with prerequisites and course outcomes is as follows:

Catalog Description: ME 3180: Machine Design (3-0-3)

Prerequisites: ME 1770 Introduction to Engineering Graphics and Visualization

ME 2110: Creative Decisions and Design, and

COE 3001: Deformable Bodies (Mechanics of Materials)

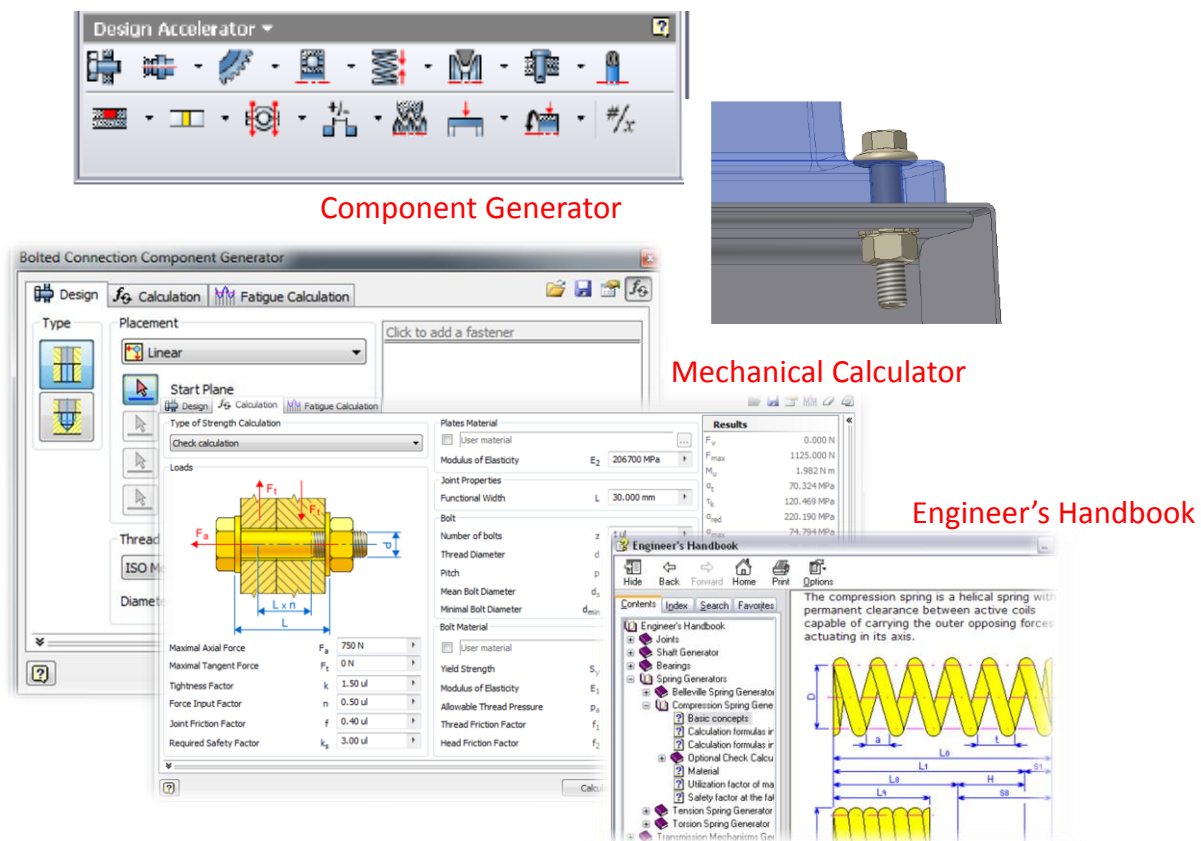


Figure 1: Use of prior knowledge: Design accelerator tool (From ME 1770) for designing mechanical elements

In the prerequisite course ME 1770, students learn a 3D solid modeling tool (Autodesk-INVENTOR) for geometric modeling of individual components and assemblies. They are also introduced to a specific module called “Design Accelerator” for modeling most of the mechanical elements of ME 3180 such as shafts, gears, bolted connections, bearings, springs,

welded designs etc. Design Accelerator is a collection of tools and resources that enables you to efficiently create and validate your designs within a saved assembly file. The tools and resources are divided into three groups: (i) Component generators (ii) Mechanical calculators and (iii) an Engineer's Handbook (see Figure 1). Using component generator tools, one can create mechanically correct components automatically, based on the values that you enter. With mechanical calculators, one can conduct different engineering calculations to help ensure that your design meets specific requirements (check for allowable deflection and slope, etc.). To facilitate use of the generators and calculators, the corresponding formulas and supporting information are included in the Engineer's Handbook. One can access this information for details about the formulas being used, or to ensure that the methods of calculation match your design use and requirements. Visualization with interactive tools like this will help students appreciate the design principles and speed up their learning process.

While CAD tools are useful for visualization of various designs, coding the design equations in MATLAB will help with quick what-if analyses for various design changes. Most of the students who take ME 3180 are also familiar with MATLAB coding through ME 2016: Computing techniques. Coding the design approach and failure theories discussed in ME 3180 also helps student understand material selection and the effect of materials' geometric parameters on static and fatigue life of various mechanical elements.

Course Organization and teaching/learning approaches:

For the purpose of this work, the organization and teaching / learning approaches used in three different sections of the course are described in figure 2. In Fall 2011, experimental section-1 of the Machine design course at [removed for blind review] was taught using process oriented approaches in which project based take-home exams and team projects were introduced for the first time. The students were encouraged (optional) to use INVENTOR - Design Accelerator CAD knowledge (From ME 1770) in learning the new material and solving machine design problems in take-home exams and team projects. Students' engagement in the class and end-of-course surveys indicated that explicitly utilizing prerequisite prior CAD knowledge to support learning Machine Design was well received by students and resulted in commendable performance in process oriented activities using CAD tools. However it was observed that students' performance was worse in traditional time-bound final exams with textbook problems. In Fall 2012, experimental section 2 was taught with a traditional content-centered approach and experimental section 3 was taught with an integrated approach as described in Figure 2.

Process- Oriented Approach

- Home Works (text-book problem-solving)
- Two Take-home exams (process-oriented)
- Team Project (process-oriented)
- Final Exam (text-book problem-solving)
- Use of CAD and Analytical Tools Optional

Experimental Section 1: Fall 2011

- Process-oriented project and take-home exams were well received by students and resulted in commendable performance in process-oriented activities.
- However resulted in worse student performance in traditional time bound end -of-term exams.

Content-Centered Approach

- Home Works (text-book problem-solving)
- Two time-bound exams (text-book problem-solving)
- Final Exam (text-book problem-solving)
- Use of CAD and Analytical Tools Optional

Experimental Section 2 : Fall 2012

- Common Homework 1 (with section 3) -Text-book style problems
- Common Set of Final Homework problems (textbook style and problems with use of CAD and analytical tools)
- Same grading rubric for common homework problems

Integrated Approach

- Home Work (Process-oriented problems)
- Two time-bound mid-term exams (problem-solving)
- Team Project (Process-oriented)
- Final time-bound Exam (Problem-solving)
- Mandatory to use Prior Knowledge in CAD and Analytical Tools for home works and Projects

Experimental Section 3: Fall 2012

- Compared to Section 2, this section has 25% team project with low weightage (10%) for final exam.
- Compared to section 1, this section has two traditional time-bound mid-term exams.
- Compared to section 1, this section has all process-oriented home-works except homework 1.

Figure 2: Description of various teaching/learning approaches

Table 1: Comparison of various teaching/learning approaches

	Process Oriented Approach	Content Centered Approach	Integrated Approach
Lectures	Traditional : Discuss concepts, design equations and failure theories	Traditional : Discuss concepts, design equations and failure theories	Traditional : Discuss concepts, design equations and failure theories
Home works	Text-book Problems	Text-book Problems	Process Oriented with CAD and analytical tools (see Appendix 3)
Exam 1	Take-home case-study design problem (see Appendix 1)	Text-book Problems	Text-book Problems
Exam 2	Take-home case-study design problem (see Appendix 1)	Text-book Problems	Text-book Problems
Final	Tex-book Problems	Text-book Problems	Text-book Problems
Team Project	Design and analysis of Mechanical System (see Appendix 2)	No Team Project	Design and analysis of Mechanical System (see Appendix 2)
Use of CAD & Analytical tools	Optional	Optional	Mandatory

Comparison of various approaches in terms of lectures, home works, exams and projects is shown in Table below. All sections meet 3 lecture hours per week.

Next section quantitatively and qualitatively provides insight on the following aspects:

- Why did students perform poorly in traditional final exams in experimental section 1?
- Does learning fundamentals (content understanding) get diluted in entirely process oriented approaches?
- What are the positives in Experimental Section 1? How to quantify student learning through project-based take-home exams and team projects in section 1? (student grades are much better in projects compared to final exam)
- Did students learn better in Integrated approaches (experimental section 3) compared to section 1 and section 2? How to quantify that? Did section 3 students gain more without compromising on fundamental content understanding?
- In section 3: How has the prior knowledge in Design Accelerator (CAD tool from ME 1770) and programming in MATLAB (ME 1616) helped students understand the design of mechanical elements for functionality and parametric analysis?
- Are the students relatively more engaged in sections 1 and 3 compared to control section 2? How do we measure that?

Assessment and discussion:

Comparison of Student Performance Across Section Types

In Fall 2011, experimental section 1 was taught using process oriented approaches in which project based take-home exams and team projects were introduced for the first time. While homework (HW1 – HW5) and final exam are text book problems, exam1, exam 2 and the project are open ended and process oriented problems using analytical tools like MATLAB and 3D-CAD tools. Table 2 shows the comparison of students' grades:

Table 2: Final exam grade Vs other grades (Process Oriented Approach) - Fall 2011									
Title	HW1	HW2	Exam1	HW3	HW4	Exam2	HW5	Project	Final
Max Points	20	30	100	30	40	100	30	200	100
No. of students	90	90	90	90	90	90	90	90	90
Min	0	0	29	0	0	76	0	0	26
Max	20	30	100	30	40	100	30	200	89
Avg	16.52	18.12	87.81	24.29	29.24	95.87	21.92	170.83	60.64
Avg. (%)	82.60	60.40	87.81	80.96	73.10	95.87	73.06	85.40	60.64
Sdev	4.63	10.54	16.73	8.24	12.22	5.18	9.78	23.95	10.98

As can be seen from the Table2, students did well in process oriented activities (Exam 1, Exam2 and Project) compared to textbook problem solving activities (homework and final exam). In particular, students' performance on the time-bound final was worse compared to take-home exams. As one student wrote in the course survey, *"I really liked the take home tests and projects. I feel like this is better preparation for real world assignments."* Process-oriented activities in the take-home exams and projects improved students' understanding of the subject matter, and poor performance on the final cannot be attributed to a lack of understanding of the subject matter. While students liked the idea of open ended take-home exams, they were not trained on how to prepare for time-bound tests on this subject, as students' understanding of the subject was mostly assessed, for majority of the semester, through homework and take-home exams, while the final exam was the only traditional time-bound test in section 1. Although we acknowledge that time-bound exam may be an imperfect metric to gauge student learning, in this work it is used as a metric in all three approaches discussed

Based on the above observations, in Fall 2012 an integrated approach is used in section 3. Note here that section 1 and section 3 were taught by the same instructor, and section 2 was taught by a different instructor using a content-centered approach. Table 3 shows students' performance in an integrated approach:

Table 3: All Grades (Integrated Approach) - Fall 2012									
Title	HW1	HW2	Exam1	HW3	HW4	Exam2	HW5	Project	Final
Max Points	25	35	50	30	30	50	30	200	100
No. of students	78	78	78	78	78	78	78	78	78
Min	0	0	0	0	0	24	0	0	4
Max	25	35	50	30	30	50	30	190	100
Avg	23.40	28.03	41.64	21.51	24.04	40.99	23.60	170.55	71.82
Avg. (%)	93.60	80.08	83.28	71.70	80.13	81.98	78.66	85.28	71.82
Sdev	3.42	10.06	8.71	10.00	9.52	5.68	11.83	31.94	15.72

In an integrated approach, students' understanding of the subject was tested using traditional time-bound exams (Exam1, Exam2 and Final) and a process oriented approach was introduced in homework (HW1 – HW5) and projects.

Table 4 shows improved students' average on the final exam for in section 3:

Table 4: Final exam grade comparison		
Title	Process Oriented	Integrated approach
Max Points	100	100
No. of students	90	78
Min	26	4
Max	89	100
Avg	60.64	71.82
Sdev	10.98	15.72

Use of CAD and analytical tools were made mandatory and students were systematically trained through homework problems on how to use these tools for the design and parametric studies of mechanical elements. Students used this knowledge in team projects for the design and analysis of mechanical systems. The integrated approach was well received with improved students' performance in process oriented activities as well as traditional time-bound exams, as evident from the above two tables. As one student commented in the course survey, *"Integrating tools like MATLAB and CAD proved to be very helpful in making me confident with the material. The homeworks were large and time-intensive, but very rewarding. I actually enjoyed the homeworks a lot, especially compared to typical book problems"*.

One process oriented common homework problem was introduced in section 2 (control) and section 3. In section 2, all homework and exams are content-centered textbook problems and the use of CAD and analytical tools are optional. Out of 65 students in section 2, 10 students did not attempt the homework problem, 5 students did only the MATLAB part, and one student did only CAD part of the homework. While it is qualitatively evident that students in section 3 experienced more understanding of the subject without compromising traditional problem solving skills, answering the following questions need more data processing from control sections and is currently under progress.

- Did students learn better in the Integrated approach (experimental section 3) compared to section 1 and section 2?
- Are the students relatively more engaged in section 1 and 3 compared to control section 2? How can we measure this?

Insight from Pre and post surveys in Section 3:

A pre-survey based on the Colorado Learning Attitudes about Science Survey was conducted during the initial phase of the course. This survey occurred as students were beginning to work on the process oriented assignments, but after they had spent several weeks in the course establishing their perceptions about the field of Machine Design. A post-survey based on the Student Assessment of Learning Gains survey was conducted at the very end of the course and had 21 respondents.

The pre-survey had seven respondents complete the survey, so data must be viewed with a good degree of skepticism. Nonetheless, results from the pre-survey indicate that students who did respond have developed a moderately strong professional attitude about the process of machine design. Figure 3 summarizes how the students view particular aspects of machine design. Scores high on the favorability scale indicate more agreement with statements about how experts view machine design, while scores high on the unfavorability scale indicate more agreement with statements about novice approaches to machine design. Thus, results in the upper left quadrant indicate attitudes closest to those of professionals, while results in the lower right quadrant represent those closest to a novice. In general, these students are moderately professional in their

view of machine design as requiring effort, they are confident in their ability to do machine design, and they understand how problem solving skills are an integral part of machine design. However, they are in between the novice and expert stages regarding their attitudes about the importance of their conceptual understanding as an integral part of machine design, and are still developing a sophisticated view of problem solving.

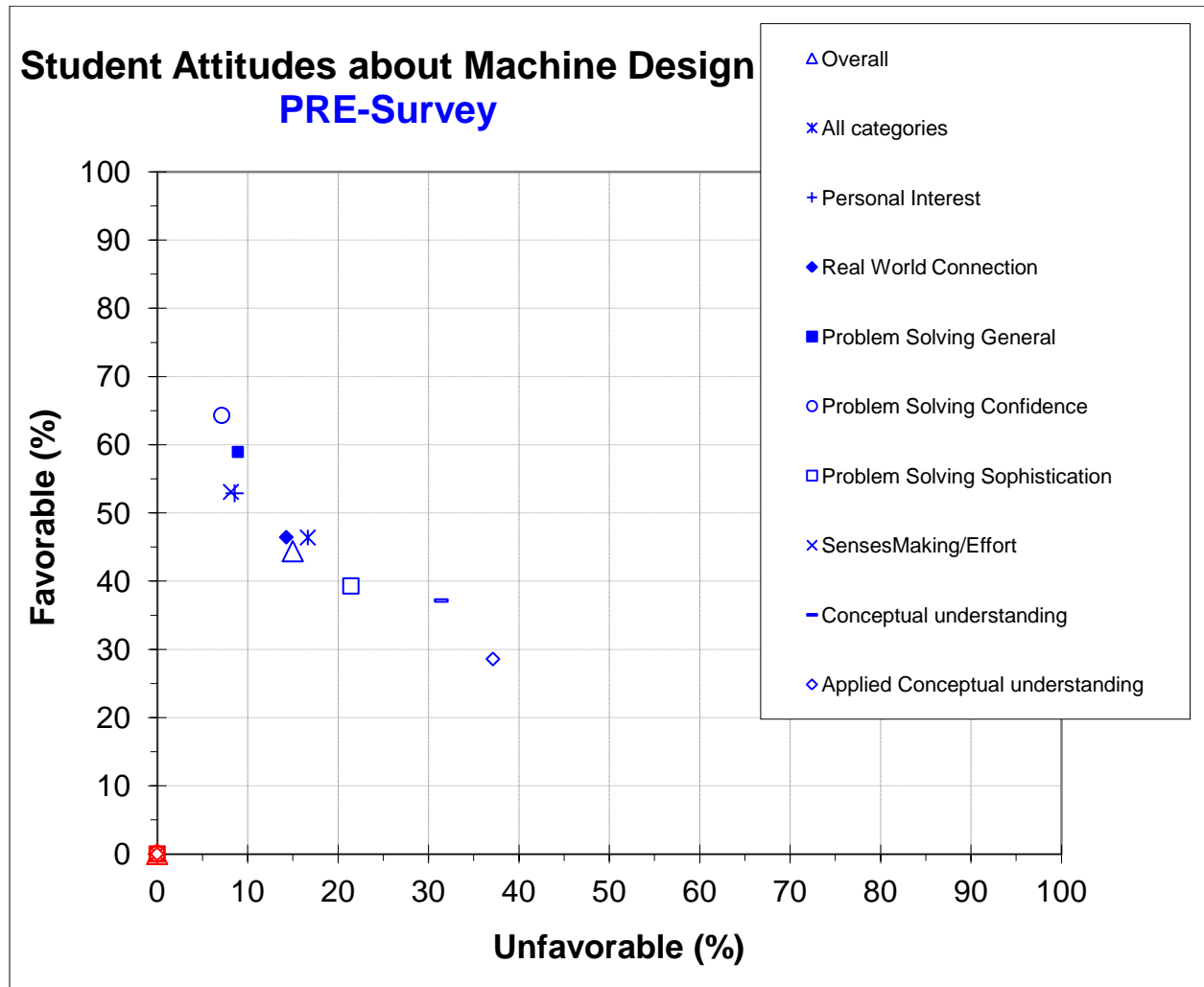


Figure 3 - Student attitudes about the process of machine design

The moderate professional attitude indicated in the pre-survey is likely a contributing factor to students' positive comments in the post-survey about their learning from the process oriented homework assignments and team project. For example, on the post survey all but 3 out of 21 respondents in the indicated good to great amounts of improvement in their understanding of machine design concepts and how they relate to other coursework, with 2 indicating moderate gains and 1 indicating no gain. Comments on the post survey indicate how the students valued the process-oriented approach in the course:

- “This class has done a great job with relating everything to the big picture.”
- “This is the first class I felt would be applicable in real life situations. I learned more than I do in most classes due to teaching style.”
- “I know that if tomorrow in any industry I need to design on of the mechanical elements covered in the book, I will be able to apply my knowledge and achieve objective.”
- “This class focused less on memorization and difficult exams so I was able to focus more on conceptual ideas.”
- “Having to code for hws and the project, i felt that i needed a great knowledge and understanding of the material.”

Further, post-survey results indicated that most students felt strongly that what they learned in the integrated approach can transfer to other contexts. Finally, on average students rated the instructor’s lecture notes, specially designed integrated process oriented homework, and the team project as the most useful components of the course. This contrasts with lower ratings for the usefulness of exams and working with their peers. One area to explore further is that the students found the team design projects especially useful even though they did not feel they learned much from working with their peers. One student commented that “as far as the team project goes: I learned a lot through the project itself, but I ended up doing a remarkable amount of anything that was assigned individually.”

Conclusions:

Preliminary results indicate that prior knowledge supported process oriented approaches were well received by students and resulted in commendable performance in process oriented activities. However the teaching methodology with a primary focus on process oriented activities resulted in worse student performance in traditional time-bound end-of-term exams. Teaching with more integrated approaches combining content and process oriented approaches indicates potentially improved performance based upon our initial student performance-based data. In addition, the integrated approach appears to retain much of the student interest generated in the primarily process oriented approach, as indicated by positive student perceptions about learning in the integrated version of the course.

References:

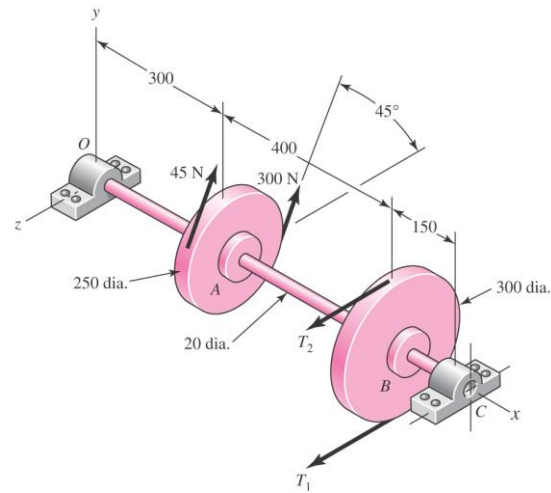
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Appendix 1: Process-oriented Take-home exams (Fall 2011)

Take-home Exam 1: Shaft Design Case Study:

A countershaft carrying two v-belt pulleys is shown in the figure. Pulley A receives power from a motor through a belt with the belt tensions shown. The power is transmitted through the shaft and delivered to the belt on pulley B. Assume the belt tension on the loose side B is 15 percent of the tension on the tight side.



1. Determine the tensions in the belt on Pulley B, assuming the shaft is running at a constant speed. Find the magnitudes of bearing reaction forces, assuming the bearings act as simple supports.
2. Draw shear force and bending moment diagrams for the shaft in both the planes. At the point of maximum bending moment determine the bending stress and the torsional shear stress.
3. At the point of maximum bending moment, determine the principal stresses and maximum shear stress. Draw a Mohr's circle. (you can use Matlab codes)
4. For the steel countershaft find the deflection and slope of the shaft at A (you can use any available software)
5. Determine the minimum factor of safety for yielding. Use both maximum shear stress theory and the distortion energy theory and compare results. The material is AISI 1035 CD steel.
6. Determine the minimum factor of safety for fatigue based infinite life. The shaft rotates at a constant speed, has a constant diameter, and is made from cold-drawn AISI 1018 steel.
7. Obtain a shaft layout design for this application. Sketch the designed shaft layout with details. The material is AISI 1035 CD steel. The gears seat against the shoulders, and have hubs with setscrews to lock them in place. The effective centers of the gears for force transmission are shown in the above figure. The key seats are cut with standard endmills. The bearings are press-fit against the shoulders. Determine the minimum shaft diameter for a factor of safety of 1.5. This is a design problem with material and certain layout details already given. (Check the analysis problem 7.21 discussed in class)

Extra Credit: Use any CAD software. Sketch (2D) layout of the shaft design details (Example: Figure 18.3) (10 points).

Take-home- Exam 2 - Gear Design Case Study:

Form into two member teams and select two extreme set of design parameters and provide comparisons for problems 1 and 2 below

Design a two-stage compound reverted gear train (spur gear) as a speed increaser with your unique choice of input speed between 40 - 100 rev/min and output speed of 2000 - 3000 rev/min. Select your unique choice of power to be delivered between 10 hp – 60 hp. Select a pressure angle of 20 degrees.

- (1) Sketch the gear train (with appropriate gear box size) and specify the number of teeth on each gear to avoid interference [30 points]
 - (2) Identify the smallest gear with highest transmitting load for design and select gear materials for each gear to achieve a factor of safety of 1.3 for wear and bending. Consider all the factors influencing the design according to the AGMA 2001-D04 (page 766 and 767 – Text book – 9th edition) [40 points]
 - (3) Compare and discuss your designs with two extreme set of parameters from the given specifications of speed and power. [10 points]
 - (4) If a Grade 2 steel hardened to a Brinell hardness of 300 is used for a life of 12000 hours with a 98% reliability – determine the factor of safety for bending and wear. [20 points]
- Assume any other parameters needed for the design (problems 1,2 and 3) and clearly mention your assumptions.
 - Describe your design approach clearly with appropriate reference and equation numbers from the text book.
 - Support your design with MATLAB/excel codes and CAD tools as appropriate and submit it along with your work.

Appendix 2: Team Project description and examples (Fall 2011 and 2012)

Learning Outcome: This project allows students to apply modern computer-based techniques algorithms in the selection, analysis, and synthesis of components and their integration into complete mechanical systems.

Brief description of project

Select a mechanical system/product that has several of following mechanical elements Submit a two page project proposal with details: (see t-square for proposal format) Each team selects an **engineering structure** with at least **6 functional mechanical elements** (Shafts, Bearings, Gears, Springs, Screws, fasteners etc. as shown in the picture). The Team members work on the selected mechanical elements from the proposed system to work on throughout the semester (one part each as individual responsibility and remaining two parts as a team). The team **defines system specifications and functionality requirements** (power, speed, torque, life, design and safety factors etc.) and real forces acting on the proposed mechanical system based on functionality (decide on Units).

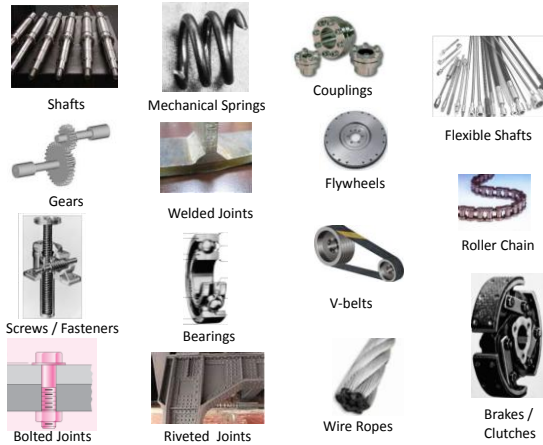
Team Project aspects that can enhance students ability on integrated thinking in the design of mechanical elements and systems

Define system specifications and functionality requirements

Load and stress analysis
Free body, shear force and bending moment diagrams, deflection analysis, principal stresses etc..

Design for functionality, static and fatigue Life

Component and system Design considerations and trade-offs

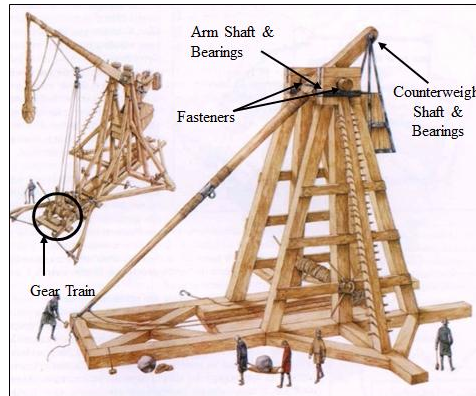


Use Design Accelerator CAD tool for component design and Layout

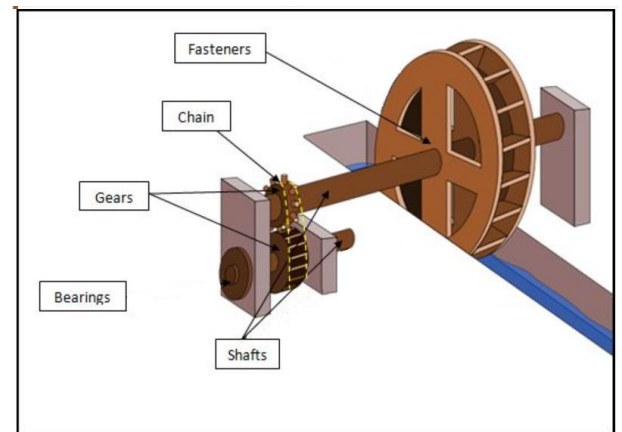
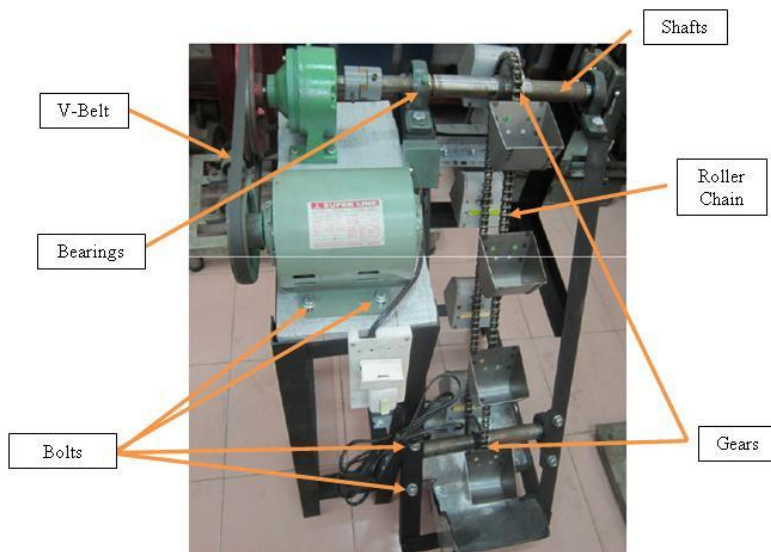
Use CES EduPack for material selection process

Use Matlab programming for parametric what-if analysis

Use of standards, empirical equations, maximum slope and deflection requirements



Student Project Examples



Appendix 3: Process Oriented Homework example (Fall 2012)

ME 3180 Machine Design: Homework (Must use MATLAB and CAD)

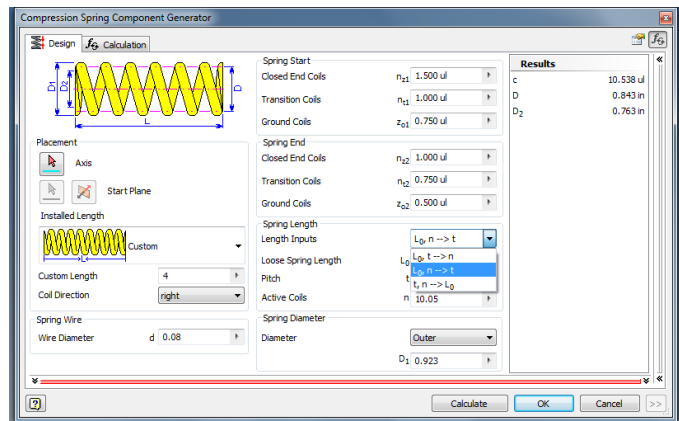
Compression spring static design (15 points) – fatigue design (15 points)

1. Using Matlab - program the generic approach and associated equations for compression spring design for static service using textbook Example 10-2 (p.530) discussed in lecture. Submit your code with input and output parameters. From your code directly output the following table for various wire diameters with the numerical data from the example and submit the table with discussion.

d:	0.063	0.067	0.071	0.075	0.080	0.085	0.090	0.095
D	0.391	0.479	0.578	0.688	0.843	1.017	1.211	1.427
C	6.205	7.153	8.143	9.178	10.53	11.96	13.46	15.02
OD	0.454	0.546	0.649	0.763	0.923	1.102	1.301	1.522
N_a	39.1	26.9	19.3	14.2	10.1	7.3	5.4	4.1
L_s	2.587	1.936	1.513	1.219	0.964	0.790	0.668	0.581
L_0	4.887	4.236	3.813	3.519	3.264	3.090	2.968	2.881
$(L_0)_{cr}$	2.06	2.52	3.04	3.62	4.43	5.35	6.37	7.51
n_s	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
fom	-0.409	-0.399	-0.398	-0.404	-0.417	-0.438	-0.467	-0.505

Using the geometric parameters (N_a , OD and L_0) verify the spring index C value (10.53) for wire diameter $d = 0.08$ using Inventor design accelerator. Submit your screen shot as below.

2. Extend the MATLAB code in problem 1 to program the approach and associated equations for compression spring design for fatigue service using textbook Example 10-5 (p.539) discussed in lecture. Submit your code with input and output parameters. From your code directly output the following table for various wire diameters with the numerical data from the example and submit the table with discussion.



Using the geometric parameters (N_a , OD and L_0) Verify the spring index C value (6.4) for wire diameter $d = 0.08$ using Inventor design accelerator. Submit your screen shot as in problem 1.

d:	0.069	0.071	0.080	0.085	0.090	0.095	0.105	0.112
D	0.297	0.332	0.512	0.632	0.767	0.919	1.274	1.569
ID	0.228	0.261	0.432	0.547	0.677	0.824	1.169	1.457
OD	0.366	0.403	0.592	0.717	0.857	1.014	1.379	1.681
C	4.33	4.67	6.40	7.44	8.53	9.67	12.14	14.00
N_a	127.2	102.4	44.8	30.5	21.3	15.4	8.63	6.0
L_s	8.916	7.414	3.740	2.750	2.100	1.655	1.116	0.895
L_0	11.216	9.714	6.040	5.050	4.400	3.955	3.416	3.195
$(L_0)_{cr}$	1.562	1.744	2.964	3.325	4.036	4.833	6.703	8.250
n_f	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
n_s	1.86	1.85	1.82	1.81	1.79	1.78	1.75	1.74
f_n	87.5	89.7	96.9	99.7	101.9	103.8	106.6	108
fom	-1.17	-1.12	-0.983	-0.948	-0.930	-0.927	-0.958	-1.01