AC 2011-2447: CLOSING THE DESIGN LOOP IN FRESHMAN ENGINEERING

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Closing the Design Loop in Freshman Engineering

Abstract

Teaching engineering design and graphics to a freshman class presents the challenge of balancing prescribed lessons vs. open-ended questions. Given that few students have experience with the design process, and fewer still have formalized designs using CAD software, the teaching process is often one of demonstration. Given time constraints there is rarely time to visit the topics of verification or the practice of design iteration. We present a model for teaching freshmen design that incorporates documenting the idea, formalizing the design, and model simulation for verification and improvement. Most courses of this type, especially at the freshmen level, focus primarily on the first two elements. Using a common symbolic modelling and visualization software package, students import their CAD model designs for testing and immediate verification. This closing of the design loop makes the material more engaging for students of all disciplines and allows the instructor to go much further in the design discussion. Student work and feedback will be presented along with suggestions of how this process could apply to other engineering courses.

Introduction

Over the past few decades the trend in first year engineering graphics courses has gradually transitioned from drafting tools to computer aided design. In fact, the trend is such that now most Universities have marginalized or completely removed hand drafting and drafting tools in deference to computer aided design tools. Concurrently, the scope of such courses has been in flux as many are now asked to teach design. This seemingly innocuous addition has many, certainly this instructor, wrestling with the fundamental question -- Am I not already teaching them design?

Background

The first year Design and Graphics course at McMaster University is part of a common year. The course runs in the Fall and Winter terms with approximately 450 students each offering and is structured with lecture, lab, and tutorial each week. Before the changes implemented in September 2010, the labs were three-hour assignments in solid modelling CAD, the tutorials were instruction on hand sketching techniques with assignments due the week following, and lecture would bring together theory, modelling, and design through demonstration, example, and discussion. In addition, there was a team dissection and modelling project[1,2] , including a course competition, to reinforce the course material.

Given that the course is taught with the expectation that students have no background in the material, the prior format seemed appropriate, was well liked by the students, and better engaged the class as a whole. However, the question now - was I teaching design, or *only* demonstrating it?

Dissection is a common method of teaching and learning about design[3]. Dissection does not require the student to do design.

Form vs. Function

In the dissection and modelling of any of the student projects (e.g. cordless screw driver, disposable camera, floppy drive, etc.) the author would argue that students did perform design in the precise measurement and creation of each software modeled part. The rationale being that, although we teach the tools, the order and application of those tools are still at the discretion of the designer. The level of detail that teams incorporated in to their final projects[1,2] impressed the instructor, competition judges, and faculty members. Unfortunately, while most students were quite adept at the CAD software, some students were not aware of how their project product mechanically functioned. This result highlights the problem with many traditional graphics courses because the emphasis of assessment is based on the mechanical form and not on the function.

It is the author's assertion that this, in part, is the result of class sizes, limited resources, and insufficient assessment tools. The incorporation of a visualization and simulation tool into traditional graphics courses would permit students to gain experience and insight into the mechanical function of parts they are creating. Simultaneously, this tool may be used to evaluate the function of a mechanical assembly.

System Modelling

McMaster's Design & Graphics course was reorganized to incorporate a system modelling tool to permit the "what if" and iterative scenarios that engineers use to gain experience and insight. Instead of an independent mechanical dissection, the course had a directed dissection led by the instructor. The directed dissection ensures all students understand the mechanism and important components for their retrofit design. The system modelling application (MapleSim 4) is a visualization and modelling software that may be applied to any engineering discipline. We worked with Maplesoft to develop specific mechanism modules for students to use as building blocks in system modelling component of their project. Providing these modules allows the instructor to introduce the concept of system modelling in the design process, without requiring the student to immediately master the software application. In effect, this tool closes the design loop by providing the students a method to test their designs and iteratively refine them.

Mechanisms and Simplified Gear Design

In the reorganization of McMaster's Design & Graphics course, there has been a concerted effort to shift lecture material from the *form* to the *function* of common mechanisms and gear trains.

For a first year engineering class, the mechanisms and gear trains are explained using a simplified approach combining practical and theoretical design. The primary resource for this material is Dudley's ``Practical Gear Design"[5] with references to current AGMA and

ISO standards. While there are many aspects to gear design, given the audience, we focus on the three SI-unit design parameters of gear module (m), pitch circle diameter (D), and number of teeth (z). Figure 1 illustrates the design triangle that students use to calculate these parameters. For other gear design parameters, students are provided a practical value that is from either the standards or used in common gear design (e.g. 20° pressure angle for spur gears). In addition, the focus of gear type is limited to the discussion of spur, worm, and bevel.

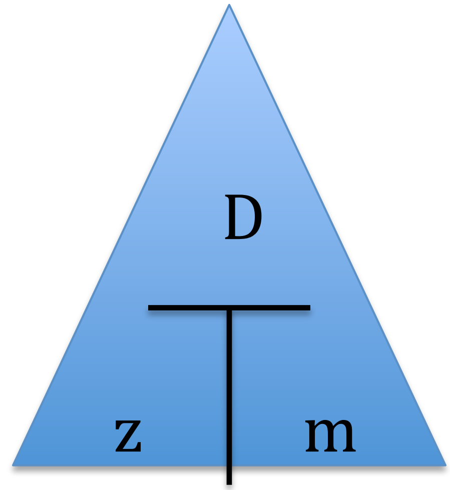

Figure 1: Memory aid triangle for simplified gear design parameters.

Figure 2 is an example of the type of simplified gear pairs that are used to introduce concepts such as gear ratio and angular velocity. Students then extend this by creating the gearing in a solid modelling CAD application. The Autodesk Inventor's Design Accelerator is used to generate the gear geometries based upon the student calculations.

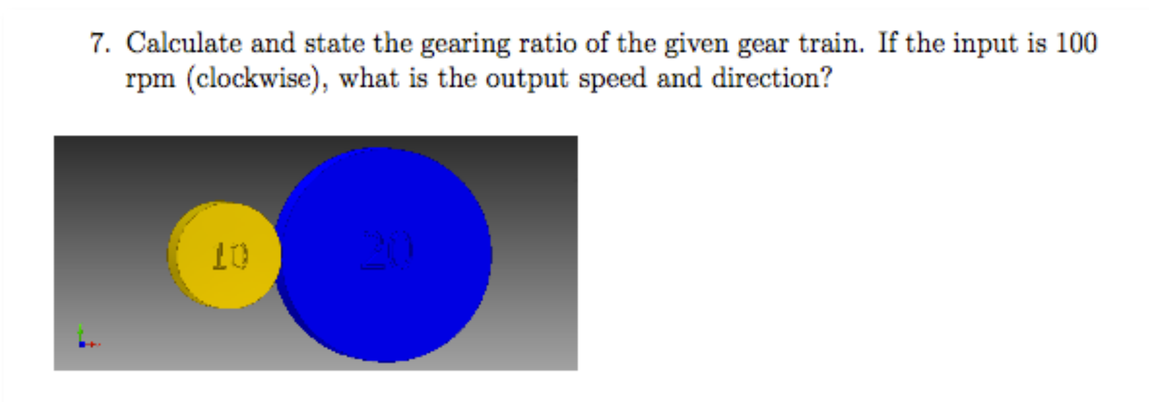

Figure 2: Sample simplified gear pair assignment question.

The process of moving from part modelling in Inventor to system modelling using MapleSim is demonstrated in Figure 3. Figure 3 a) is a spur gear-pair result generated by the Inventor Design Accelerator. Each part model must be exported to the industry standard STL file format. Figure 3 b) is the MapleSim system-modelling module. Students enter their calculated design parameters for a gear pair into the module dialog box and also specify the STL files associate with the part model (Inventor) geometries. Figure 3c) illustrates the visualization result that is now interactive. At the stage of Figure 3c), students can run the simulation and plot system parameters, such as angular velocity.

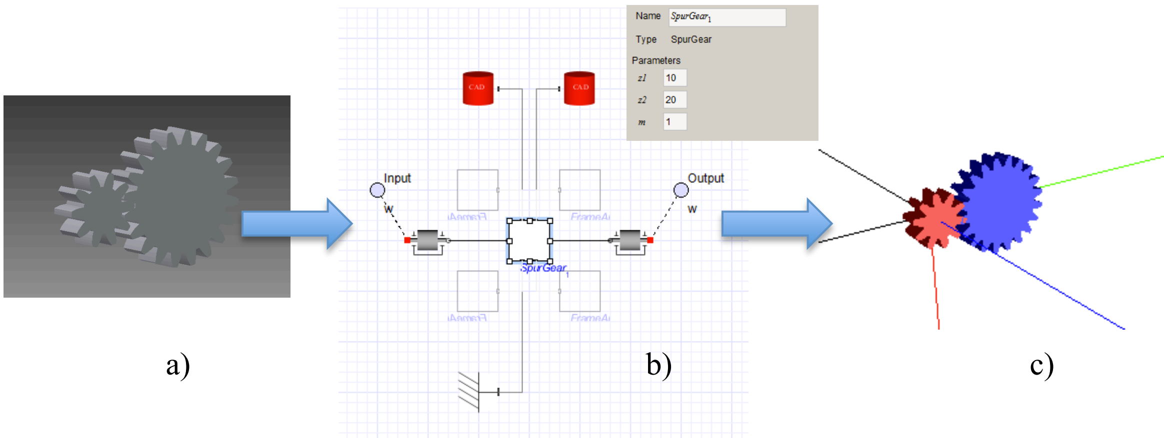

Figure 3: Process of going from part model to system model.

Design Project

The design project is performed by a self-selected group of three students. The project is framed to be a small team of young design engineers that must retrofit an existing company product, but before the retrofit will be approved the team must prove their design meets the given specifications.

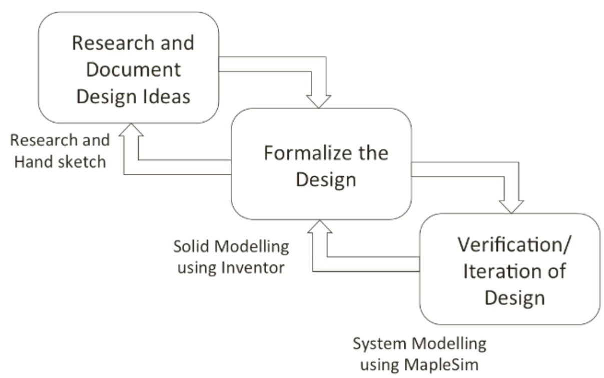

Figure 4: Team project workflow

The September 2010 project was the design of a retrofit mechanism for the control of a floppy drive read-head. The existing motor is no longer available and the new motor was in an alternate location and orientation. Teams had to design a new gear train that met the prior system specification. The expected team project workflow is shown in Figure 4.

Storage devices, such as floppy drives, hard drives, and CDROMS, are typically characterized according to their data transfer rate, seek time, and latency. Total access time for data is given by latency + seek time. These parameters are not independent of each other, but the average seek time is what we used for the mechanism-train specification. The total distance of the floppy drive read head movement (full stroke) was 20 mm. The typical average seek time of our floppy drive was stated as 160 ms. Using the simplification that our read head rested at the center of full stroke and average stroke distance was 10 mm, we derived an ideal target linear speed of 1/16 mm/ms (0.0625 m/s) for the read head.

The class was provided with the floppy drive chassis and the restriction that they must fit their new retrofit mechanism train into the existing space. No modifications of the chassis were permitted. Alternative gear designs and mechanisms were an option for bonus marks. Each team was specified a different input motor speed; however, all teams were required to meet the specified output condition of the original read head speed. Assessment criteria included: preliminary research report, part and assembly modelling, system modelling, design testing, engineering report and drawings, and individual interviews.

Modelling

There were two types of modelling that students performed in [placeholder]'s first year design and graphics course:

1. Part and Assembly Modelling
2. System Modelling

The part and assembly modelling of the entire gear train required the students to examine their input conditions against output requirements. Based upon the team's assigned input speed their design must consider gear ratio, gear pairs, practical gear design considerations, and space constraints. After working through their calculations the teams entered their gear-pair parameters into Autodesk Inventor's Design Accelerator to generate the geometries of their complete gear train. Once completed, each component is exported as an STL CAD file. Figure 5 is an example of a student team submission for this project component.

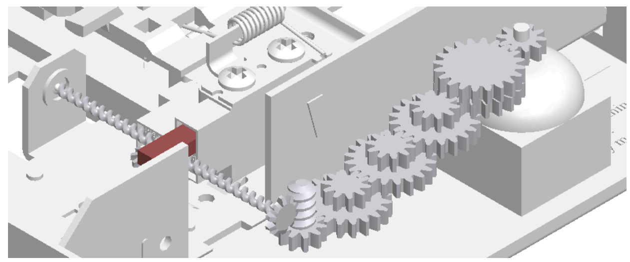

Figure 5: Example team project part and assembly model

The system modelling was performed using MapleSim and the custom gear-pair modules. A typical gear train is illustrated in Figure 6. Each red bin represents a gear geometry connected to a gear-pair model module. Each module implements a meshing gear relationship based upon the parameter values that the team has entered for each pair. Each module is linked to provide relative position and to cascade the output from one pair to the next.

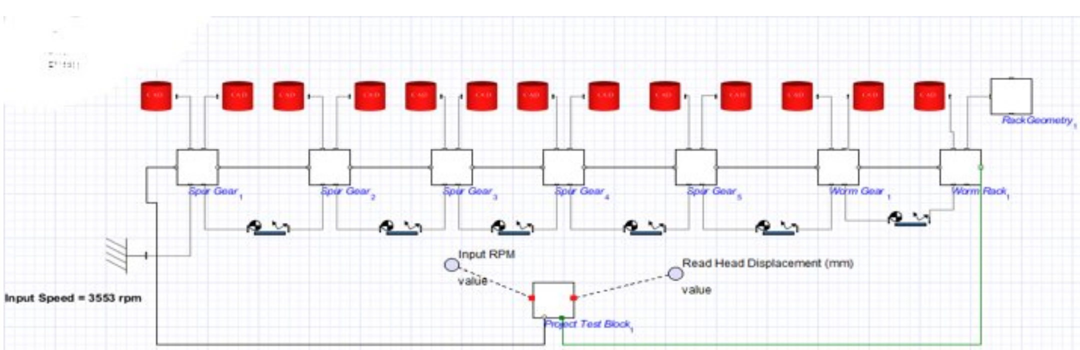

Figure 6: Example team project system model

Visualization

After the system model is compiled, the students were able to visualize the complete working gear train as a three dimensional model. This enabled the ``what if" scenarios that were previously unavailable. Figure 7 presents a three dimensional system model from the example student submission shown in Figures 5 and 6.

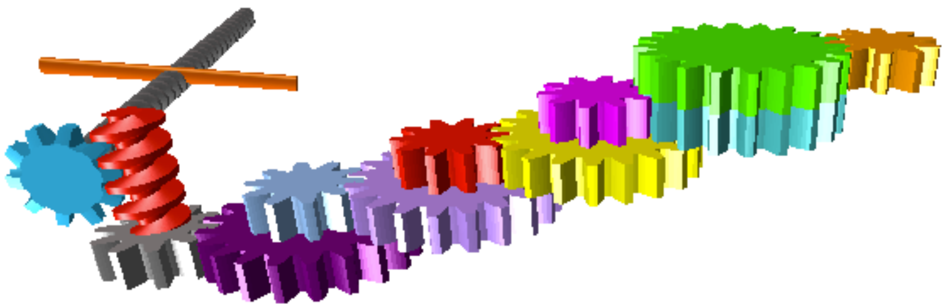

Figure 7: Example tem project three dimensional system model

The authors are aware that alternative tools are available to perform similar visualization; however, given that the first year engineering course at [placeholder] is a common year, the multimodal flexibility of MapleSim makes it a better choice because it can be used by all engineering disciplines beyond first year.

Verification

At the point of interactive visualization, teams were easily able to verify their design against the specified criteria. Figure 8 a) is a square wave input with a period of 320 ms and 50% duty cycle. This input represents the ideal input motor speed and direction (neglecting mechanical losses and assuming instanteneuous direction change). Figure 8 b) is a graph of the output read-head displacement. Recall that the read-head was required to traverse 10 mm in 160 ms. This graph verifies the team design has met the specification for read-head speed and displacement.

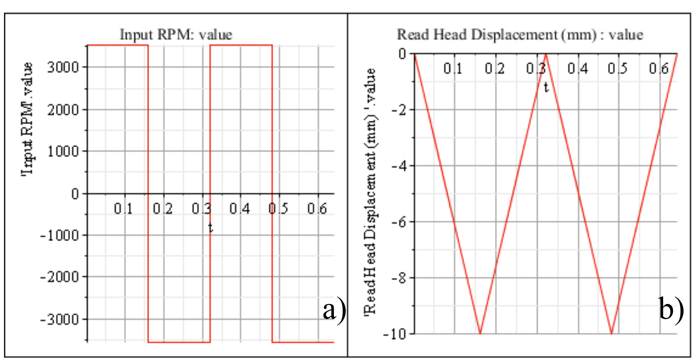

Figure 8: System model input and output graphs

Student Feedback

A small focus group was interviewed by an independent faculty member to collect student feedback on the course project and the system modelling aspect of the course. The interviewer compiled a summary of common responses.

Did the project improve your understanding of how common mechanisms function?

- The project did help – it helped learn about gears.
- Some did not see the purpose of using MapleSim when Inventor has similar tools.
- MapleSim aspects should be made more challenging.
- Some felt the MapleSim component only involved arbitrary plugging in of numbers until the results were correct.
- MapleSim coverage should be expanded.

Did using MapleSim for system modelling and visualization improve your understanding of design?

- Visualization was helpful.
- MapleSim was better for testing than it was for design.
- Some felt that even with a successful completion of the project that they still do not know how to use MapleSim.

Conclusion, Recommendations, and Further Work

The distinction between teaching about design vs. teaching how to do design in a large first year class is not a trivial transition, nor can it be done without some scaffolding. The goals of enhancing student learning and improving engagement are positively reflected in student feedback. Student feedback also suggests an intellectual curiosity to explore more of the system modelling. In addition, the goal of closing the design loop has been met with positive feedback.

As an initial offering the course instructor wanted to expose first year students to the tools that would be used in an iterative design process. This exposure required some consideration as the complexity of some topics and some tools can quickly turn the learning experience into an exercise in frustration.

The authors are encouraged to see first year students wanting to know more about the system modelling tool. The feedback also indicates that a better treatment of the system modelling tool, along with clearer rationale regarding its purpose are items for future improvement.

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