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## **A Significant Reverse Engineering Project Experience within an Engineering Graphics Class**

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# **A Significant Reverse Engineering Project Experience within an Engineering Graphics Class**

## **Abstract**

At the University of Alabama at Birmingham engineering department since the spring of 2007 a project experience has been incorporated similar to that of a practicing engineer in terms of timeline and scope of responsibility in the context of an engineering graphics class. The goal of the project is to cement the course content and assist students early in their school career to decide if engineering is a good choice for them. The project is to reverse engineer, from a geometry perspective, a real assembly of significant complexity. The course has developed over time to make the project very memorable and successful. Examples of projects include instruments, computer systems and peripherals, toys and industrial equipment (Fig. 3). This one semester course is the student's only formal engineering graphics training. The topics covered include hand sketching, dimensioning, projections and use of the computer aided design (CAD) package to generate parts, assemblies and formal documentation. The topics and structure of the class are arranged in a manner to support the progress of the reverse engineering project. Successful execution of the class as an instructor requires detailed planning for the activities of each class period with consideration of the learning period for the acquisition of the skills and knowledge required to successfully complete the project. Some of the educational principles utilized in the course are constructionism, spiraling, and immediate use of learning. The course is taken both by freshmen students as part of their first year experience and by transfer students.

The purpose of this presentation is to outline how the course is structured to enable students to create an assembly of professional quality. The in-class component is part lecture; part demonstration; and part in-class exercise, both guided and independent. The course is taught on four tracks. The first track is hand sketching and engineering graphics principles; the second is solid modeling, including assembly and formal drawing generation; the third track is the reverse engineering project and the fourth track is a small design project. The first two tracks start within the first 2 weeks of the semester. Both the initiation of learning solid modeling and the introduction of the reverse engineering project occur early in the semester with solid modeling started on the 3<sup>rd</sup> day of class while the project is introduced on the 7<sup>th</sup> day of class. The structure of the class and the rationale for the method and order of material is introduced and presented.

## **Rational for the class structure**

The class material is based primarily on three principles. The first principle is in the arrangement of the course material. Material is built on preceding material in an orderly fashion and the material is also organized such that knowledge and skill are introduced prior to their need for the

project. Course content is also arranged as introduced by Jerome Bruner[1] through the use of scaffolding or spiraling. This spiraling occurs at many levels. One level is that each skill taught is returned to in later lectures and built on with expanded capabilities or increased in difficulty by complication. Spiraling of student's visualization capability also occurs moving from concrete to imaginary. An example is having a physical object to create drawings from moving to creating drawings from other drawings to having to imagine and draw a totally new object in the design project. Even in the introduction of the extrusion process it is initially demonstrated in a concrete fashion. Spiraling also occurs in terms of moving up the levels of Bloom's Taxonomy where students initially learn solid modeling operations (knowledge) and then must determine the solid modeling operations to use to create their reverse engineering project (apply, analysis and synthesis) and design project (synthesis and evaluation). The second principle is immediate use of learning or active learning [2, 3]. Students participate in hands on activities in all but a few of the lectures. The amount of active learning is varied to assisting in keeping students' interest. The third is collaborative learning as the project for the freshmen student must be completed in a group of 3 or more students. The parts for the project must fit together yielding the cooperative portion of the project yet they are graded individually on the portion of the project that they completed.

### **General Class Structure**

The general structure of the course is a 2 credit hour course that meets two times per week for 1 hour and 15 minutes. The setting is a studio classroom with four laptops per hexagonal table. Three projection screens meet the needs of students facing in all directions. Due to the number of laptops the number of students is limited to 48 students per section with 4 sections in the fall semester, 2 sections in the spring and 1 section in the summer. An undergraduate TA that previously did well in the course assists in class and has some lab hours. The instructor also provides lab hours to move assistance to a student friendly environment.

Inspired by the learning pyramid only short lectures are used and the majority of the class time is spent in hands on activities either hand sketching or solid modeling. Most classes consist of in-class exercises. In-class exercises become homework assignments for completion. For the solid modeling assignments movie files of how to create many of the in class and homework exercises are provided that were created by the instructor. The instructor also wrote a checking program to allow the students to verify the correctness of their solid models. The program has the capability of checking both volume and overlap of the models. The checker is also used to automatically grade the student's parts. Students are required to place their files on a network drive for checking. The recommended book for the class is Visualization, Modeling, and Graphics for Engineering Design [4].

The course is taught on four tracks. The first track is hand sketching and engineering graphics principles; the second is solid modeling, including assembly and formal drawing generation; the third track is the reverse engineering project; and the fourth track is a design project. Figure 1 is a

modified schedule of topics for fall 2012 that clearly identifies the 4 tracks. Figure 2 is a flow chart to indicate how the information and work products connect together to make it possible to create professional assemblies as can be seen in figure 3.

### **Project definition**

The project is to create a virtual assembly of a real assembly. When this assignment was originally created design projects were also allowed but typically did not exhibit the range or difficulty of solid modeling requirement that was desired. Students form groups from 1 to 6 students. Each student is responsible for sketching, modeling and documenting their parts. In this manner it is possible to assign an individual rather than a group grade. Each of the students must have 6 unique solid modeling operations on their parts and have at least 3 unique operations on one of their parts. All of the project assignments must be placed in a specified type of notebook. The final for the class is a power point presentation presented by each group.

### **Track 3 Reverse engineering project sequence**

The following description of the timeline for the project activities demonstrates a combination of well scheduled due dates for project assignments and how the class content supports those assignments. Figure 1 is a modified class topic schedule from fall 2012. The schedule shows how the topics are interleaved with each other to enable the early introduction of solid modeling and the project. Figure 2 is a flow chart of the topics and how they sequence to create a support structure of knowledge and experience for the project. Figure 2 does not include the design project (track 4) for simplicity and also that the tasks are similar to the reverse engineering project (track 3).

Project introduction during class 6 provides a 2 week time period for students to think about the project before the idea sheet is due. The class 8 activity of sketching, measuring, and modeling provides a clear example of the type of activity that the project will require. Class 8 occurs one week prior to turning in the project idea.

Idea sheet due in class 10 is a formal description of the assembly that they will be documenting. This requires students to follow directions in putting together the notebook and have formed groups and determined an idea. Idea sheets are returned in class 11 in case there is a rejection of the idea to give the students till the next class to determine a new idea.

Photos due in class 12 are of each of the parts and the assembly assembled and disassembled. This requires students to follow instructions on what photos to take, where to place them on the network drive, determine what the parts are and to distribute responsibility for each of the parts to group members.

First hand sketch due in class 14 is a multi-view orthographic drawing of one of the student's parts. This is supported by class 1 on drawing and measurement, class 4 multi-view orthographic

drawing of physical parts, class 7 dimensioning methods and class 8 sketching, dimensioning and modeling of physical parts. The hand sketch is returned with corrections to be incorporated in the next sketch.

Second hand sketch due in class 16 is supported by classes for the first hand sketch and additionally by class 15 fasteners. After class 15 all threaded fasteners in hand sketches are expected to be in simplified form with thread notes properly specified.

Operations sheet due in class 18 is a list of the parts that the student is responsible for and the operations that they expect to use to create each of these parts. This assignment is supported by the feature operation classes 3, 5, 6, 10, 12, 14, 16, and 17. The primary goal is to verify that the feature operation requirements of the project will be met. Creative operation use is allowed.

Third hand sketch due in class 21 should take into account the corrections on sketches 1 and 2.

All hand sketches due in class 25 must take into account the corrections on sketches 1, 2 and 3. The number of sketches due will vary based on the number of people in the group.

Assembly sketch due in class 26 is a sub-assembly sketch of the number of parts the student is responsible for. This assignment is supported by classes 1, 2, 12, 14, 20, 23 on general drawing, isometric drawing, assembly drawing content and creation of an assembly drawing in the solid modeling package. While the preferred method is an exploded isometric drawing an outline assembly drawing is accepted.

The due dates for the remainder of the project components are intentionally left for the students to plan. This is an opportunity for students to exercise time management skills taught in their introduction to engineering courses.

Part model creation is supported by all the classes on solid modeling feature operations. Those classes are 3, 5, 6, 8, 10, 12, 14, 16, 17, 18 and 25.

Creating an assembly is supported by classes 20, 21 and 24.

Part drawing creation including a section and detail view is covered in classes 23 and 28.

Assembly drawing creation is covered in class 22.

Information on creating the power point presentation is part of the project definition and examples of previous projects are posted on the network drive.

### **Track 1 Hand sketching and information**

The following is a description of the contents of the hand sketching and engineering graphics information track 1. The purpose of track 1 is to provide students with the skills required to make intelligible sketches and to gain familiarity with some common standards of engineering

graphics. There are only 2 class periods within the class that contain a lecture without a hands on exercise which are both within this track and are the lecture on drawing standards and on manufacturing. The manner in which the tracks are intertwined is presented in figure 1.

The goal of the first class is to capture the students' interest and prepare them with the understanding that this will be a very active class. Class 1 introduces the basics of hand sketching of lines, circles and contours. An exercise on drawing a contour using the “not looking” method which requires looking at the object but not the pencil movement is to assist in removing feelings of inadequacy about drawing capability [4]. There is also a dimensioning exercise measuring a Popsicle stick and tongue depressor which requires derived dimensions.

Class 2 includes a standard lecture on the place of engineering graphics in engineering and then has an in class exercise on creating isometric drawing from coded plans [5]. The provided material includes multi-view orthographic and assembly drawings of Lego assemblies. The introduction to isometric drawing using coded plans also acts as an initial introduction to multi-view orthographic representation and assembly drawings. The introduction to isometric coded plans is eased by providing a physical representation of the object.

Class 4 is a formal introduction to creating multi-view orthographic drawings from Lego assemblies. Both unexploded and exploded assembly drawings and Legos are provided to assist students in visualizing the orthographic projections. An ability to determine where hidden lines are required is particularly assisted by having the physical part available for consideration. Dimensions are based on grid counting.

Class 7 builds on class 4 and introduces dimensioning methodology through a Socratic power point with the students determining dimensioning rules by choosing between examples for the preferred style.

The remainder of the classes in this track do not contain any unique teaching methodologies. The topics are introduced in a timely manner to support the project and threaded fasteners are introduced before the helical sweep solid modeling operation. The remaining topics covered in this track are multi-view orthographic drawings from isometric drawings (class 11 and 12), fasteners focusing on threaded fasteners and the simplified representation (class 15), part and assembly drawing standards (class 19), tolerance and its graphical representation (class 26), sections (class 27), auxiliary views (class 29), and non-geometric engineering graphics (class 30).

## **Track 2 CAD solid modeling, assembly and drawing creation**

The following is a description of the contents of the CAD, solid modeling, assembly, and drawing creation track 2. The purpose of track 2 is to provide students with the skills required to become proficient in use of the CAD system. Their proficiency is demonstrated by their use of the CAD system to create the reverse engineering project and design project. All of the class

periods within the track include hands on exercises. The manner in which the tracks are intertwined is presented in figure 1. All of the solid modeling and drawing creation topics are introduced prior to the need for their use in the reverse engineering and design project. The introduction of the use of the software over the whole semester allows students to master the software.

Class 3 is an introduction to the 3D virtual solid modeling environment and to the extrusion feature using a Play Doh fun factory as the physical example of extrusion. The assignment does not require that the objects are dimensioned. Extrusion capabilities of extrusion from multiple datum planes, extrusion from a surface, removing material with extrusion and extrusion in both directions are sequentially introduced. 2D sketcher operations of rectangle, circle, ellipse, line segment and spline curve are utilized.

Class 5 required dimensioning of the created solid models. The parts are based on creating solid models of Lego assemblies. Legos are available to create a physical representation to assist with visualization. The assignment parts are documented in multi-view orthographic and assembly drawings. Only rectangles are used to create the parts to minimize the introduction of sketching constraints and to exercise the ability to see how to create volumes by adding or subtracting volume. Some of the parts are designated for volume addition and some of the parts for starting with the overall volume and removing volume. The 2D sketcher constraints of coincident, equal length, horizontal and vertical are used.

Class 8 integrates lessons learned in all the previous classes in track 1 and 2. The class exercise is to measure and document a Lego block using a multi-view orthographic sketch with dimensions and then to create a solid model of the part. The homework assignment is to perform the same tasks for a Duplo block. This sequence also prepares students for the reverse engineering project that entails these same tasks.

The remainder of the classes in this track do not contain any unique teaching methodologies in the introduction of the topics and so will just be listed with their class numbers. The rest of the classes in this track are the revolve operation (class 10), the shell operation and adding color (class 12), the sweep operation (class 14), the helical sweep operation (class 16), the pattern and hole operations (class 18), creating an assembly (class 20), creating an exploded assembly and an assembly drawing (class 22), creating a part drawing (class 23), datum planes, axes and points (class 24), drawing sections and details (class 28) and auxiliary views (class 29).

#### **Track 4 Design project**

The design project was added to the engineering graphics class in 2011. The reverse engineering project works well for students to exercise their sketching and solid modeling skills. However since the focus of the reverse engineering project is on documentation, students were biased to view engineering graphics as a documentation tool and not as a design tool. This observation was made of students who had taken the class in 2007 and were then in their senior design project.

The design project to create a support structure based on specific geometric constraints is introduced in class 21. This is after all of the hand sketching and solid modeling and assembly skills to create it have been introduced. Class 21 also introduces how to convert IGES files to part files. The remaining knowledge required to document the design with CAD generated drawings is introduced in the next two classes. There is a work day (class 24) specifically dedicated to the design project because this is likely the students first design experience.

## **Conclusion**

A project that simulates the time requirements of a professional engineering project both in terms of elapsed time and accumulated time has been created that enables students to create professional results. Figure 3 presents the students' choice for 1<sup>st</sup> 2<sup>nd</sup> and 3<sup>rd</sup> best projects for the fall 2011 semester. The high degree of fidelity to the actual parts can be seen by comparing photos to the solid model screen shots. The quality of the project results are made possible by: 1) introducing knowledge and skills in a spiral and timely fashion 2) the introduction of solid modeling operations spanning more than 50% of the semester 3) having a course that engages students' interests.

Along with introducing students to the engineering graphics skills that they can build on for future classes and careers; another purpose of the class is to assist students in deciding if engineering is the correct career path for them. Anecdotal evidence from discussions with students supports the class working in this fashion. Students have reported that the class either convinced them that engineering was not the correct career choice or confirmed their choice of an engineering career.

The teaching methodology has also been reported as being effective by the instructors of the senior design courses in mechanical and materials engineering where engineering graphics skill are again brought to bear on a significant project. Prior to the introduction of the current method of instruction class periods were scheduled in the senior design class for CAD review and still students performed poorly with the CAD system. The senior design instructors report that students now come to senior design with competent CAD skills and do not require a review.



	Track 1	Track 2	Track 3	Track 4
Class #	Knowledge \ Hand sketching	CAD	Reverse Engineering Project	Design Project
1	Sketching \ dimensioning			
2	Isometric coded plan			
3		Extrusion		
4	Orthographic from Legos			
5		Extrusion (dimensions)		
6		Chamfer \ Fillet	Introduction	
7	Dimensioning			
8		Design analysis		
9	Orthographic from drawing			
10		Revolve	Idea	
11	Isometric with lines			
12		Shell \ color	Photographs	
13	Isometric with arcs			
14		Sweep	Sketch 1	
15	Fasteners \ pitch			
16		Helical sweep	Sketch 2	
17		Blend		
18		Pattern \ hole	Operations	
19	Drawing standards			
20		Part assembly	Sketch 3	
21				Introduction
22		Assembly drawing		
23		Part drawings		
24			Sketches	Work day
25		Datum planes \ axis \ points		
26	Tolerance		Assembly sketch	
27	Sections			
28		Section \ detail		
29	Auxiliary views	Auxiliary views		
30	Manufacturing			
31			Work day	

Figure 1 Modified class schedule from fall 2012 syllabus showing the 4 tracks of hand sketching, CAD, the reverse engineer project and the design project.



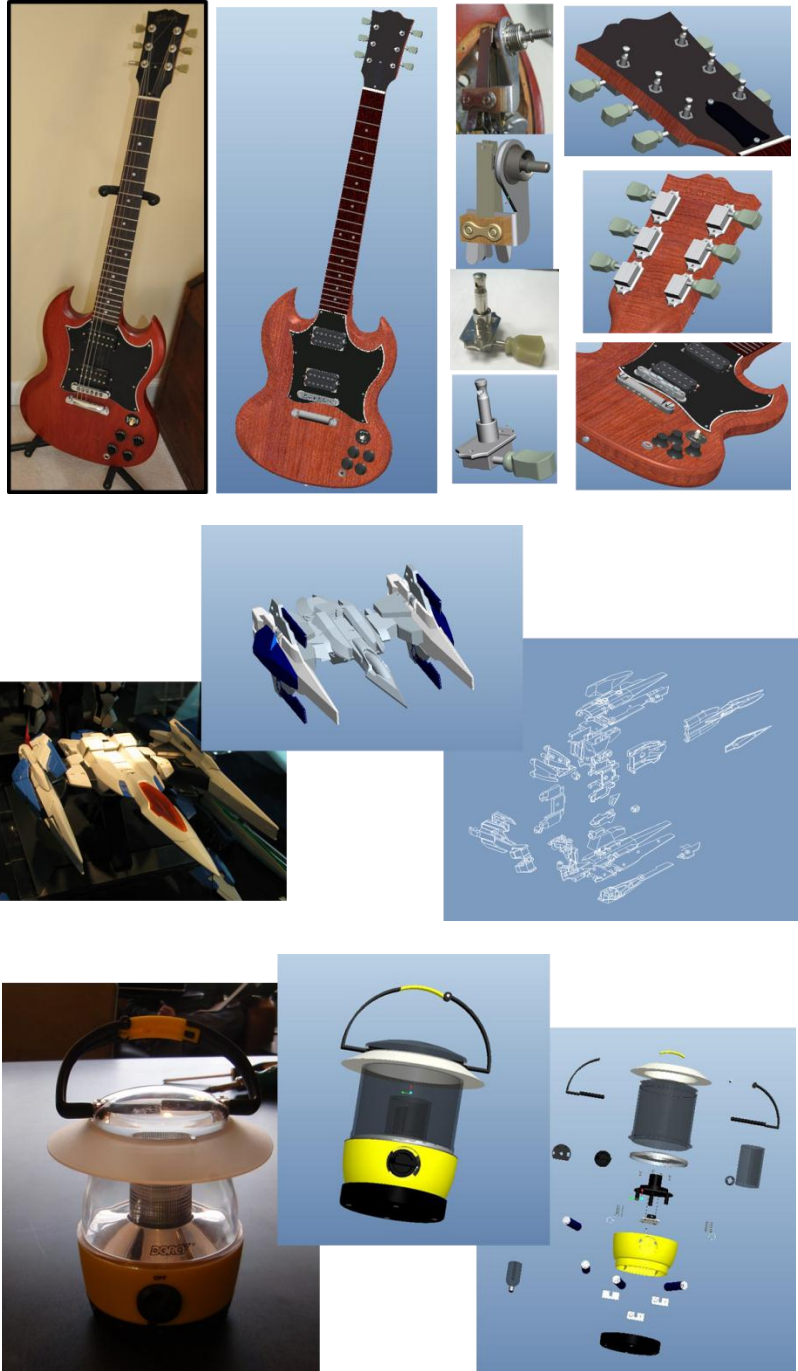


Figure 3 Electric guitar, Gundam model and camp lantern reverse engineering projects. Popular reverse engineering projects include instruments of all types, models, toys and appliances. Any project with a sufficient number of parts and geometric complexity is approved.

## References

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