

Incorporating Graphics, Audio, and Motion in a Freshman Engineering Technology Course

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Abstract

The objective of this paper is describe an experimental freshman level 3D design course which was designed to expose students to the engineering design process by incorporating 3D graphics, audio, and graphical motion analysis with technology, visualization and spatial design. In this experimental course, freshman Computer Graphics Technology students were asked to design and build an operational 3D virtual music box using a manually operated mechanical gear train to play one verse of a popular children's song.

1. INTRODUCTION

The course "Geometric Modeling for Visualization and Communication" taught in the Department of Computer Graphics Technology at Purdue University is a freshman level course designed to expose introductory engineering technology students to many aspects of the engineering design environment. It is a three-credit semester-long course that has two one-hour lectures and a two-hour lab each week. The focus of the course is on introductory 3-dimensional modeling, but all aspects of design graphics documentation are utilized. The students are exposed to conceptual and iterative sketching, 2-dimensional and 3-dimensional CAD environments, and mathematical-based motion as a visualization tool.

The following pages will describe and show in more detail the contents of the course, and discuss the results of the authors' experiences in teaching it for the first time.

2. COURSE DESCRIPTION

2.1 Lecture Topics

One lecture per week is usually designated as a "theory" lecture that focuses on a significant topic relative to design graphics. Over the course of the semester, there are approximately twelve periods available for such lectures.

For this course, the following topics were discussed as theory-based lectures: sketching principles and practices, the design process (linear and concurrent), 2-dimensional spatial geometry, 3-dimensional spatial geometry, 3D CAD modeling entities and practices, 2D and 3D coordinate space and understanding, visualization techniques and practices, multiview sketching and drawing, pictorial drawing, section views, standard gear application, and CAD file management and structure.

2.2 Demonstration Topics

The second lecture period each week is typically used for a demonstration of software tool or design graphic technique, such as conceptual sketching. For this class, initial emphasis was placed on iterative sketching for ideation purposes, and documentation of the creative design process. Both pictorial and multiview sketching techniques were used to achieve this purpose.

There were several CAD and illustration software tools that were used during the course of the semester. As the students were not familiar with these software packages, the demonstration periods were utilized to expose them to various aspects of the tools. Solid Edge® software was used for basic 2D CAD modeling and basic and advanced 3D solid modeling and assembly modeling. This product was convenient to learn and robust enough to do everything that the students requested of it. It proved to be a good solid modeler, although not strong in the surfacing area. The students were able to master the product through a series of laboratory assignments (described below) that required the students to progressively master new techniques and abilities weekly.

Additionally, the students were exposed to IronCAD® software, another CAD tool. It was used briefly for modeling gear sets and for exposing the students to effective data transfer processes. This software package has a strong parts library, including gears, which can be "dragged and dropped" into the modeling area. Transferring from this CAD package to 3D Studio Max® was easily accomplished and effective in showing the class issues involved in moving between software platforms.

Finally, 3D Studio Max was used to expose the students to mathematically based expressions to control movement. The students were tasked with simulating the motion of their project in the software after transferring their part models from Solid Edge and IronCAD. They were also required to embed a music file in the simulation (see "Project" below).

2.3 Laboratory Assignments

Students were given laboratory assignments during the weekly laboratory period to be completed by the following week. These laboratory assignments were closely aligned with the lecture (theory) topic and demonstration period topic, and were designed to prepare students for successful completion of the major laboratory project that was the capstone assignment of the course.

Assignment topics included the following: design ideation sketching in both multiview and pictorial layouts, visualization exercises to improve 3D ability, basic 2D CAD modeling and basic and advanced 3D solid modeling, and CAD assembly modeling. Several of the assignments were used later in the capstone project.

Appendix 1 shows an example of one of the laboratory assignments that was utilized later in the laboratory project.

2.4 Laboratory Project

The capstone laboratory project for the class was designed to apply all of the techniques and methods covered during the semester. The goal was to emulate the design process as much as possible in a simulated environment to design a children's toy/music box. The students' were tasked with working through several iterations of design sketches for the casing or outer shell of the toy, which needed to match the theme of the music that was selected.

The next task was to create a part model of the outer shell in Solid Edge, and to model each internal part required to supply appropriate motion to the gear train, music drum, and related shafts as well as stationary parts.

Next, in Solid Edge, the students needed to create an assembly model from all the individual part files. Due to time constraints, the students were not required to provide mounting structures or bosses to the interior of the shell.

The students were then required to transfer the Solid Edge modeled parts to 3D Studio Max. They were also required to design accurate gears in IronCAD and transfer them to 3D Studio Max. Finally, the project required them to accurately assemble all of the parts in 3D studio Max.

From the completed assembly in 3D Studio Max, the students were required to apply mathematical expressions to the gears and related moving parts to accurately depict the rotary motion and step-down ratios of the gear train from initial input to final output. The appropriate music to match the theme was also embedded in the Max file to match the motion of the music box apparatus.

In order to complete the project successfully, the students had to submit their complete sketch history, final Solid Edge part and assembly models, and 3D Studio Max model with operational expressions and embedded music file.

Appendix 2 shows the Project Description Assignment that was given to the students.

2.5 Course Assessment

The course was graded on theory examination and practical skills. There were two theory examinations, a mid-term examination worth 15% of the final course grade, and a comprehensive final examination that was worth 20 % of the course grade. Both of these examinations consisted of multiple choice and matching questions. Additionally, the final examination included several sketching exercises, both pictorial and multiview.

The laboratory project was worth 30% of the course grade. It was evaluated based on the design criteria for the project, the creativity of the student's solution, and accuracy and precision of modeling and simulation.

The weekly laboratory assignments were worth a combined 20% of the overall course grade. Heavy emphasis was placed on submitting the weekly assignments, as the skills mastered in these exercises were necessary to successfully complete the laboratory project.

A laboratory practical examination was administered approximately half way through the semester. This examination addressed mastery of basic Solid Edge® and sketching skills, and was worth 10% of the total course grade.

The final 5% was applied to a student notebook that each student was required to submit. This notebook was to contain all of the laboratory assignments from the semester and all supporting documentation for the class.

3. COURSE ANALYSIS

The purpose of the course was to expose students to the design process, develop skills in creative design, achieve competency in CAD solid modeling and graphic documentation. It was difficult to achieve these goals for all students based on the sheer number of attendees (ninety three students submitted final projects). However, given the quality of the student work in general, it is felt that the authors were successful in instilling the students an understanding of these topics and satisfactory accomplishment in skill development.

There are several topics that the authors feel need to be strengthened for future use. These include: a more detailed theory presentation of the design process, and more detailed analysis of the subsets of the process, such as ideation, refinement, and implementation.

Furthermore, the authors felt that the time frame for the students' projects was too compressed. To alleviate this issue, the authors intend to begin the laboratory project work several weeks earlier in the semester than was done this first time. This modification will impact other areas of the course, such as when specific lectures are presented, and also weekly laboratory assignments, but can be accomplished in the given semester schedule.

Another general modification that the authors will be including in future semesters is an interactive web page including a sample of past projects, current grades for the students, and up-to-date announcements, tips, hints, and changes that the students need to be aware of.

4. CONCLUSION

In conclusion, this freshman level design project was found to be motivational and challenging for students. The integration of sound, time based events, motion, 3D computer graphics, visualization, and basic engineering design methods helped a large number of students to grasp many of the issues involved in the basic mechanical design process.

With modification and refinement, the continued development of '3D virtual design/simulation' learning activities will continue to be a primary goal in the CGT 116 course at Purdue University.

5. APPENDICES

Appendix 1: Sample Weekly Laboratory Assignment

CGT 116

Assignment #6

The Rhythm of Geometry - Designing a Sound Solid.

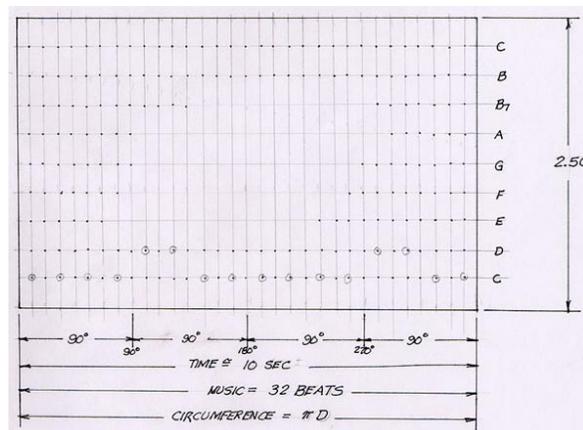
Create a solid model of a 'rotating spiked cylinder' for a mechanical music box that is designed to play a simple tune or nursery rhyme in one octave (notes C, D, E, F, G, A, B[orB7], C). The cylinder is designed to rotate around its axis. As the cylinder rotates, the spikes on the cylinder are designed to 'pluck' a set of adjacent chimes and play a tune.

Music Specifications: The tune must be a familiar simple child's nursery song that can be played with a one octave set of chimes. The song is to be played with single and harmonic notes as demonstrated. Available songs include *London Bridge*, *Chopsticks*, *Three Blind Mice*, *Yankee Doodle*, *Red River Valley*, *I'm a Little Teapot*, or *Twinkle Twinkle Little Star*. One verse of the song will be recorded and furnished to you with a playing time of between 10 and 16 seconds. Digital versions of the songs will be available as .wav audio files.

Music for Mary Had a Little Lamb

For this example, the music for *Mary had a Little Lamb* is shown below. As an example of how to visualize the music and

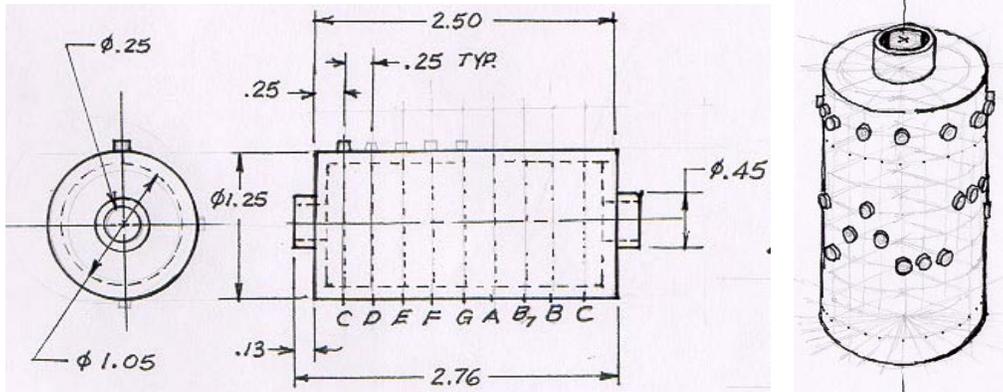
convert it to a 3-D geometric form, a tablature chart laying out the cylinder is also shown.



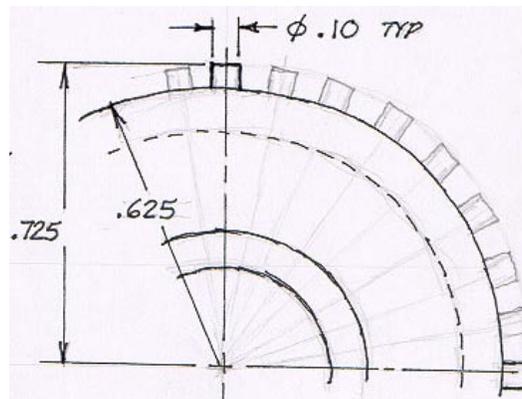
Drum Layout for Plotting Spikes

3D Solid Model: A geometric solid model of the cylinder is to be built in inches with the following specifications. Diameter = 1.25. Length = 2.50. Spikes are to have a diameter of .10 and protrude above the surface of the cylinder by .10 inches. Down the length of the cylinder each note (C, D, E, F, G, A, B[B7], and C) will have its own cross-sectional location. As the

cylinder rotates, there must be a spike at the right angular location around the cylinder to pluck the correct chime at exactly the right time. See the design sketch below to help you further visualize the model.



BASIC DIMENSIONS AND PICTORIAL



Spike Dimensions

Getting Started: Determine the exact placement of the spikes by unrolling the cylinder onto a flat plane. The circumference is equal to one complete 360 degree rotation. In the case of *Mary had a Little Lamb*, the circumference also equals 10 seconds as well as 32 beats for the song. Now, use what you have already learned from high school math to determine the exact angle and location (cylindrical coordinates!) for each of the spikes

on the cylinder. Make a valid solid model of the 'tune'. Good luck!

NOTE: Do a thorough job here because we'll be using this model later in the semester as part of a larger design project.

Appendix 2: Laboratory Project Assignment

CGT 116

Lab Project – Spring 2001

Preliminary Project Description – March 19, 2001

Design Problem: A mathematically operated 3D computer graphic simulation of a virtual mechanical music box to play the song from your musical cylinder.

Product: Music Box - Operational 3D Virtual Prototype

Theme: A mechanical-musical ‘whatzit’ toy based on children’s musical themes.

Target Market: Ages 3 to adult. Toy or novelty store with \$5 - \$12 price range.

Mechanism: Hand or wheel cranked gear train used to rotate and play a mechanical music box mechanism consisting of a rotating studded cylinder and steel pronged chimes.

Material & Visual Appearance: Outer music box case - Plastic/acrylic see through outer case made in at least two pieces with hollow interior for gears, shafts, music cylinder, soundboard & chimes. Gears – plastic, primary colors. Shafts & Screws – Steel. Music cylinder & Chimes – steel.

Unit/Size: Design in decimal inches. Finished design must be no larger than 9 inches in any exterior dimension.

Operating Conditions & Limitations: When the driving gear is turned (by crank) or rolled (by wheel) at a rate of approximately once per second (+/-), the gear train is put in operation which causes the music cylinder to revolve one complete rotation every X seconds (length of song in seconds) to play the song once. Therefore, the length of the motion based cycle is equal to the length of the song.

Rotational Motion: This is continuous rotational motion. The music box must contain at least 2 gear ratio changes requiring a minimum of three shafts and four gears to play the song. Sound is generated by a steel comb with variable length prongs which are struck by the rotating studs on the musical cylinder. The prongs on the comb have a one octave range (C, D, E, F, G, A, B, including Bflat, and C) similar to the music cylinder.

Music Timing & the Gear Ratio: Listed below are the names and run times for each of the songs which has been recorded and which will require a unique 3D model for its music drum. Remember that the length of each song in seconds is also the number of turns the gear crank must make in order to play the song once. Therefore, calculate your gear train accordingly as discussed in lecture.

NAME OF SONG SECONDS	LENGTH	IN SECONDS
London Bridge		16
Twinkle Twinkle		20
Three Blind Mice		16
Yankee Doodle		12
Hail Purdue		24
Brother John		16
Red River Valley		20
Row Your Boat		10

NOTE: The sound files listed above are available in .wav format on the G: drive. Checkout and download your file as soon as possible.

Intermittent Rotational or Linear Motion: This is ‘back and forth’ motion. Each music box must also have at least one intermittent motion that is mathematically tied to the rotational motion of the main gear train. Examples of this could be London Bridge going up and down, Yankee Doodles hat bobbing up and down, tails swinging back and forth for Three Blind Mice, stars swinging back and forth for Twinkle Twinkle Little Star, a rotating tail for Mary Had a Little Lamb, etc.

Material-Physical Design Conditions in Cavity: Design the webbing and bosses inside of the plastic cavity of the music box case to mount the music comb, hold the shafts, gears, and screws in place with room for parts to move as required.

Moving Parts Outside of Cavity: External cranks, wheels used to operate the music box, as well as, flapping ears, swinging mouse tails, etc., must be directly connected to the main drive train in the cavity.

Design of Outer Music Box Case: The Outer Music Box Case is to be see-through plastic/acrylic and made in at least two pieces with hollow interior cavity for mechanism. Holes and small openings need to be designed into the Outer Case to accommodate hearing the sound, cranks, shafts, wheels, and other moving exterior parts.

Computer Graphic Technology Specifications: 3D CAD Models (except for gears) are to be built and assembled in SolidEdge software. Gear blank (plain cylinders), based on pitch diameter are to be built and assembled in SolidEdge. Gears are to be generated in IronCAD. Individual part files from the assembly model are to be exported out of CAD programs and imported for re-assembly 3DS MAX software for development of mathematical expression development to drive the 3D virtual assembly and play the music. File format and file management techniques to be announced.

Ideation Sketches: A. Interior Cavity grid paper layout assembly for planning, sizing, and placing gears, shafts, etc. B. Design sketches used for building 3D exterior or Outer Music Box Case model.

Digital Files: Your 3D musical drum model, digital recording of your song, specifications for modeling a comb with steel pronged chimes, a SolidEdge assembly model with all 3D parts, 3D gears from IronCAD, a 3DS MAX file containing an expression (mathematically) operated assembly of the Music Box with associated music file.

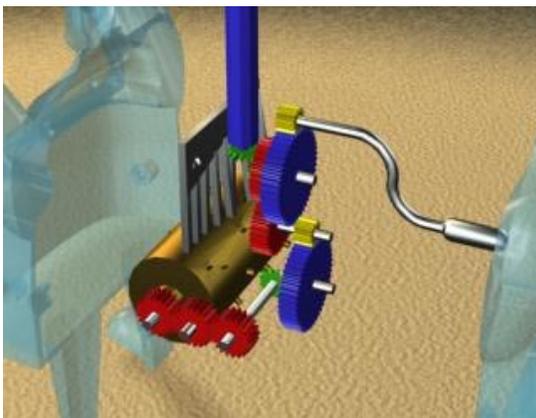
Project Documentation: Use a 3 ring binder ONLY. Begin by keeping all of your preliminary concept sketches and notes, even for the ideas you don't use (including the

really bad ones). A more detailed assembly sketch for the gear train as well as all concept sketches for the exterior shell design are required. Printouts from Solid Edge of the final external shell model and the completed assembly are required. One printout of the rendered/completed assembly in MAX is also required. Label and date all project sketches, notes, and printouts and keep the material in chronological order.

Due Dates: To Be Announced.

Primary Final Evaluation Criteria: Projects will be judged using two different but complimentary methods. 1. AESTHETIC: The project will be judged on how well the case design and mechanism arrangement meets the theme of the song as well as for visual, simplistic, creative, graphical qualities. 2. TECHNICAL: The creative technical solution of how the gear train is integrated into the music box is important. Here, the project will be judged on how technically accurate and precisely the gear train is designed. An complete assembly model must be completed in Solidedge and 3DS MAX. The project must have a basic operational gear train by means of expressions in 3DS MAX (even if the intermittent motion feature doesn't work).

Appendix 3: Sample Student Project Results



Inspector Gadget: Gear Train



Inspector Gadget: Assembled Model

6. REFERENCES

- [1] Bertoline, G. R., et. al. (1995). *Engineering Graphics Communications*. Chicago, IL: Irwin Publishing Company.
- [2] Miller, P., et. al. (1999). *Inside 3D Studio MAX 3*. Indianapolis, IN: New Riders Publishing.
- [3] User's Guide. (2000). *Getting Started with Solid Edge*. Maryland Heights, MO: Unigraphics Solutions, Inc.

About the authors

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William A. Ross is Professor of Applied Computer Graphics in the School of Technology at Purdue University in West Lafayette, Indiana. Prior to joining the faculty at Purdue in 1988, he received his Bachelors and Masters degrees from North Carolina State University where he developed a funded, UNIX-based, applied solid modeling instructional laboratory. Since joining the faculty at Purdue, he has received the Outstanding Non-Tenured Faculty Award from the School of Technology, was elected as Chairman of the Engineering Design Graphics Division (EDGD) of the American Society for Engineering Education (ASEE) for 1994-1995, and is currently serving as Area Head for the Technical Animation & Spatial Graphics Professional Program within the Department of Computer Graphics Technology. Research interests include development of applied computer graphics tools for education, training, communication and testing purposes.

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