2006-2165: REVISION OF FRESHMAN ENGINEERING GRAPHICS TO SUPPORT AN EVOLVING CORE DESIGN SEQUENCE

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Revision of Freshman Engineering Graphics to Support An Evolving Core Design Sequence

Introduction

Engineering Graphics is a core requirement in the first semester for all engineering undergraduates and has followed a standard approach based on 3-D solids modeling with SolidWorks™. The course has leaned heavily on associated tutorial materials. The Graphics course is taught concurrently with Engineering Design I, the first course in the core design sequence that runs through all four years. A recent curriculum review prompted a number of changes to the design sequence including understanding and practicing design in a systems context and its articulation through the sequence. This is introduced in Engineering Design I with a first introduction of the concepts of the systems approach starting with a much increased emphasis on an analysis of customer requirements, particularly focused on systems rather than isolated artifacts. This then leads into the technical aspects of design. In the second design course the systems concepts are extended to introduce consideration of use aspects. In support of this approach, it was recognized that Graphics should be broadened in scope and better integrated into the early design pedagogy. This objective is to expose students to the range of graphical communication in engineering from three-dimensional hand sketching to virtual reality as well as introduce contemporary aesthetic design, a topic missing from the traditional approach but critical from a customer needs and product success perspective in many applications. Some elements of this approach have been recently incorporated into introductory graphics courses at other Schools. For example at University of Texas at Austin[1] they have incorporated Finite Element Analysis and kinematics as a complement to 3-D modeling.

Implementation

A pilot has been conducted with three (of ten) sections of the first semester Graphics course. The primary course outcomes were kept the same as those for the other sections. SolidWorks™ was also kept as the primary tool. However, the syllabus was revised to include the introduction of a broader set of digital design and visualization tools. Thus as part of the core undergraduate curriculum, the revised Graphics syllabus now looks to address a wider array of user needs and customer requirements associated with both the various engineering disciplines and a more systems oriented approach to design. It is also anticipated that this revision will realign the perception of students who may feel that this course mostly relates to mechanical engineering and not necessarily to their major.

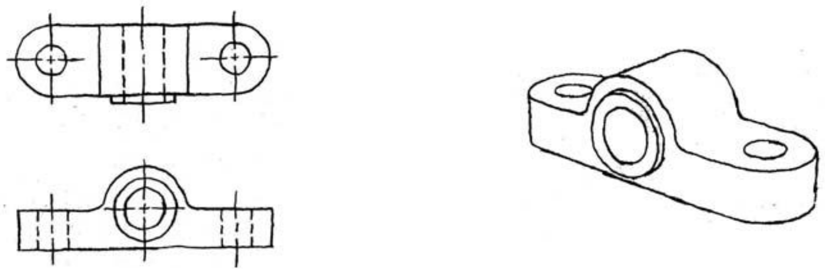
Nascent design tools, such as rule-based modeling, advanced replication, virtual reality and scripting environments, tools that did not exist as recently as 10 years ago, are now introduced in the context of contemporary product design and engineering.

Revised Course Syllabus:

WEEK	CONTENT	TOOL
Week 1	Introduction	Sketchbook
Week 2	Hand Sketching	Sketchbook
Week 3	2D Vector Based Drawing 1/2	AutoCAD™
Week 4	2D Vector Based Drawing 2/2	AutoCAD™
Week 5	Part Modeling 1/2	SolidWorks™
Week 6	Part Modeling 2/2	SolidWorks™
Week 7	Advanced Part Modeling	SolidWorks™
Week 8	Quiz 1: (part)	
Week 9	Assembly 1/2	SolidWorks™
Week 10	Assembly 2/2	SolidWorks™
Week 11	Rule Based Modeling	SolidWorks™
Week 1 2	Surface Modeling/ Advanced Replication	SolidWorks™
Week 1 3	Bill of Materials / Analysis	COSMOS™
Week 1 4	Project Presentation/ Virtual Reality	CATIA™ / EON Reality™

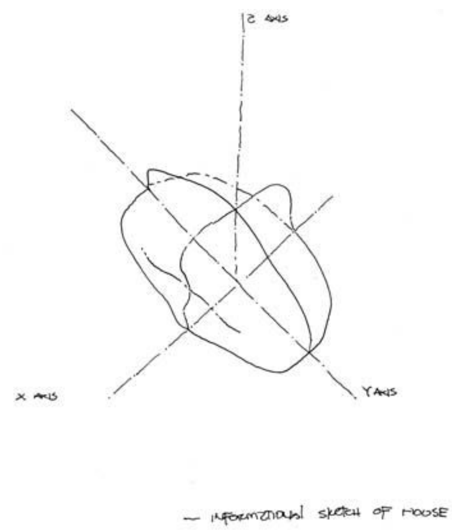
The course commences with 3-D free hand sketching of contemporary objects with complex surfaces. The goal is to use the sketching exercises to help students think through how they will tackle the graphical representation of complex three-dimensional objects before they turn to the digital tool. This is in addition to learning the valuable skill of how to make effective freehand sketches for communicating ideas. This approach contrasts the normal teaching of free hand sketching in which the focus is on representing simple euclidean objects (see Figure 1).

Fig. 1 Traditional Sketching Techniques (after Bertoline[2])



In this regard, the sketching module introduces the idea of Bezier-based[3] geometry, in particular the use of b-splines as a surface generator as shown in Figure 2 for an asymmetrically contoured computer mouse.

Fig. 2 Informational sketch of computer mouse



This approach to sketching maps directly into how the students will approach the digital modeling of complex contemporary objects. Here, students from the outset were instructed to sketch in three-dimensional space as opposed to more traditional two-dimensional orthographic projection methodologies. This fostered a stronger understanding of the relationships of directional surface geometries. It also promoted an intuitive and creative mindset in the students work, as opposed to a focus on the mechanics of orthographic projection.

Following sketching with a brief introduction to 2-D vector graphics (AutoCAD™) immediately exposed the limitations of an important and pervasive digital graphics tool.

However it also showed the applicability of vector drafting to certain engineering applications. This is important because as a core undergraduate course for all disciplines, students can appreciate tools appropriate to not only their discipline but also individual tasks at hand. Here, the future electrical and civil engineer sit side by side with mechanical engineers for whom a sole focus on solid modeling may seem more appropriate.

Solid modeling then forms the core of the revised course and occupies the majority of time in the semester, with part modeling, assembly modeling and interactive 2-D drawing generation being the key components. Although the content here was similar to that of the other seven non-pilot graphics sections following the existing curriculum, the pedagogy was focused on a workshop approach rather than a lecture/tutorial environment. In this regard the time spent working through the tutorial material was significantly reduced compared to the other sections. This recognized that students could easily revisit this on their own once they were aware of the topics and techniques. This change freed up time, particularly later in the course, to apply what had been learned to individual project work of the student's choosing. In so doing, it raised the level of engagement and enthusiasm for the course.

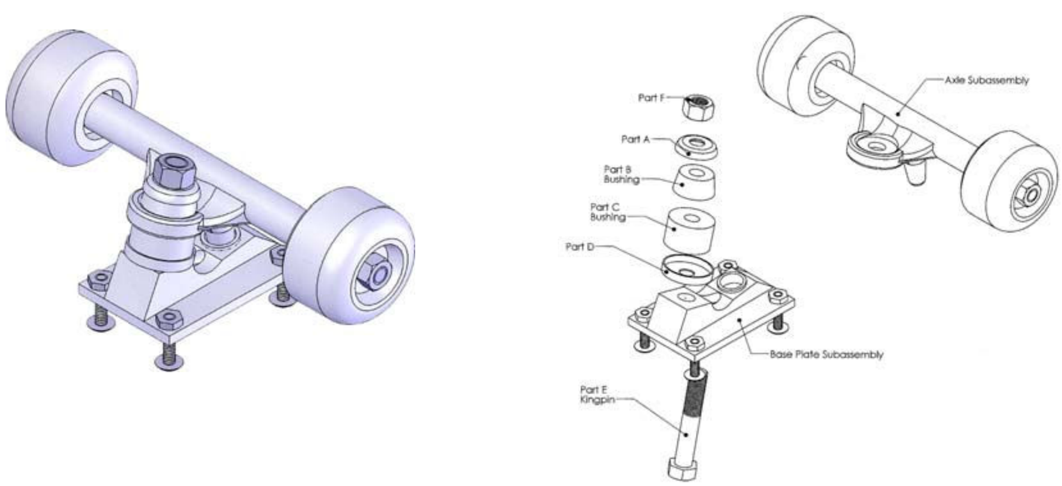
At this point, in the tenth week of the semester, fluency in solids modeling was apparent and the tutorial workshop was replaced with individual student projects. This was a departure from the existing curriculum by not trying to be exhaustive in the exploration of the capabilities of SolidWorks™. Short demonstrations were given on select advanced topics with the expectation that students would see the applicability and need for these methodologies in their individual tasks. For example, building on the sketching exercises in which Bezier-based geometries were introduced in an intuitive manner to deal with complex geometries, their need was now demonstrated in applying the digital tools to advanced surfacing. In Figure 3 the connection of orthogonal circle and rectangle elements in (a) would typically be limited to application of a simple lofting as in (b). In contrast the use of tangency has been explored in the pilot sections to create aesthetic shapes such as (c).

Fig. 3 Advanced Surfacing and Tangency

(a) Starting point (b) Normal loft approach (c) Incorporation of tangency

The importance of the individually selected projects cannot be understated, as there are generational issues in interest and environment that are not reflected in standard texts and associated examples. These contemporary objects are in turn a reflection on contemporary design and manufacturing methodologies. A counter point is the hand-held screwdriver exercise typical of a final examination in the existing syllabus. This contrasted with the more dynamic geometries of cell phones, gaming consoles and skateboard surface and truck assemblies in the modified syllabus. At a point in which the traditional graphics section typically exhibits stagnating student interest, the proprietary interest associated by the student to his/her project became a reinvigorating factor in the latter part of the semester.

Fig. 4 Student Project: Skateboard Truck



An example of a student project illustrating the dynamic geometry is seen in Fig. 4. Here, an avid skateboarder in choosing an object of considerable personal interest, also was able to gain some insight into some aspects of engineering and manufacturing and by doing so successfully completed the geometric modeling exercise.

Fig. 5 Student Project: Travel Mug

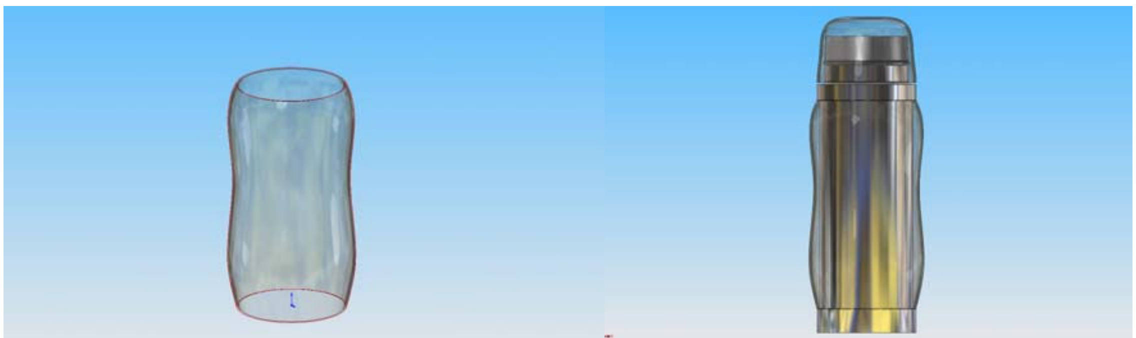


Fig. 6 Student Project: Collapsible Headphones

Figures 5 and 6 show examples of applying advanced surfacing as the most appropriate method of modeling complex geometries. This illustrates the departure described above from the traditional scope of the introductory graphics course.

Having now used SolidWorks™ in depth to meet the majority of the course outcomes consistent with what was expected in the existing syllabus, the final two weeks provided a further enhancement by exposure to the power of digital tools to go beyond three-dimensional modeling to analysis, kinematics and virtual reality. COSMOS™, an enhanced module for SolidWorks™ was introduced in the context of finite element analysis (FEA) to show the stress distribution in an object created in SolidWorks™. So while FEA was not taught at this point, the power of linking advanced engineering analysis and visualization within the design environment was a glimpse of how modern digital tools have shaped the engineering profession.

Demonstrations using CATIA™ provided awareness of advanced topics such as advanced replication. The opportunity was taken to also demonstrate the use of kinematics in design. While aspects of this can be done in SolidWorks™, the example was a sophisticated one developed as part of a Graduate design program to demonstrate leading edge design.

The course culminated with a glimpse into the power of virtual reality as a means of communicating not only the hyper visualization of design as an independent endeavor, but also the value of human interaction with the design. To achieve this, students were taken to a virtual reality theater where a stereoscopic projection system was used. A SolidWorks™ assembly file, after conversion through EON Reality™ V.R. software, was made to appear with the object floating in the three-dimensional space of the room.

The revised course not only recasts the teaching of introductory graphics, but also provides the first step in moving early engineering design education beyond the purely technical aspects to consideration of contemporary aesthetic design. It can be argued that the aesthetics will not be a primary concern for the majority of engineering disciplines. Nevertheless, in the broader sense of an engineering education in which design is a key component within the integrated systems environment, an appreciation of aesthetics should contribute to the development of the student's awareness.

The power of modern digital visualization tools provides a vehicle to seamlessly explore creative design alongside the mechanics of modeling and representation. Along with these innovations, the concurrent evolution of the design course sequence is providing the opportunity for the implementation of these tools and approaches right from Freshman Year. Changes to syllabi through the core design course sequence out into the disciplinary design courses will provide enhanced opportunity and requirements to leverage the broadened graphics foundation.

One example is in the follow on second semester Freshman-year Engineering Design II course. In this course students are required to use what they have previously learned in Engineering Graphics to produce a CAD model as part of the seven week design project. In addition and of particular significance to the revised approach in Graphics, a connection is made to the extensive Engineering Design II use of LabVIEW™ to interface the students' computers with sensors for data acquisition. The students are introduced here to examples of the recent development whereby actual physical test data obtained on a prototype from sensors via LabVIEW™ can be mapped onto the original CAD model and associated analysis used in the design phase, e.g. via SolidWorks/COSMOS (e.g. http://ni.com/design/mechanical.htm). This allows actual test behavior to be directly compared to that of the design phase simulation as a means to accelerate product development. Examples could be the stress in an aircraft wing, or the temperature profile of a heat exchanger.

Assessment

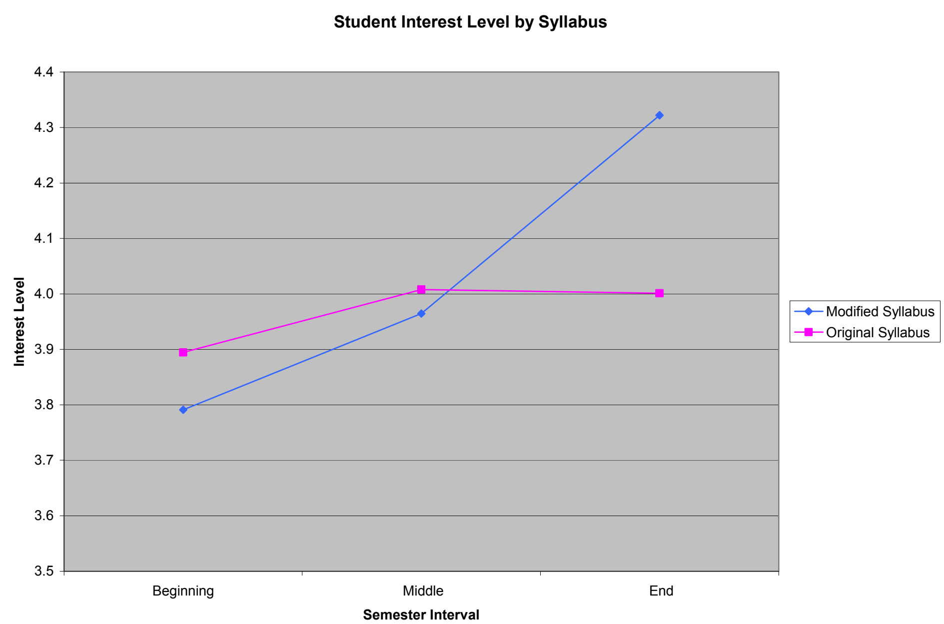
Assessment of all ten graphics sections was conducted with the School of Engineering's online survey tool (ACE) that is used for all engineering curriculum courses. Surveys probe both course delivery and educational outcomes topics. As previously mentioned, the course educational outcomes were kept the same for all sections and were reflected in the survey. In addition to rating instructor effectiveness, students were asked to rate learning against four outcome questions:

1. *You are able to effectively use computer-based and information technology tools for preparing transmitting, and displaying multimedia documents, including technical drawings/presentations.*
2. *You are able to visualize objects (parts/assemblies) and represent them using standard graphical methodologies.*
3. *You are able to help specify the geometric size and shape characteristics of a component or unit required for its manufacture.*
4. *You are able to help establish part of a complete design by producing the technical drawings.*

The survey results (not shown for brevity) did not reveal a significant difference between the responses from the students taking the modified syllabus and those on the original. This was not too surprising as a primary goal was to expand the perspective of the students in the revised syllabus while meeting a common desired set of outcomes for all students.

In order to gain further insight into the impact of the syllabus revision, we conducted an additional end-of-semester paper survey in which the questions probed students' perceptions. One key question asked students to rate their interest level at the beginning, middle and towards the end of the course using a scale of 1 (not interested) to 5 (very interested). The results are shown in Fig. 2 comparing the mean of responses for students who followed the original syllabus (n=144) versus those who took the modified syllabus (n=93). There is an indication that interest levels were similar at the beginning and middle of the course for both groups but diverged toward the end. Those in the modified syllabus indicated an increased interest while those on the original syllabus showed no increase. Analysis of the end of course data shows this difference to be statistically significant (t-test: $p = 0.02$ for $\alpha = 0.05$) and a quite meaningful increase.

Fig.1 Comparison of mean ratings of student interest level at different stages of the course for those on the modified syllabus versus the original



The data in Fig. 2 give some indication that the modified syllabus was more interesting toward the end on average, but the effects of the changes are more apparent from a review of the students' comments.

- Quite a few students in the non-piloted sections showed a waning interest level in the rote delivery of tutorial materials as they became more familiar with the digital tool.

- In contrast, the comments of students in the piloted sections indicated an increased interest level in the latter part of the course as they became immersed in their individual projects and this is consistent with the survey data.
- When students in the piloted sections were asked to specify their favorite aspect of their project, they tended to highlight the most challenging features in the modeling exercise.
- Students in the non-piloted sections were aware of the project in the piloted sections and many expressed the view that this was a desirable element that they wished they had experienced.

Interestingly, Fig. 2 shows that the mean interest level at the beginning for the modified syllabus was slightly below that of students in the original syllabus. Again student comments are revealing. The use of AutoCAD in weeks 3 and 4 of the modified syllabus was not as positively received by students as subsequent elements of the course, especially in the context of knowing other students in the original syllabus who were already using 3-D solids modeling. A number of students indicated that they had already used AutoCAD in High School or found it boring, at least as perceived looking back. The other negative comment seen more often in the piloted sections was that the course required a lot of work for the credit.

Acknowledgements

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References

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2. Bertoline, G., *"Introduction to Graphics Communication for Engineers"*, 3rd Edition, McGraw-Hill, New York, 2006.

3. Definition: A Bezier curve is a mathematically defined curve used in graphic applications. The curve is defined by four points: the initial position and the terminating position (anchors) and two separate middle points (handles). The shape of a Bezier curve can be altered by moving the handles. The mathematical method for drawing curves was created by Pierre Bézier in the late 1960's for the manufacturing of automobiles at Renault in order to handle the curvilinear shapes of modern design. Computer graphics tools lend themselves to the use of such a technique.