A Cornerstone Course for Engineering Education: The Engineering Design Graphics Collaboratory

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Abstract

The ABET accreditation criterion 5 requires a "culminating major engineering design experience" in the curriculum (ABET, 2018). This is commonly referred to as the senior capstone design course. The freshman engineering education experience is loaded with required science and mathematics courses, and there is little room for an engineering experience. Nonetheless, most faculty want to have some engineering course during the freshman year, and many ideas have been tried over the years. Of these many ideas, the concept of a design project with hands-on activities seems to be the most popular and most beneficial (Smith 2003; Ross, 2013). This paper reports on such a proposed freshman cornerstone course, the Engineering Design Graphics Collaboratory (Barr, 2018). This freshman cornerstone course would mimic the senior capstone course in some ways, and would give the students a realistic glimpse of their engineering future.

Keywords
Engineering Education, Engineering Design, Engineering Graphics, Collaboratory

Introduction

This paper is the closing chapter in a four-decade career dedicated, in part, to transforming Engineering Design Graphics (EDG) from a mechanical drafting course to an engineering design course, while retaining appropriate graphics visualization skills that are still needed in design. Changes in the EDG curriculum over the last four decades have been driven by changes in technology. The drafting machine has been replaced by a computer, and the pencil and paper have been replaced by 3-D modeling software. Faculty started transitioning to solid modeling as the core topic in the EDG curriculum in the 1990's and beyond (Barr et al., 1994; Ault, 1999; Branoff et al., 2002; Bertozzi et al., 2007; Planchard, 2007). A concurrent engineering paradigm (Figure 1) was developed in 1994 to express the author's ideas at that time, and over time has had an international influence (Borges and Souza, 2015).

Full implementation of the paradigm was not fully realized until 15 years after it was first published. Now, as we enter the third decade of the 21st century, the 3-D computer model is firmly entrenched as the epicenter of the modern digital design and manufacturing enterprise. It is time that our teaching methodologies and spaces reflect this modern design reality. During the conceptualization of the EDG Collaboratory course, certain imperative goals were established:

1. There should be a design project with a recognized process and with hands-on activities.
2. There should be significant teamwork and interpersonal communication in class.
3. The full array of graphics needed for modern design should be presented, in both computer and freehand sketching modes.
4. The course should lend itself to design analysis and digital prototyping.
5. The classroom space for the course should be arranged to facilitate collaboration among the instructor and the students.

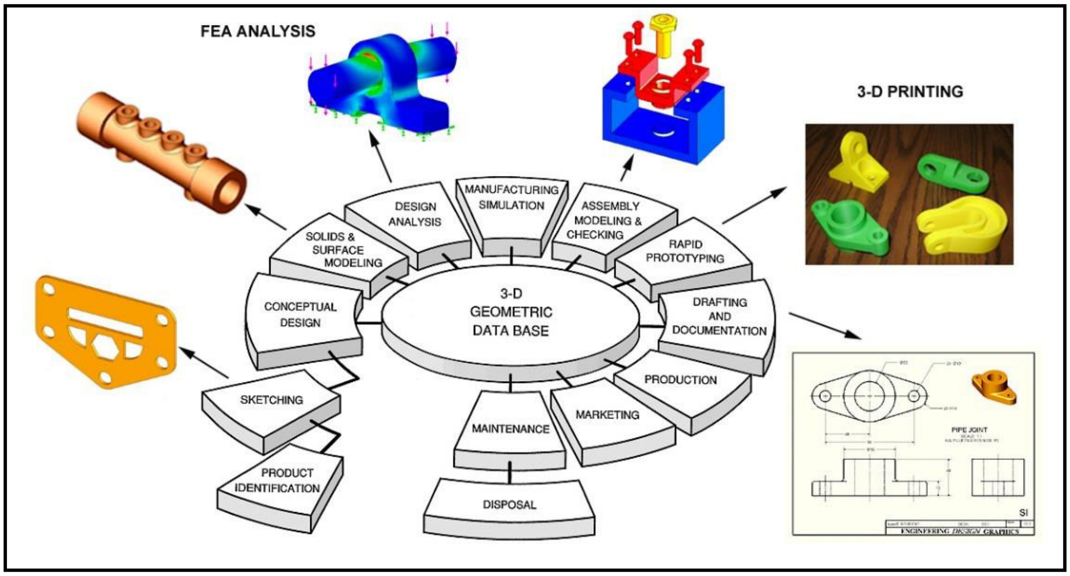

Figure 1: The Concurrent Engineering Instructional Paradigm.

The Collaboratory Space

The word "collaboratory" (Wulf, 1993) is used to describe a creative space where a group of people work together to generate solutions to complex problems. In this context, by fusing two elements, "collaboration" and "laboratory", the word "collaboratory" suggests the construction of a space where people explore collaborative innovations. The proposed space for Engineering Design Graphics is shown in Figure 2. The ten flat tables, with four chairs surrounding each table, enable students to interact face-to-face while they work on their design projects using self-supplied laptops. The instructor's podium is in the center, so that the instructor becomes a facilitator with access to all tables, rather than a lecturer at the head of the room. Surrounding the studio are projector screens showing instructional content, and equipment for design documentation such as

3-D printers. Thus, the collaboratory layout encourages teamwork, as would happen in a design studio, as opposed to individual work, as would happen in a traditional drafting room.

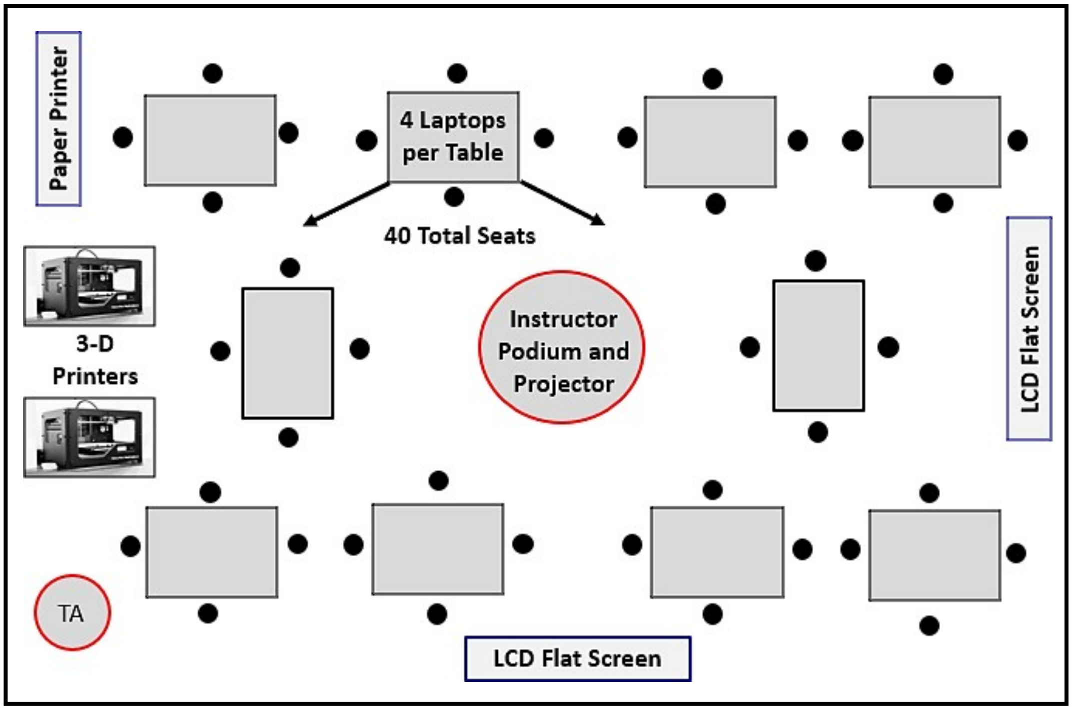

Figure 2: The Engineering Design Graphics Collaboratory Space.

Design Visualization Skills: Freehand Sketching and Computer Modeling

Graphics is the language of design, and many research studies have shown that good visualization skills are important for success in engineering (Hsi et al., 1997; Leopold et al., 2001; Adanez and Velasco, 2004; Sorby, 2005; Contero et al., 2006; Connolly, 2009). Furthermore, Danos et al. (2014) recently coined a term “graphicacy,” calling for a universal improvement in graphics capability for all students, thus extending these principles beyond engineering into everyday society. The instructional triad shown in Figure 3 serves as the basis for the sketching, computer modeling, and design project exercises used in the cornerstone course. The graphics instructional topics have been driven by recent efforts to define a modern graphics concept inventory (Sadowski and Sorby, 2014), by graphics outcomes surveys (Barr, 2012), and by current leading textbooks (Lieu and Sorby, 2009). Delivery of the graphics concepts is primarily through the freehand sketching mode. Freehand sketching has been reported as an important skill for developing “hand and mind” coordination in both early designers (Marklin et al., 2013; Booth, et al., 2016; Bairaktarova, 2017) as well as in advanced mechanical design courses (Yang and Cham, 2007).

The 3-D computer modeling instruction begins with sketching 2-D profiles and then creating 3-D parts through extrusions and revolutions. However, students in the collaboratory see the true power of the concurrent engineering paradigm (Figure 1) when the parts they build are extended to engineering analysis using finite elements (Balamuralikhrishna and Mirman, 2002), animation studies (Lieu, 2004), and 3-D rapid prototyping applications (DeLeon and Winek, 2000).

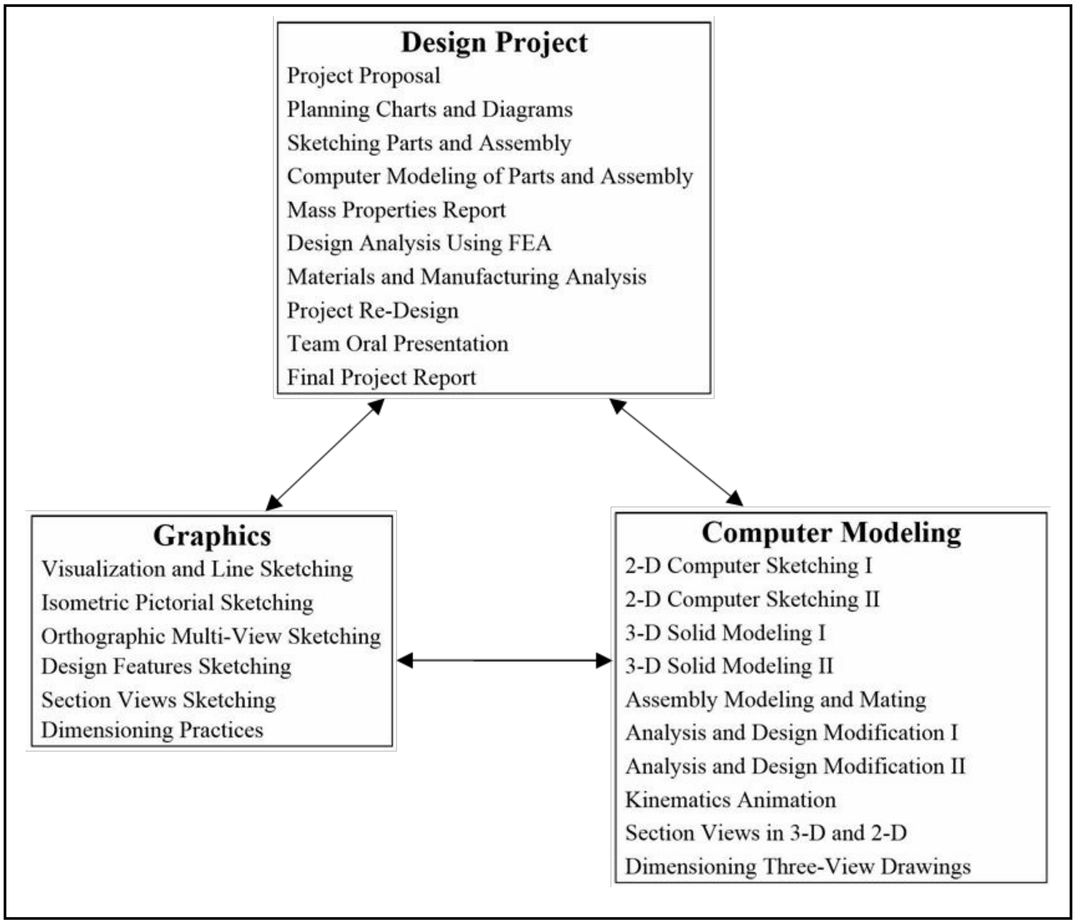

Figure 3: The Instructional Triad for the Engineering Design Graphics Collaboratory.

The Design Project

Many different design projects have been tried in the EDG curriculum over the decades. One project type that has been popular in recent years is reverse engineering (Sheppard, 1992; Mickelson, et al., 1995; Barr, et al., 2014). Reverse engineering is the dissection of a common mechanical assembly into its individual parts, studying the geometry and design function of each part, and then reconstructing the parts into 3-D solid model data bases. The students are divided into 4-member teams and each team selects a mechanical assembly. Using simple tools, they dissect the mechanical assembly into individual parts, make measurements and sketches, build 3-D solid models and assemblies, apply the solid models to various analyses, and then digitally print 3-D parts. The whole project is eventually documented in a bound final report with sketches, 3-D model image printouts, various analysis reports, printed 3-D prototypes, and final dimensioned part drawings. The teams also make a brief in-class oral presentation on the last class day. Figure 4 shows an example of some of the graphics sketches, part and assembly models, and drawings created in the team project involving a hand-held drill.

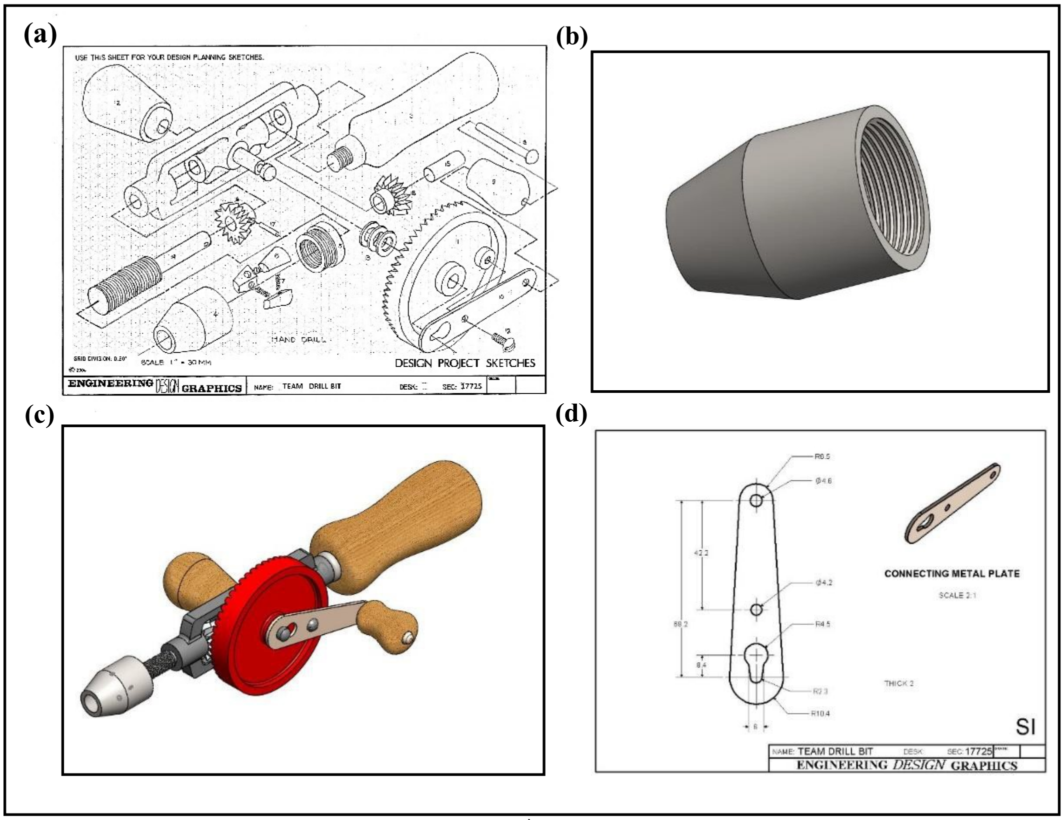

Figure 4: Examples of the Design Project Documentation: (a) Sketches, (b) 3-D Computer Model of Part, (c) Computer Assembly Model, and (d) Dimensioned Part Drawing.

Student Surveys

A student survey of the collaboaratory topics was conducted during two different school years to gain feedback from the students. The survey asked students to rank the topics based on how helpful the activity would be in their future engineering career. The responses were on a seven- point Lickert scale, with 7 (extremely helpful), 4 (somewhat helpful), and 1 (not helpful at all). Results of the survey for the Spring 2017 and Spring 2018 semesters are shown in Tables 1 and 2, respectively.

In general, the results of the surveys support the contention that the students liked the course exercises. Not surprising, the highest ranked topics pertained to 3-D computer modeling using the popular software SolidWorks. Five of the ten computer topics received scores of 6.00 or higher for both 2017 and 2018. Some of the sketching exercises, and in particular isometric sketching, also received good scores. The students also liked the team design project, particularly the 3-D printing aspect of the project.

It is gratifying to note that the relationship of graphics to engineering design was also ranked very high (scores of 6.19 and 6.02). The most important objective of the course was to transition from an historical drafting course, with one-hundred-year roots on campus, to a design-centric course. Thus, showing how graphics can contribute to a design project is extremely important.

On the negative side, the students rated the oblique sketching exercises the lowest in both surveys (scores of 5.51 and 5.32). In retrospect, the concept of oblique sketching is of little value to designers, since in gives a somewhat distorted view of the object's dimensions. This topic will likely be dropped from the collaboratory in the near future. Also, the lowest rated topic in both surveys was the method of assigning teams (scores of 4.79 and 4.17). Experienced faculty might think that using a personality-typing method, such as the MBTI, would be very useful in forming teams. However, these results disprove that thinking. As faculty, we must realize that college freshmen nowadays have other ways of intermixing, socializing, introducing themselves, and finding team partners. The MBTI is a foreign concept to them. So, another way of forming teams in the collaboratory will need to be devised.

One final comment was offered by one of the students in the survey. It pertains to the perception that sketching and graphics fundamentals are less important now during this age of 3-D computer modeling. This student quoted: "The results of the survey will probably show that the class thinks the sketching assignments are less helpful for their careers. However, I believe that the sketching exercises helped me understand 3-D objects and made learning SolidWorks easier." Visualization is the key to good design work and team interaction, and the various forms of graphics projected in the course help to develop this visualization skill.

Conclusion

The EDG collaboratory as described in this paper has not been fully realized. In particular, the space layout for the collaboratory does not yet exist, but Figure 2 is still the goal. In addition, the sketching exercises currently used in the collaboratory date back to the 1990's, and new exercises need to be created or redone so that they can be executed with only freehand sketching and no manual tools. The main strategy is to have grid lines (isometric or orthographic) in the sketching solution space to facilitate the freehand mode while retaining some technical quality. Also, some more design checks (intermediate submissions) should be added to the team project. A simple FEA analysis for one of the parts would be a nice addition to the project, as would also asking the team to redesign one part to make it better, and then re-model it in SolidWorks. Moving forward, faculty will continue to seek student feedback and make small improvements to the EDG collaboratory, as it progressively becomes a premier cornerstone course for engineering education.

Table 1: Student Survey Results for Spring 2017 (N = 84).

Design Graphics Sketching	Ratin g
Design Sketching: Visualization Techniques	6.05
Design Sketching: Isometric Views	6.02
Design Sketching: Section Views	5.89
Design Sketching: Dimensions	5.87
Design Sketching: Orthographic Multi-Views	5.83
Design Sketching: Sketching Lines	5.77
Design Sketching: Design Features and Modifications	5.60
Design Sketching: Oblique Views	5.51
Ave.	5.82
3-D Computer Modeling	Ratin g
SolidWorks: Creating 3-D Parts and Features	6.54
SolidWorks: Creating Parts Using Extrusions and Revolutions	6.52
SolidWorks: Assembly Modeling and Mating	6.45
Loading and Using SolidWorks on Your Laptop	6.15
SolidWorks: Kinematic Animation	6.10
SolidWorks: Creating Section Views	5.96
SolidWorks: Dimensioning Layout Drawings	5.95
SolidWorks: Finite Element Analysis and Re-Design	5.93
SolidWorks: Mass Properties Analysis and Design Tables	5.77
Ave.	6.15
Team Design Project	Ratin g
Relationship of Graphics to Engineering Design	6.19
Team Project: Printing Rapid Prototypes	6.15
Team Project: Oral Presentation	6.01
Introduction to Engineering and Teamwork	5.96
Team Project: Dimensioned Layout Drawings of Parts	5.94
Team Project: Computer Modeling and Mass Properties	5.88
Team Project: Final Written Report	5.85
Team Project: Project Re-Design	5.81
Team Project: Sketching Project Parts and Assemblies	5.63
Team Project: Written Proposal	5.61
Team Project: Planning Charts and Diagrams	5.55

Team Project: Materials and Manufacturing	5.49
The MBTI and Assigning Teams	4.79
Ave.	5.76

Table 2: Student Survey Results for Spring 2018 (N = 47).

Design Graphics Sketching	Rating
Design Sketching: Isometric Views	5.83
Design Sketching: Visualization Techniques	5.74
Design Sketching: Section Views	5.68
Design Sketching: Orthographic Multi-Views	5.62
Design Sketching: Design Features and Modifications	5.62
Design Sketching: Dimensions	5.60
Design Sketching: Sketching Lines	5.40
Design Sketching: Oblique Views	5.32
Ave.	5.60
3-D Computer Modeling	Rating
SolidWorks: Creating 3-D Parts and Features	6.45
SolidWorks: Assembly Modeling and Mating	6.32
SolidWorks: Creating Parts Using Extrusions and Revolutions	6.19
SolidWorks: Finite Element Analysis and Re-Design	6.11
SolidWorks: Creating Section Views	6.02
Loading and Using SolidWorks on Your Laptop	5.89
SolidWorks: Mass Properties Analysis and Design Tables	5.81
SolidWorks: Dimensioning Layout Drawings	5.79
SolidWorks: Kinematic Animation	5.77
Ave.	6.04
Team Design Project	Rating
Team Project: Printing Rapid Prototypes	6.26
Team Project: Final Written Report	6.17
Team Project: Computer Modeling and Mass Properties	6.13
Relationship of Graphics to Engineering Design	6.02
Team Project: Dimensioned Layout Drawings of Parts	5.83
Team Project: Oral Presentation	5.70
Team Project: Materials and Manufacturing	5.68
Team Project: Project Re-Design	5.68
Team Project: Sketching Project Parts and Assemblies	5.64
Team Project: Written Proposal	5.62
Team Project: Planning Charts and Diagrams	5.62
Introduction to Engineering and Teamwork	5.60
The MBTI and Assigning Teams	4.17

Ave.	5.70

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