ASEE AMERICAN SOCIETY FOR ENGINEERING EDUCATION

Paper ID #35082

A Cornerstone Course for Engineering Education: The Design Graphics Collaboratory

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Session XXXX

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Abstract

The ABET accreditation criterion 5 requires a "culminating major engineering design experience" in the curriculum[1]. 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 team design project with hands-on activities seems to be the most popular and most beneficial. This paper reports on such a proposed freshman engineering cornerstone course, the Design Graphics Collaboratory. This freshman cornerstone course would mimic the senior capstone course in some ways, and would give the students a realistic glimpse of their future in engineering education.

Introduction

This paper summarizes the current status of a four-decade effort to transform a freshman Engineering Design Graphics course from a mechanical drafting course to a predominantly Introductory Engineering Design course, while retaining some graphics visualization skills that are fundamental to design. Changes in this 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 The drafting machine has been replaced by a computer, and the pencil and paper have been replaced by 3-D modeling software.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 graphics curriculum in the late 1990's and beyond[2,3,4,5,6]. A logo shown in Figure 1 was developed in the early 1990's to express the author's ideas at that time, and over time has had an international influence[7]. Full implementation of the paradigm was not fully realized until 20 years after the logo 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.

A second motivation for the proposed Design Graphics Collaboratory is to support the concept of design course scaffolding throughout the four-year engineering curriculum. The concept is illustrated in Figure 2. The freshman Design Graphics Collaboratory serves as a cornerstone course that is meant to reflect similar educational experiences that the students will eventually receive in their senior capstone design course. In between, it is expected that they will receive some intermediate design course experiences, based on their engineering major.

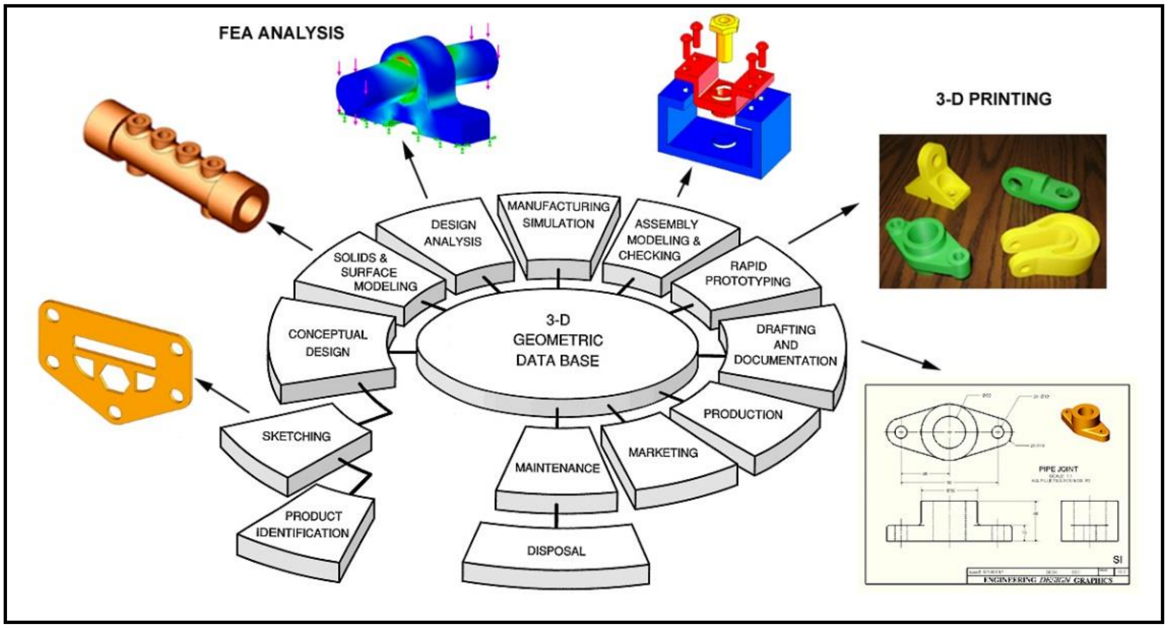

Figure 1: The Concurrent 3-D Modeling Instructional Paradigm[2].

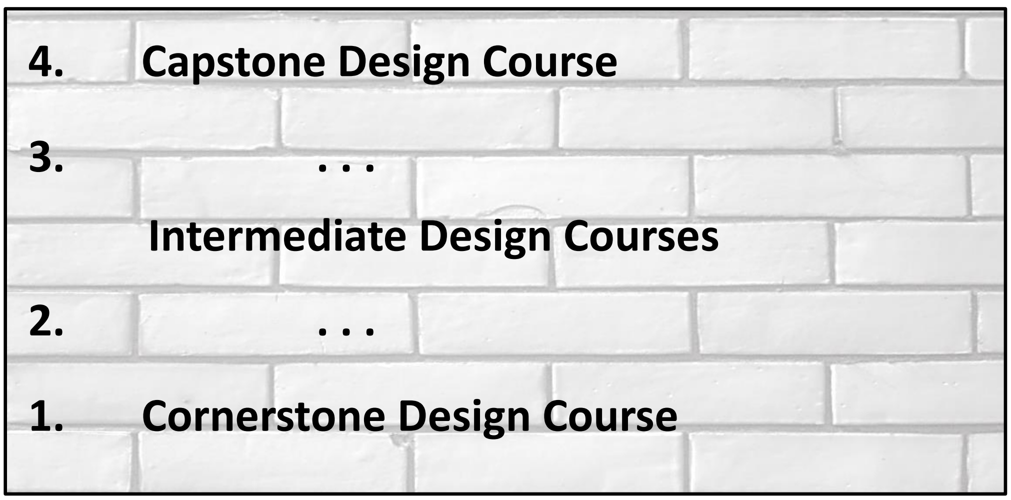

Figure 2: The Scaffolding of Design Courses Through the Four-Year Engineering Curriculum.

During the conceptualization of the Design Graphics Collaboratory course, certain imperative goals were established by the author:

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, and among the student members within each team.

The Collaboratory Space

The word "collaboratory" 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[8]. The proposed space for the Design Graphics Collaboratory[9] is shown in Figure 3. 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.

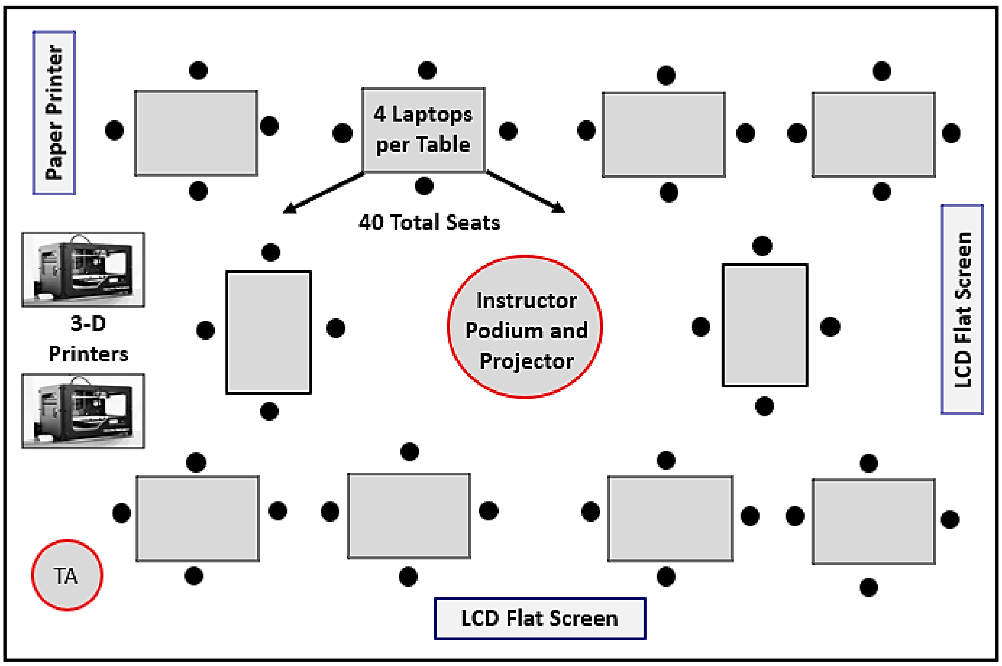

Figure 3: The Engineering Design Graphics Collaboratory Space.

Design and Visualization Skills

Graphics is the language of design, and many research studies have shown that good visualization skills are important for success in engineering[10,11,12,13,14,15]. Furthermore, Danos et al.[16] 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. Hence, the tailoring of a traditional Engineering Graphics course and joining it to a freshman cornerstone Introduction to Engineering Design course seems like the logical approach to meet the modern design educational goals stated earlier.

The Instructional Triad

The instructional triad shown in Figure 4 serves as the basis for the design project, sketching, and computer modeling exercises used in the cornerstone course. The design project serves as the over-arching theme for the course. Teams of four students each are formed very early in the class and much of the work is performed as a team task. The visualization skills needed to accomplish the design project are taught through some freehand sketching exercises and through a systematic study of the capabilities of the computer modeling software used in the course. A total of 28 lab periods, meeting twice per week, can be accomplished in a 14-week semester.

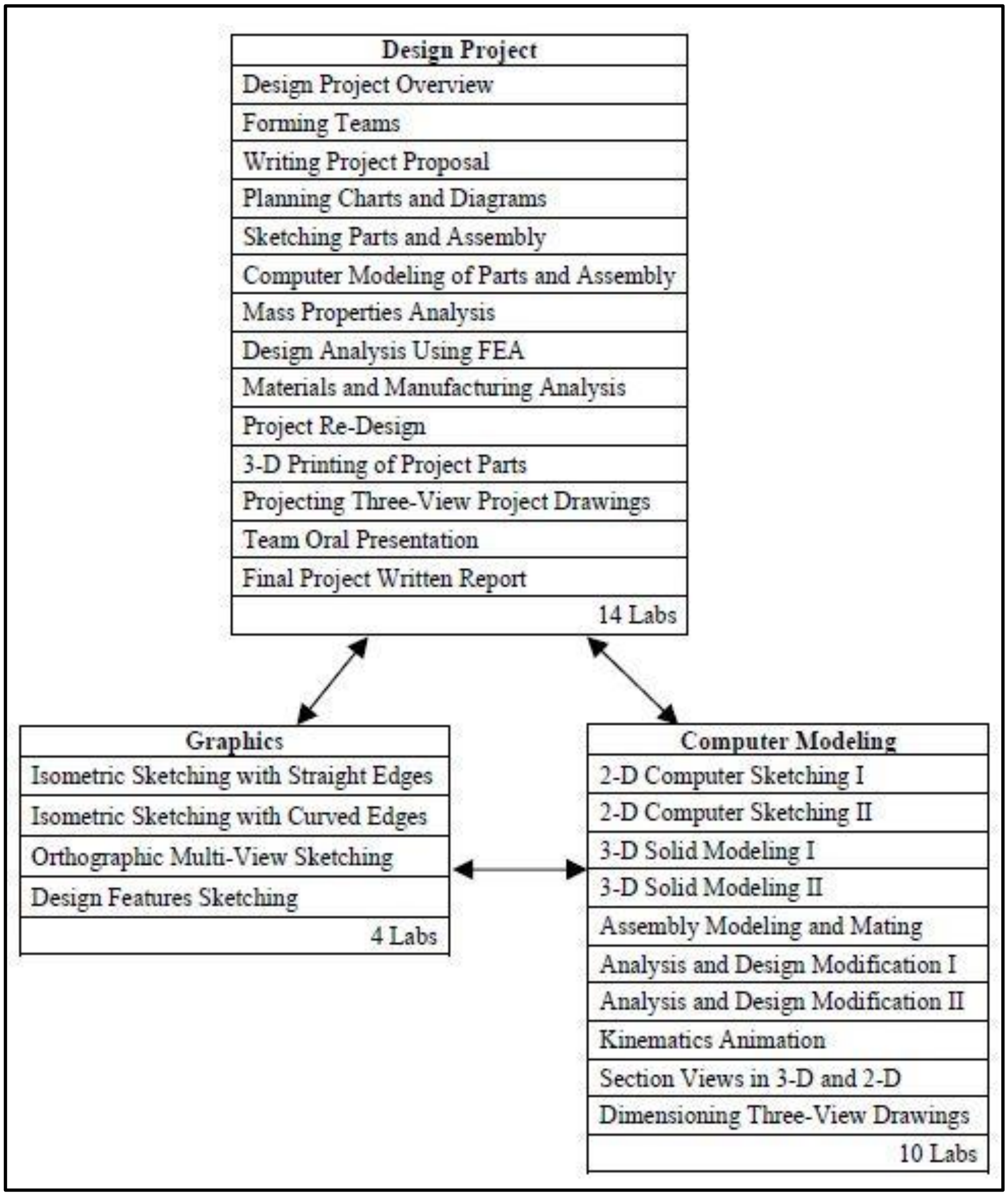

Figure 4: The Instructional Triad for the Engineering Design Graphics Collaboratory.

Design Project

Many different design projects have been tried in the design graphics curriculum over the decades[17,18]. One project type that has been popular in recent years is reverse engineering[19,20,21]. 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 computer 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, and build 3-D solid models and assemblies. Using advanced applications of the modeling software, the teams apply their computer models to various forms of analyses[22,23], and then digitally print 3-D prototypes[24] of all the 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. So, in some ways, this freshman cornerstone design project somewhat mimics the design experiences the students will see in their senior capstone course. Figure 5 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.

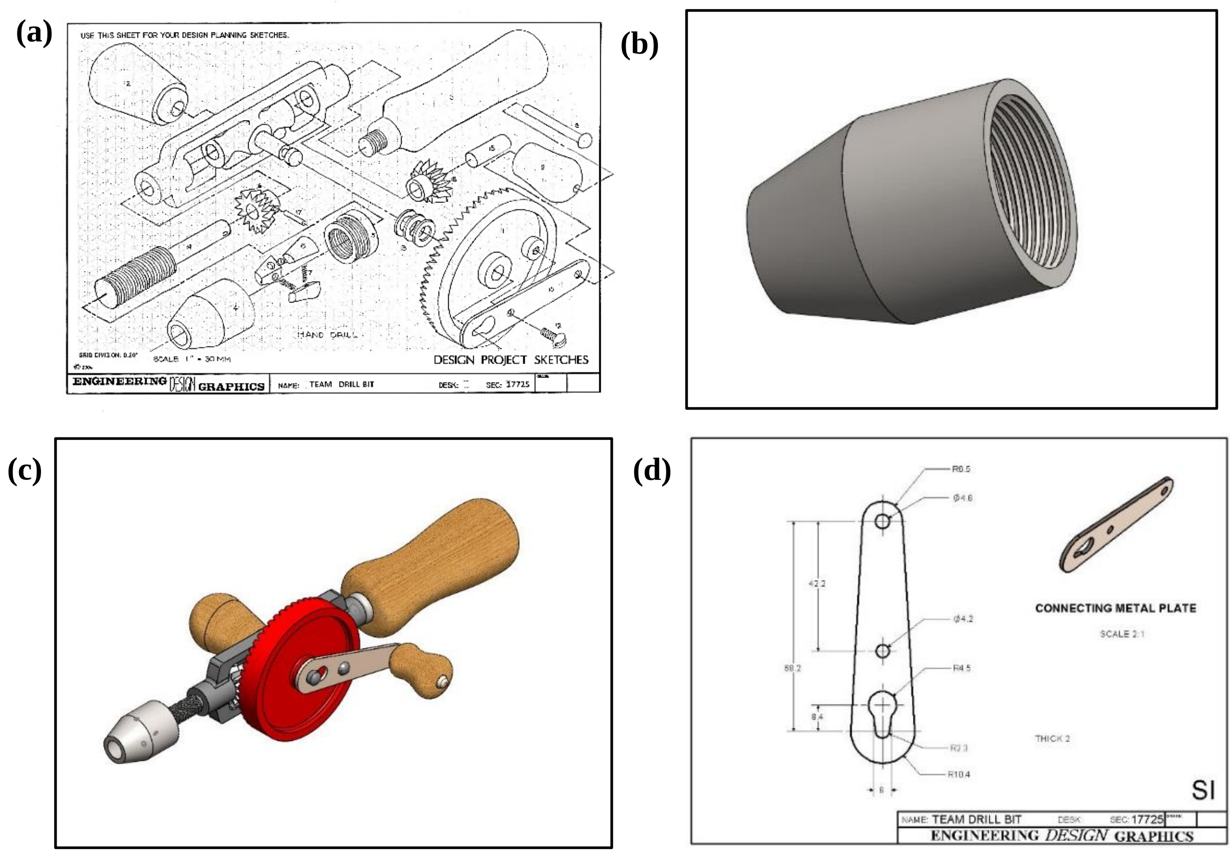

Figure 5: Examples of the Design Project Documentation: (a) Sketches, (b) 3-D Computer Model of Part, (c) Computer Assembly Model, and (d) Dimensioned Part Drawing.

Graphics

The graphics instructional topics have been driven by recent efforts to define a modern graphics concept inventory[25], by graphics outcomes surveys[26], and by current leading textbooks[27]. 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[28,29,30] as well as in advanced mechanical design courses[31]. Since freehand sketching is presented to the students as a design ideation and visualization tool, the main modes of isometric pictorial sketching and orthographic three view sketching dominate the graphics instructional exercises.

Computer Modeling

The 3-D computer modeling instruction is delivered using a ten-unit tutorial workbook[32] that the authors update annually to the latest version of the software. The tutorial units begin with sketching 2-D profiles and then creating simple 3-D parts through extrusions and revolutions. The next units show students how to create more complex parts using advanced editing features, like sweeping and lofting, and then how to mate the parts into a mechanical assembly. Next, the students see the true power of the concurrent engineering paradigm (Figure 1) when the parts they build are extended to engineering analysis. There are units for analyzing the mass properties of the parts, how to perform simple finite elements analysis of parts, conducting animations, and 3-D printing of part prototypes. The workbook finishes with two tutorials on how to project conventional three-view engineering drawings from the computer model, and how to apply standard sectioning and dimensioning practices. While the students are learning all these modeling software capabilities from the workbook, they are also applying them to their team design project, as indicated in the triad diagram in Figure 4.

Pilot Testing of the Cornerstone Course

Over the past three years, the author has taught pilot sections of the cornerstone course, with the goal of transitioning from a predominant graphics course to a predominant freshman design course, and with the philosophical underpinning of continuous improvement. To aid in this transitioning, a student survey of the collaboaratory topics was conducted. The survey asked students to rank the topics based on how helpful they think the activity would be in their future engineering design career. The responses were on a seven-point Likert scale, with 7 (extremely helpful), 4 (somewhat helpful), and 1 (not helpful at all). Results of the survey are shown in Table 1.

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. 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 was also gratifying to note that the relationship of graphics to engineering design was also ranked very high, underscoring the argument that visualization skills are vital to proper design education, and particularly to early design student instruction.

On the negative side, the students rated some of the sketching exercises, such as oblique and line sketching, very low. Those have since been removed from the course exercise list. Furthermore, sectioning and dimensioning have been completely relegated to the computer modeling exercises, where many practical tools are at the students' convenience. Also, the lowest rated topic in the survey was the method of assigning teams. College freshmen today have other ways of intermixing, socializing, introducing themselves, and finding team members. The MBTI is a foreign concept to them. So, another way of forming teams in the course will need to be devised.

Table 1: Student Survey Results (N = 131)

Graphics Sketching	**Rating**
Design Sketching: Isometric Views	**5.95**
Design Sketching: Visualization Techniques	**5.94**
Design Sketching: Section Views	**5.82**
Design Sketching: Dimensions	**5.77**
Design Sketching: Orthographic Multi-Views	**5.76**
Design Sketching: Sketching Lines	**5.64**
Design Sketching: Design Features and Modifications	**5.60**
Design Sketching: Oblique Views	**5.44**
Ave.	**5.74**
3-D Computer Modeling	**Rating**
SolidWorks: Creating 3-D Parts and Features	**6.50**
SolidWorks: Creating Parts Using Extrusions and Revolutions	**6.40**
SolidWorks: Assembly Modeling and Mating	**6.40**
Loading and Using SolidWorks on Your Laptop	**6.06**
SolidWorks: Finite Element Analysis and Re-Design	**5.99**
SolidWorks: Creating Section Views	**5.98**
SolidWorks: Kinematic Animation	**5.98**
SolidWorks: Dimensioning Layout Drawings	**5.89**
SolidWorks: Mass Properties Analysis and Design Tables	**5.79**
Ave.	**6.11**
Team Design Project	**Rating**
Team Project: Printing Rapid Prototypes	**6.19**
Relationship of Graphics to Engineering Design	**6.13**
Team Project: Computer Modeling and Mass Properties	**5.97**
Team Project: Final Written Report	**5.96**
Team Project: Oral Presentation	**5.90**
Team Project: Dimensioned Layout Drawings of Parts	**5.90**
Introduction to Engineering and Teamwork	**5.83**
Team Project: Project Re-Design	**5.76**
Team Project: Sketching Project Parts and Assemblies	**5.63**
Team Project: Written Proposal	**5.61**
Team Project: Planning Charts and Diagrams	**5.57**
Team Project: Materials and Manufacturing	**5.56**
The MBTI and Assigning Teams	**4.56**
Ave.	**5.74**

Conclusion

The freshman cornerstone course as described in this paper has not been fully realized. In particular, the space layout for the collaboratory does not yet exist, but Figure 3 is still the goal. In addition, the sketching exercises currently used in the course are dated, and new exercises need to be created or redone so that they can be executed with only freehand sketching on proper isometric or orthographic grid paper. The reverse-engineering design project has always been well-received by the student teams. However, in its current stage, the team design project is rather closed-ended and some thought should be given to making it a more open-ended project to better reflect what they will do in their capstone course. Also, some more intermediate design analysis exercises, such as a FEA analysis for one of the parts, are still being examined. Moving forward, faculty will continue to seek student feedback and make small improvements to the Design Graphics Collaboratory, as it progressively becomes a premier cornerstone course for engineering education.

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