LITEE Special

Learning-Centered Instruction of Engineering Graphics for Freshman Engineering Students

Raghuram V. Pucha and **Tristan T. Utschig**
Georgia Institute of Technology

Abstract

Teaching *Engineering Graphics* to freshman engineering students poses challenges to instructors as well as to students. While the instructors are confronted with a lack of material / text book that covers the broad scope of the subject matter, the students struggle to correlate newly developed skills to real-world engineering design problems because of a lack of documented industry design problems and case studies. Learning / teaching 'Engineering Graphics' through real world problems and case studies in a learner centered instructional paradigm can foster the required integrative thinking for tomorrow's engineers. This paper presents some learning-centered strategies supported by real-world problems and case studies implemented in a freshman 'Engineering Graphics' course. Real-world case studies are also implemented in a senior-level Computer-Aided Design (CAD) course. Some preliminary results are presented on the impact of such strategies on student learning, engagement, and performance.

Keywords: Learning-centered instruction, Problem-based learning, real-world problems, case studies

Introduction

It is now well recognized that the role of colleges and higher-education institutions is to produce learning and not merely provide instruction (Barr & Tagg, 1995). Teacher-centered instruction imposes a moratorium upon students' vocational development by forcing them to assume a passive role as a student. The teaching - centered direct instruction: (a) emphasizes on content delivery, (b) involves curriculum based closed-ended problems, (c) uses structured summative assessment, and (d) helps in providing the foundational information on subject matter. Whereas learning-centered instruction: (a) emphasizes learning, (b) builds meaning for students though inquiry-oriented and socially situated environments, (c) involves problem and case study based open-ended scenarios, (d) uses formative assessment by collecting diagnostic clues on individual needs and feedback, and (e) provides opportunities to learn the subject matter beyond surface-level understanding. In a learning-centered instruction, faculty become designers of learning environments for students, facilitators of student active-learning, and modelers of expert thought processes (Barr & Tagg, 1995). Students construct knowledge through gathering and synthesizing information, and integrating it with the general skills of inquiry, communication, critical thinking, and problem solving. This process enables students to take ownership of their learning.

According to Combs (1976), successful implementation of a learning-centered instructional paradigm requires an effective learning environment in the classroom with the following characteristics : (a) the atmosphere should facilitate the exploration of meaning. The classroom must provide for involvement, interaction, and socialization, along with a business-like approach to getting the job done. (b) Learners must be given frequent opportunities to confront new information and experiences in the search for meaning, and (c) new meaning should be acquired through a process of personal discovery. Problem-based and case-study based learning / teaching strategies can readily create such environments.

According to Savoie and Hughes (1994), problem-based learning (PBL) is the type of classroom organization needed to support a constructivist approach to teaching and learning with the following actions for creating such a process : (a) identify a problem suitable for the students, (b) connect the problem with the context of the students' world so that it presents authentic opportunities, and (c) give students responsibility for defining their learning experience and planning to solve the problem. PBL begins with the assumption that learning is an active, integrated, and constructive process influenced by social and contextual factors (Barrows, 1996; Gijselaers, 1996). PBL is characterized by a student-centered approach, with teachers as "facilitators rather than disseminators," and open-ended problems that "serve as the initial stimulus and framework for learning" (Wilkerson & Gijselaers, 1996). In addition to emphasizing learning by "doing," PBL requires students to be metacognitively aware (Gijselaers, 1996). That is, students must learn to be conscious of what information they already know about the problem, what information they need to know to solve the problem and the strategies to use to solve the problem. Being able to articulate such thoughts helps students become more effective problem-solvers and self-directed learners.

Problem-based learning has become a highly promoted practice in engineering education over the past decade. Froyd (2008) identified eight promising practices in engineering education, several of which involve problem-based learning. In addition, problem-based learning was cited by Smith, Sheppard, Johnson, and Johnson (2005) as one of two "pedagogies of engagement" with high potential to transform the student learning experience. A recent study by Yadav, Subedi, Lundeberg, and Bunting (2011)demonstrated that the problem-based learning approach yielded twice the learning gains over a traditional lecture approach in an electrical engineering course. More generally, Prince (2004) reviewed research in engineering education that shows "broad but uneven" support for problem-based learning, and reviewed problem-based learning again as part of the suite of techniques comprising inductive teaching and learning (Prince & Felder, 2006). In the latter review, Prince and Felder (2006) note that "Case-based instruction and problem-based learning involve extensive analyses of real or hypothetical scenarios," which is the exact approach taken in the courses described here.

Case based studies are traditionally associated with business, law, and social science classes, but can be used in any discipline in which students need to explore how concepts and principles learned in class interact in real-world situations. As a result, case-study based methodologies have expanded to other disciplines, including the physical sciences and mathematics. Using a case-based learning approach engages students in discussion of specific situations, typically real-world examples. This method is learner-centered and involves intense interaction between the participants. Case-based learning may also focus on the building of knowledge as a group works together to examine the case. The instructor's role is that of a facilitator and the students collaboratively address problems from a perspective that requires analysis. Much of case-based learning involves learners striving to resolve questions that have no single right answer. Many courses use case studies in their curriculum to teach content, involve students with real-life data, or provide opportunities for students to put themselves in the decision maker's shoes. Some of the primary benefits of case-based learning include: (a) real world context, (b) exploration from multiple perspectives, (c) a requirement for critical thinking and analysis, and (d) synthesis of complex course content.

Multimedia cases serve as a valuable supplement, providing students with opportunities to experience and respond to complex practical issues in a variety of professional settings. In the process, students reflect on relevant theories and techniques as they attempt to understand a real problem, develop a response, and consider the potential consequences (Halpin, Raju, Sankar, & Belliston, 2004; Raju, Sankar, & Halpin, 1999). Developing useful studies that possess an active industry component that also challenge students in the many facets of engineering design is a complex task. The Laboratory for Innovative Technology and Engineering Education (LITEE) at Auburn University has developed case studies that have a strong design/ engineering graphics component embedded within the problem. These case studies have the potential to provide authentic learning experiences, where design methodologies, such as solid modeling and animation, become more interesting to use when applied in practical problem solving (Balamuralikrishna, Raju, & Sankar, 2005).

Groupwork is an essential aspect of problem-based and case-based learning for several reasons. First, groupwork helps develop learning communities in which students feel comfortable developing new ideas and raising questions about the material (Allen, Duch, & Groh, 1996). In addition, groupwork enhances communication skills and students' ability to manage group dynamics. Finally, groupwork is interesting and motivating for students when they become actively involved in the work, and are held accountable for their actions by group members(Cohen, 1994). For these reasons, groupwork can enhance student achievement. However, groups do not always work effectively without guidance. Usually, the instructor facilitates and monitors group interactions because many students have not been taught how to work effectively in groups (Bridges & Hallinger, 1996; Wilkerson, 1996). Well designed, open-ended problems that require the input and skills of all group members are also essential to positive groupwork experiences (Cohen, 1994).

This paper presents various learning-centered instruction strategies implemented in a freshman engineering graphics course. With the instructor acting as a facilitator, the objective of each of these strategies is to increase the student responsibility in learning through improved engagement. The following sections briefly describe the instructional approaches and the impact on student engagement and learning.

Instructional Approaches and impact on student learning

The learning-centered instructional approach used here follows a natural cycle of learning that, according to Kolb's (1975) model includes: (a) abstract conceptualization, (b) active experimentation / application, (c) concrete experience, and (d) reflective observation. Figure 1 shows the learning-centered instruction approach used for a freshman 'Engineering Graphics' course (ME/CEE 1770) at Georgia Tech.

ME / CEE 1770 "Introduction to Engineering Graphics and Visualization" is a cross discipline course offered in spring, summer and fall at Georgia Tech. This freshman course involves introducing the overall aspects of the engineering design process, and the specific role of graphics and visualization at various stages of engineering design. It is a required course for civil, mechanical and aerospace engineering students. "Introduction to Engineering Graphics and Visualization" is being taught in the framework of the engineering design process. For example, in the preliminary design, free hand sketches are used as a primary medium of communication for design information. Once the design ideas are matured, 2D CAD tools are used to communicate the design information. Then, 3D CAD tools are used to optimize designs and further use that design information to communicate ideas for manufacturing and marketing purposes. The students use free-hand sketching techniques to communicate initial design ideas. The students are then exposed to basic design aspects when they do an individual 2D CAD project, with a given set of design parameters. Finally, during the team projects (four to five member teams) the students learn additional important components of the engineering design process namely (a) identifying/selecting the key design parameters / functionality of the chosen product, (b) team coordination, (c) time management, and (d) meeting the design requirements and objectives. Overall, the course is taught citing various examples from the engineering design process and correlating the role of engineering graphics and visualization at various stages. In the spring and fall, this course is offered with students enrolled in 10 sections, with each section having 40 students.

The learning strategies illustrated in Figure 1 were implemented in one section of ME/CEE 1770 as described in this paper. Each strategy is briefly described here to provide details about the context of that implementation. Currently, four of the 10 sections now use these strategies because of the encouraging results described below.

Peer Assisted Learning in Lectures: Teacher-centered instruction imposes a moratorium upon students' vocational development by forcing them to assume the role of student. *An undergraduate teaching other undergraduates* can be one of the most effective methods for achieving both cognitive and attitudinal goals of undergraduate education. Student-faculty teamwork, in teaching and learning, capitalizes on student ability to be powerful role models and agents of change in the classroom (Barkley, Cross, & Major, 2005; Miller, Groccia, & Miller, 2001). One well-studied specific form of peer assisted learning is the Supplemental Instruction model, where, typically, the peer instruction occurs outside of the regularly scheduled class hours, and over an extended period of time. General results showing significant improvement in student grades across many disciplines are documented by the International Center for Supplemental Instruction , and specific cases in engineering have also been documented such as at Rose-Hulman ("National"; Webster & Pee, 1998). This concept is implemented on

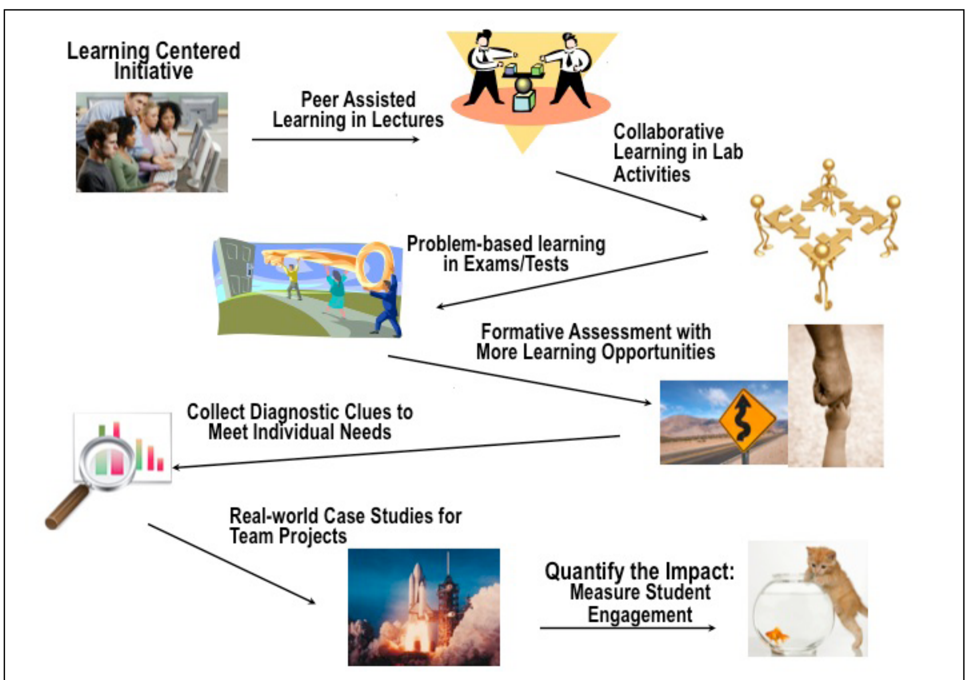

Figure 1: Learning Centered Instruction Strategies

a smaller scale and during regular class hours in ME/CEE 1770, by arranging lectures /demonstrations on specific topics from an undergraduate student who has taken the course in the earlier semesters. The approach has been well received by students in ME/CEE 1770 with a renewed sense of connectedness.

Collaborative Learning in Lab Activities: As defined by Smith and MacGregor (1992), in collaborative learning, "groups of students work together in searching for understanding, meaning or solutions or in creating an artifact of their learning" . In the sense of using groups to generate understanding, meaning, and solutions, collaborative learning methods are implemented in the lab activities of ME/CEE 1770. In this course each week, two lectures are followed by a 3 hour lab. In the lab, students sit together as groups of four and work on various lab activities in a collaborative environment. The students work in groups, and are also required to have their work peer-reviewed every period before the TAs provide their assessment and feedback. Each student is required to get a signature from a peer as proof that his/her work has been reviewed, and modifications have been made accordingly. The lab activities are then graded only after these assessments have been provided (Elrod & Stewart, 2002). Collaborative learning in lab activities is being employed in all sections of ME/CEE 1770. The collaborative environment, along with peer-review among students and an assessment from TAs before grading the work, provide many learning opportunities to students in consolidating the concepts learned in the lectures. Even though the specific evidence of students making modifications to their work after peer-review was not recorded in this class of 40 students, anecdotal evidence from TAs suggest that the majority of students benefitted from this process. However, in some cases the TAs have also observed no signs of improvement in students' work when both students involved in the peer review did not understand the concepts required for that lab activity.

Problem-Based Learning in Exams: Learning is the product of both cognitive and social interaction attained through authentic problem solving (Hmelo-Silver, 2004). Problem-based learning strategies have been successfully implemented in Biomedical Engineering courses at Georgia Tech, producing results consistent with the literature described above(Newstetter, 2006; Jacobs, 2009). This strategy is being employed in ME/CEE 1770, specifically through a series of take-home exams focusing on a single problem. To implement the basic concepts discussed in the class and to learn more by exploring these concepts on their own, the students are given industry problems with a set of company required specifications. The students are then asked to develop solutions using more and more sophisticated or advanced visualization tools as they move from Exam 1 (Sketching) to Exam 2 (2D CAD) and Exam 3 (3D CAD). As they work on their unique design solutions to a single problem, students not only demonstrate the basic concepts learned in the three phases of the course, but also showed increased involvement, ownership of the learning, the responsibility, and pride in their work. The students are given extra credit for making their initial designs more complex and geometrically challenging in the subsequent exams, which provides more opportunities for learning by exploring. In the Beverage Mug example shown in Figure 2, the students were given a problem-based scenario where they are asked to design a distinctive, attractive beverage mug for the Georgia Tech Athletic Association (GTAA), and prepare a preliminary set of visual-

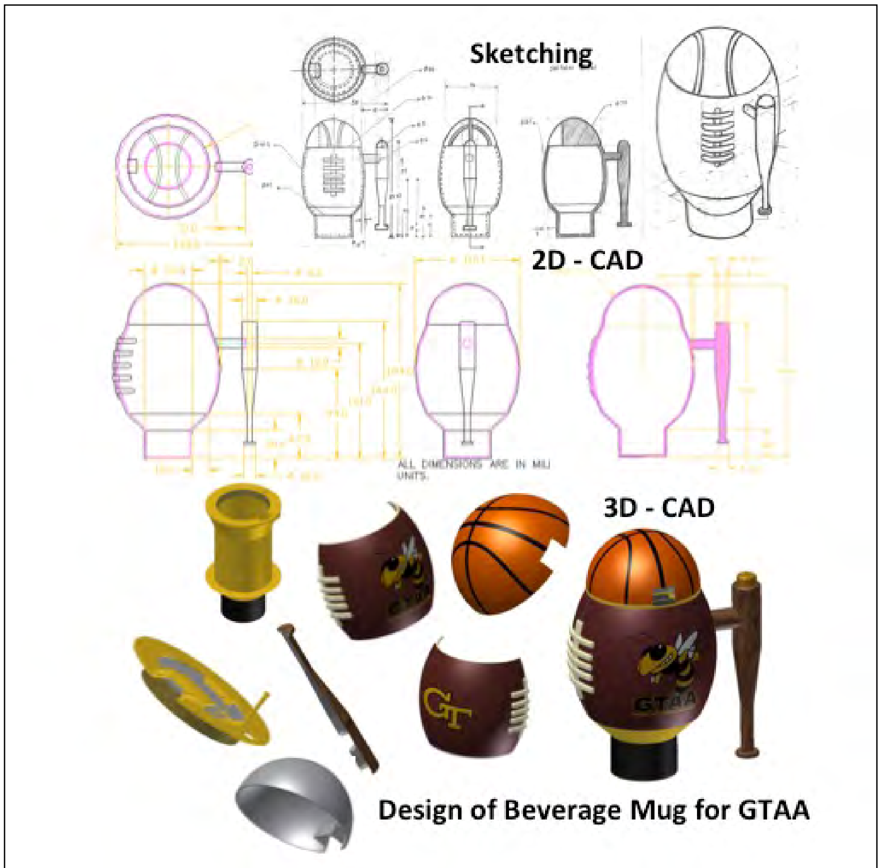

Figure 2. Problem-Based Learning Example

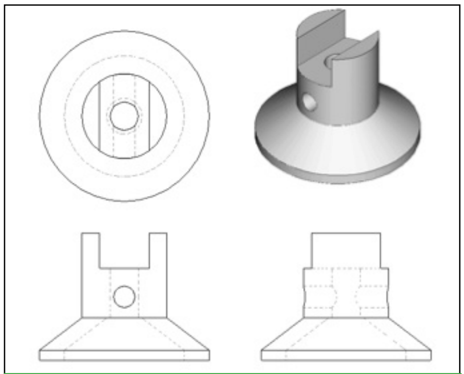

Figure 3

Section	All Correct	Correct Isometric Lines	Identify Cylindrical Features	Identify Other Features	Poor Visualization
A (40 Students)	17	27	40	27	5
B (39 Students)	15	23	39	23	5

Table 1: Understanding students learning need through formative assesment

ization sketches, 2D Drawings, and 3D Models with technical details on the proposed product. This approach produced noticeable improvement in student engagement and learning, and was a welcome change for students from the traditional testing approach with closed-end problems.

Formative Assessment and Student Individual Needs: Formative assessment provides the information needed to adjust teaching and learning while they are happening. The feedback from learning activities is used to adapt the teaching to meet the learner's needs. It is the bi-directional process between teacher and student to enhance, recognize, and respond to the learning. This concept is used in ME/CEE 1770 through assessing students' work on various concepts in the course. For example, the students were asked to sketch a 3D isometric view of an object, given the multi-views of the geometry, to consolidate their visualization skills. The students' work was analyzed based on four important concepts required for visualization of this particular geometry as shown in the Example (Figure 3). Table 1 shows the number of students meeting each of the assessment metrics. The data was collected for two sections and similar distribution is observed in meeting these metrics.

The assessment results shown in Table 1 were used in meeting the individual needs of students by reviewing these concepts again(the students have opportunity to demonstrate the same concepts later in the course in their team projects) and in improving the course in the following semesters by focusing on the concepts students routinely missed in Table 1.

Real-World Problem Solving for Integrative Thinking: Most of the team project themes in ME/CEE 1770 are based on existing products with known functionality and specifications. For example (as shown in Figure 4), aerospace engineering majors choose aircrafts, civil engineering majors choose buildings and bridges, and mechanical engineering majors choose engines and vehicles. Though these projects shown in Figure 4 can provide the opportunity for students to implement the concepts they learned in the class, their learning experience is more limited.

However, learning engineering graphics through interdisciplinary real-world case study and problem-solving strategies can foster the required integrative thinking for tomorrow's engineers. This concept was implemented in ME/CEE 1770, using the case study methodology for student learning in the spring of 2009. Specifically, a case study was chosen from the LITEE National Dissemination Grant Competition, sponsored by NSF DUE # 0442531. The same case study was also used in the senior level CAD course ME 4041: Interactive computer graphics and CAD in the summer of 2009. In ME/CEE 1770, implementation of this case study involved 3D geometric modeling. In ME 4041, implementation of this case study is involved with the failure analysis of critical components using finite element analysis (FEA).

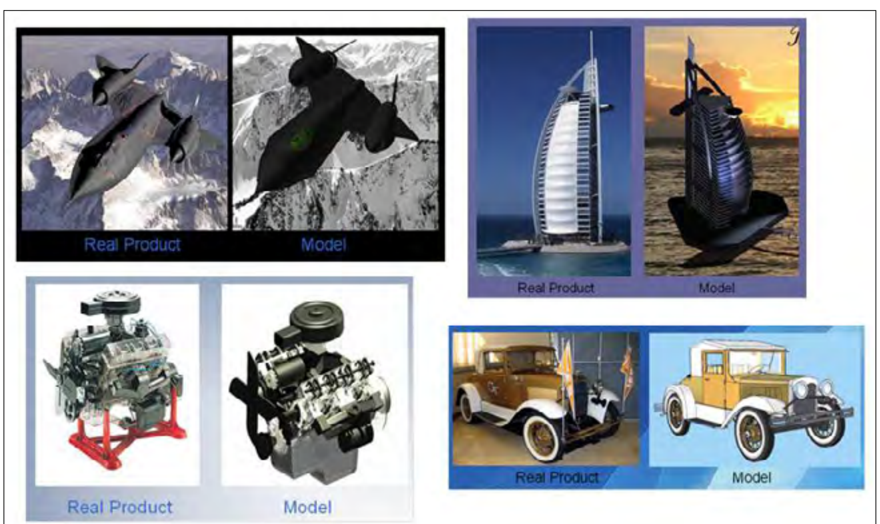

Figure 4. ME/CEE 1770 Team Project Examples

Case Study (STS Challenger 51-L) and Implementation:

The STS 51-L case study on CD-ROM provides the technical details of the design of the solid rocket booster (SRB) field joints for the timeline 1972-86. A multimedia segment describing the stages of SRB and its assembly are part of the package. The O-ring used in the field joint and its' placement in the SRB are detailed. More details about the failed joint rotation that was determined to be the cause of the Challenger accident are also available (Sankar, Sankar, Raju, & Dasaka, 2000).

In a section of about 40 students, a team consisting of five was randomly selected for this purpose at the beginning of semester. The team was asked to model various components of the Challenger through free-hand sketching, 2D CAD drawings, and 3D CAD solid models throughout the semester. Detail models of joints, fasteners, associated assemblies, and 3D animations were part of the study subjected to the availability of the actual dimensions. The impact on students learning through real-world case study was assessed through quality of the final group presentation, project report, and curriculum assessment surveys provided by LITEE. The implementation of the same case study for stress analysis and reliability of the O-rings in ME 4041 course: Interactive Computer Graphics and Computer –Aided Design, was also undertaken in the summer of 2009.

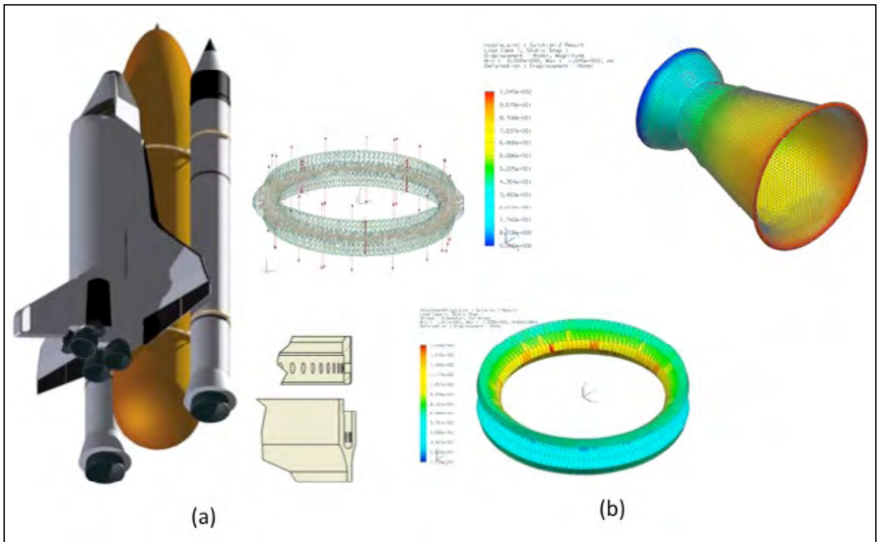

Figure 5. LITEE case study for team projects in (a) ME 1770 and (b) ME 4041

Assessing Student Learning – Engagement and Performance:

As the case study projects were assigned at the beginning of the semester, the instructor had the opportunity to qualitatively assess the student learning, general attitude towards subject matter, student engagement, and overall performances. The students that worked on the LITEE case study exhibited: (a) ease of learning subject matter, (b) good attitude towards subject matter, (c) noticeable engagement through lecture / lab activities, (d) excellent team work through more visits to the instructor's office as a team, and (e) significantly improved performance in meeting all the course requirements.

Engagement

Student engagement has been used to describe students' willingness to actively participate in learning activities. Students who are engaged show sustained behavioral involvement in learning activities accompanied by positive emotional tone. They select tasks at the border of their competencies, initiate action when given the opportunity, and exert intense effort and concentration in the implementation of learning tasks. They show generally positive emotions during ongoing action, including enthusiasm, optimism, curiosity, and interest (www.ericdigests.org).

In ME/CEE 1770, student engagement was primarily assessed qualitatively through interactions between the students, teaching assistants, and the instructor. Both the teaching assistants and the instructor noted more vibrant interactions with the students when implementing the methods described in this paper. Increased visits to office hours, questions geared more towards deep learning rather than "what do I need to know for the test?", and elevated levels of enthusiasm for the topic, were all readily apparent. Additionally, a limited amount of data to measure engagement was collected through information reported by students on the end-of-term Course Instructor Opinion Survey (CIOS). Mean scores on the CIOS questions related to *"Instructor encouraged students to consult with him/her"* and *"Class attendance important in promoting learning"* were 4.9/5.0 and 4.9/5.0 respectively. These ratings are supported by comments such as *"I really enjoyed the class and was impressed by the exams and projects which addressed a real need. We went through the planning stages to a real product just like we would in the real world"* and *"The class was one of the best I've taken so far at Tech. The course was fun and challenging and got us thinking outside the box. The instructor*

Construct	Pre (average/5)	Post (average/5)	Post-Pre
General attitude toward subject matter	3.17	3.17	0.00
Relevance of subject matter to life and society	4.30	4.35	.05
Higher-order cognitive domain of learning	4.10	3.97	-0.13
Self-efficacy	4.13	4.10	-0.03
Ease of learning subject matter	3.03	3.03	0.00
Impact on team working	3.80	3.96	0.16
Communication skills	3.87	3.33	-0.53

Table 2: LITEE pre-post survey results by construct

pushed us to learn and grow in ways that were constructive and valuable."

A questionnaire provided by LITEE was also used. The sample size was small (n=5), and results did not show strong trends on any of the seven constructs contained in the survey, so no analysis for statistical significance was conducted. Results are displayed in Table 2.

Several noticeable differences between the pre- and post- survey means for various constructs are worth discussing. First, with the construct "relevance of subject matter to life and society," a small increase was observed in the post-survey despite high ratings coming into the course. This is potentially important for freshman, as students often cite a loss of interest in the subject area when leaving engineering for another major(Seymour & Hewitt, 1997). Second, the "impact on team working" construct showed the largest overall positive change from pre-survey to post-survey. This indicates the team project utilizing the case study was effective in helping build the soft skills often mentioned as particularly desirable within the industry. Finally, two constructs showed a decrease from pre-survey to post-survey: "higher-order cognitive domain of learning" and "communication skills." In the case of higher-order learning, this result may seem disappointing at first, but it is consistent with observations in the literature where problem-based learners feel they are learning less than they do in a traditional setting, when in fact just the opposite is true (Yadev, Subedi, Lundeberg, & Bunting, 2011). The students in the LITEE group outperformed those in the rest of the class (see below), even though they perhaps felt more frustrated cognitively (as measured by this construct). Comments, however, indicated that they found the project to be one of the most useful parts of the course for learning the material, along with unanimous support for the labs being helpful. Regarding communication skills, this result is a bit surprising. Two of the five students showed significant decreases in this category on their surveys, and their qualitative comments offered no explanation.

Performance

Student performance was measured by an assessment checklist and rating scales compiled by the teaching assistants, and work sample analysis by the instructor on lab activities, exams, and project grades. The checklist and rating scale measures were not retained for the recording of final grades in the course and were no longer available at the time this paper was written. However, it can be noted that the scores marked by the teaching assistants indicated that collaborative learning in the labs with peer review and assessment have resulted in improved student performance in lab activities. Similarly, the work sample analysis by the instructor on lab activities, exams, and projects indicated students matured in their performance on fundamental concepts as the semester progressed. This improved performance may be because of, at least in part, the formative assessment strategies on students' initial work. Student comments such as this one on the end-of-the term CIOS survey support this claim: *"The instructor gives you plenty of opportunities to show him and yourself that you really understand the material. The class is structured in such a way as to promote learning most effectively."* The exam and project scores indicate that students performed extremely well in the course. The average score for the term was 91 percent. This compares to previous semesters where averages ranged from 84 to 86 percent when taught by the same instructor. This indicates that the techniques used did indeed seem to improve student performance, though additional, more detailed data will be needed to confirm this indication.

Of particular interest are the students who completed their project using the LITEE case-study example as opposed to choosing a project based on their own interest. These students, as a group, were underperformers relative to the

Average scores	Exam 1	Exam 2	Exam 3	Final project
LITEE group (n=5)	88	80	96	186
Control (n=34)	92	88	94	184

Table 3: Performance comparison with case-study group against control groups

rest of the class on the first two exams by a significant margin. However, after these first two exams, the project work began in earnest and this team outperformed the rest of the class on both the third exam and the overall final project. This occurred even with one student who did not turn in all of the work for his portion of the final project. The results of this performance comparison are displayed in Table 3.

Although one cannot necessarily attribute these changes in performance to the LITEE project alone for this group and the sample size is too small to make statistical comparisons, it is true that the only difference in the course setup between the LITEE group and the control group was the use of case study instead of a student-chosen topic. As a result, the use of this approach appears worthy of further study.

Conclusions

Traditional teaching-centered instruction focuses on transferring the instructor's knowledge to students through classroom lectures and closed-end problems. However, the basic principle of modern cognitive theory is that the learners must be *actively engaged* in learning, by making connections and organizing learning into meaningful concepts. Many learning centered classroom strategies are presented in this paper to teach engineering graphics to freshman students. With the instructor acting as a facilitator, the strategies are being implemented with two primary objectives: (a) transfer the learning responsibility to students and (b) increase the student engagement. Both problem-based and case-study based approaches are used to achieve the connection between the academic abstraction and hands-on concrete application of engineering graphics.

Preliminary results indicate noticeable improvement in the students learning attitudes and enhanced engagement reflected in their improved performance. As a result, the use of these strategies is recommended for expansion and/or adoption, along with a careful, larger-scale study, to collect statistically significant data about effectiveness. There is an initial modest time investment to plan and implement these strategies. However, the result is a more enjoyable teaching and learning experience, along with improved performance as suggested in the literature and confirmed with the available data here.

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Dr. Raghuram Pucha is a Research Faculty at the Woodruff School of Mechanical Engineering, Georgia Institute of Technology, in the area of CAD/CAE and Manufacturing. Dr. Pucha teaches computer graphics and design courses at Georgia Tech., and conducts research in the area of developing computational tools for the design, analysis and manufacturing of advanced materials and systems. Dr. Pucha has three provisional U.S. patents, co-authored over 50 research papers. He is honored with excellence in teaching recognitions and Undergraduate Educator Award for year 2012 from the Center for Enhancement of Teaching and Learning (CETL) at Georgia Tech. Dr. Pucha is a Senior member of IEEE and AIAA.

Dr. Tristan T. Utschig is a Senior Academic Professional in the Center for the Enhancement of Teaching and Learning and is Assistant Director for the Scholarship and Assessment of Teaching and Learning at the Georgia Institute of Technology. Formerly, he was a tenured Associate Professor of Engineering Physics at Lewis-Clark State College. Dr. Utschig has regularly published and presented work on a variety of topics including assessment instruments and methodologies, using technology in the classroom, faculty development in instructional design, teaching diversity, and peer coaching. Dr. Utschig completed his PhD in Nuclear Engineering at the University of Wisconsin – Madison.