# Integrating Engineering Applications into First-Year Calculus in Active, Collaborative, Problem-solving Sections

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Abstract

In Fall 2007 Cornell University engineering students who are enrolled in *Calculus for Engineers*, the first course in the required engineering math sequence, are working together in groups to apply the basic calculus concepts and methods they are learning to solve engineering-related problems. Typically, students would not be introduced to such problems until later in the engineering curriculum. Through this innovation, faculty hope students will a) develop a deeper and more lasting understanding of the basic calculus concepts, b) learn to apply mathematical concepts to modeling and solution of engineering problems, and c) experience a sense of engagement and connection to their interests earlier on in the curriculum resulting in greater motivation to continue in engineering. This innovation was approved by the faculty in February 2007 and an engineering faculty member with experience implementing active and collaborative learning in engineering classrooms was recruited to lead the development and implementation of a pilot program. Discussions with the Mathematics Department, which offers the engineering math courses, resulted in the development of mechanisms for a cross-college collaborative effort to implement the proposed course revision. The engineering applications have been integrated into the course by transforming one of the two weekly teaching assistant (TA)-led recitation sections into a collaborative problem-solving session facilitated by the course TA along with an undergraduate course assistant (CA) who is an upperclass engineering student. The problems have been developed with the help of engineering faculty teaching the 200-level engineering courses in which basic calculus is routinely applied, and then reviewed by a liaison committee of mathematics and engineering faculty. The teaching assistants and course assistants receive training on facilitating active, collaborative problem-solving. The training was developed and led by engineering faculty and staff, drawing on other successful collaborative learning efforts in the college.

Background

In 2006, Cornell College of Engineering Dean Kent Fuchs formed a Curriculum Task Force and charged it with the task of developing recommendations for changes in the Engineering College Common Curriculum. The group was composed of senior faculty members from most engineering departments in the College, the Associate Dean of Undergraduate Programs, and the Director of Engineering Learning Initiatives. The Task Force was expected to take into account the Undergraduate Studies Objectives from the Cornell College of Engineering Strategic Plan of 2005:

- Enhance the undergraduate educational environment and experience
- Enhance the engineering undergraduate curriculum and implement procedures for assessment and change.
- Become a leader in the education of women and underrepresented minority engineers.

In addition, the Task Force considered trends in engineering education and investigated curriculum revisions taking place in several other US universities.

The key goal of the Mathematics sequence in the Cornell Engineering Common Curriculum is to teach students to use mathematics to solve problems in science and engineering. This type of mathematical thinking is critical to all engineering fields. However, the Task Force felt that the current core courses are not as effective as they could be in this regard because the math and engineering courses are completely independent from each other. The math courses are not adequately motivated by real problems in science or engineering, and most science and engineering courses do not use the full palate of math skills that are, in principle, available based on the syllabi of the prerequisite math courses. Meanwhile, numerous studies and curricular experiments[1, 2] have shown that an integrated approach, in which science and engineering problems are used to motivate the math, and math skills are applied immediately and constantly in science and engineering courses, pays off handsomely in terms of comprehension, retention, and fluency in problem solving. Therefore, the Task Force proposed a number of strategies to integrate mathematics, science, and engineering in first-year courses.

For the goal of integrating science and engineering into core math courses, the Task Force proposed an enhancement to the first two required calculus courses taken by first-year engineering students. Specifically, the Task Force proposed that one of the two existing TA-led recitation sections be replaced with a longer, interactive, discussion-group-style problem-solving session. The faculty approved this proposal and all students in *Calculus for Engineers* are participating in these Engineering Math Workshops as of Fall 2007. In these special sections, students use mathematics to solve problems that deal with stimulating and thought-provoking real-world physics and engineering applications. The sections are facilitated by the course TA along with an upper-level undergraduate course assistant. An engineering faculty coordinator generated the workshop problems and works with college staff to recruit, train, and oversee the course assistants.

In the rationale for the proposed changes, the Task Force noted that many students have difficulty relating math to science and engineering applications. In the current engineering curriculum, students learn abstract math concepts and engineering principles without necessarily tying the two together at first. Based on the outcomes of curricular innovations implemented elsewhere, the skill of using mathematics to model engineering problems can be explicitly taught, and the earlier this is done in an engineering student's career, the better[1, 3]. It is expected that students who receive this type of integrated education will not only be better at solving engineering problems sooner, but will develop better "intuition" for mathematics and perform better in math courses as well. Our objective is for students to acquire an appreciation of how math describes the physical world through practice in solving stimulating, thought-provoking, word problems that refer to real-world engineering applications. By making connections between math, science, and engineering early in their core engineering courses, we expect their comprehension, retention, and fluency in these subjects to improve.

These observations resonate with engineering faculty observations that students often do not recognize basic mathematical principles that are well covered in the engineering math sequence. When students are then shown the math in the context of a math textbook, syllabus, or course notes, they often have an "aha" experience and recognize the connection. While this may seem surprising, the education research literature suggests that these connections are not as automatic as one might think[4-6].

Furthermore, studies have shown that students learn better in a comfortable social environment in which peer support, encouragement, and feedback exist. Supervised and facilitated problem solving practice has been shown to be far more effective than faculty or TA demonstrations of how to solve problems. Student learning, fluency, and retention of concepts can be dramatically enhanced by use of an interactive group learning experience[7-12]. In the proposed recitation sessions, the students would work in small groups to solve collaboratively, with the help of a facilitator, problems closely related to the material presented in lecture. The problems would come from engineering and would include as much of the background as needed to make the context and motivation for the problem clear.

## Implementation

A pilot implementation program to implement this specific proposal in the first required math course for engineering students – *Calculus for Engineers* - was approved by the Engineering faculty in February 2007. Professor Michael Kelley, an Electrical and Computer Engineering faculty member with experience implementing active and collaborative learning in engineering classrooms was recruited to lead the development and implementation of the pilot program. Discussions with the Mathematics Department, which offers the engineering math courses, resulted in the development of mechanisms for a cross-college collaborative effort to implement the proposed course revision.

Over the spring and early summer eleven workshops, usually consisting of two problems each, were jointly developed and tested in the summer version of *Calculus for Engineers*. Two graduate student teaching assistants were funded jointly by the two colleges to facilitate the sessions, along with the lead Professor, and to make revisions as needed. With these changes, the full set of workshops were compared to the Fall syllabus, modified as needed and implemented in Fall of 2007.

The Engineering Math Workshops are staffed by the course teaching assistants (TAs) along with undergraduate course assistants (CAs). The teaching assistants are graduate students assigned by the math department, most lacking any affiliation with the engineering college. The course assistants were recruited from the group of engineering students already facilitating, or expressing interest in facilitating, in the college's pre-existing supplemental collaborative learning workshops. Currently, there are sixteen sections of the *Calculus for Engineers* course that are divided among eight TAs and 14 CAs.

The graduate teaching assistants and undergraduate course assistants attend a training session at the outset of each semester designed to prepare them to facilitate the active, collaborative, problem-solving sessions. The training includes an explanation of the motivation for the workshop program and the expected learning gains for students, a description of the optimal workshop environment they are called on to create and tips on how to foster that optimal environment, important information on administrative procedures and record-keeping for program evaluation, and practice guiding group work on the actual workshop problems.

There are some practical issues not to be ignored if such a program is to be successfully implemented. The geometry of the rooms to be used is very important. The availability of moveable tables and chairs suitable for three- to five-person groups is crucial. Scheduling is also an issue. Sessions of at least 90 minutes are preferred, but the academic day is divided into 50 minute segments. For our initial implementation, we found that these boundary conditions led to a limitation of the workshops to the same 50 minutes usual for the recitation sections even though we knew that 50 minutes is too short a time for such sessions. We plan to overcome this limitation in future terms.

As the semester is progressing, we are soliciting feedback on how the workshops are going and discussion among TAs and CAs through an e-mail listserv. We also have asked TAs to keep records on how far each group in their sections gets on the workshop problems for each session. To date, the feedback from TAs and CAs has been very positive in terms of the value and enjoyment they see students getting from the workshops, and in terms of their own experiences facilitating the workshops. Several also have specific suggestions on how to clarify and improve workshop problems and are eager to form a working group to collaboratively make improvements. A working dinner was organized for the group after one month to learn from that experience in time to make some changes on future workshops. This de-briefing will be repeated next month.

## Evaluation Plan

Based on experiences reported in the engineering education literature, we are confident that the Engineering Math Workshops will improve the undergraduate experience at Cornell. We were thus unwilling to establish control groups of peers not exposed to this experience in order to set up an experimental comparison. We will, nonetheless, engage in several other short- and long-term evaluation strategies. We have defined four central goals for the engineering math workshops and propose assessment strategies for each.

Goal 1**:** Enhance conceptual understanding and retention of math content.
*Assessment strategies:*

- Administer a test of basic calculus content to students beginning 200-level Engineering courses for which *Calculus for Engineers* is a pre-requisite. Compare Fall 2007 scores of Sophomores having taken the old version of *Calculus for Engineers* with Fall 2008 scores of Sophomores having taken the enhanced version of *Calculus for Engineers*.

- Survey participating students on the effect of the workshops on their understanding of course material, and on their motivation to learn the math well and retain it (i.e, do they see course content as useful for their upcoming courses and career as an Engineer?).
- Survey teaching assistants and course assistants facilitating workshops on their observations and impressions of student learning gains.

Goal 2: Enhance ability to apply math to engineering problems.
*Assessment strategies:*

- Survey engineering faculty teaching 200-level engineering courses in which students must apply basic calculus content to determine whether they detect changes in students' ability to recall and apply basic calculus concepts and techniques.

Goal 3: Retain and nurture student interest in engineering during the first year.
*Assessment strategies:*

- Survey participating students on effect of workshops on sustaining their interest in engineering.
- Track student retention in Engineering through first year and into second year. Compare retention rates for cohort participating in workshops with previous cohorts.

Goal 4: Create positive peer learning communities among Engineering students through early engagement in a structured, collaborative, non-competitive learning environment.
*Assessment strategies:*

- Survey participating students on effect of workshops on their sense of connection to other Engineering students, and their sense of teamwork and cooperation among Engineering students.
- Survey teaching assistants and course assistants facilitating workshops on their observations and impressions of workshop environments and student benefits.

## Conclusion

Active learning workshops have been implemented in the introductory engineering calculus course at Cornell. Following our summer pilot program and our experience in the first semester so far, we have found that the time limit is the only real problem we have encountered. The students and staff like the social aspect and there seems to be a genuine collaborative environment. Assessment is challenging since we did not feel it appropriate to create a control group. However, by proceeding with the strategies above we hope to gain feedback essential to continuous improvement of our approach and also demonstrate progress toward our goals.

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## Biographical Information

LISA SCHNEIDER has been the Director of Engineering Learning Initiatives in Cornell University’s College of Engineering since December 2002. Learning Initiatives’ programs enhance the educational environment of the College by providing opportunities for collaborative learning, undergraduate research, teaching skill development, peer instruction, and leadership development. Schneider received her PhD in Sociology from Cornell in 1997.

MICHAEL KELLEY came to Cornell in 1975 after a PhD and postdoctoral appointment in the Physics Department of UC Berkeley. His research is in Upper Atmospheric Physics where he studies the electrodynamics of the ionosphere and its coupling to the neutral atmosphere. He has been the chairman for 20 PhD students at Cornell, five of which are faculty members at other universities. He has won many teaching awards at Cornell including the prestigious Weiss Presidential Fellowship.

SHEFFORD P. BAKER received MS (1988) and PhD (1993) degrees from Stanford University. From 1993 through 1997, he was a member of the scientific staff at the Max-Planck-Institut für Metallforschung in Stuttgart, Germany. Baker joined the faculty in the Department of Materials Science and Engineering at Cornell in 1997. His research focuses on the unique mechanical properties of materials having microstructural or dimensional length scales in the nanometer regime.