Center for Engineering Education: Colorado School of Mines

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Abstract

Faculty at the Colorado School of Mines have become increasing interested in engineering education research. In response to this interest, the Center for Engineering Education (CEE) was created in January 2000. CEE's activities are organized around Ernest Boyer's model of four types of scholarship: the scholarships of discovery, integration, application, and teaching. In addition to conducting research in engineering education, CEE also disseminates the results of that research through courses and seminars for faculty, graduate students, and the K-12 community.

I. Introduction

Over the past several years, the faculty of the Colorado School of Mines (CSM) have become increasingly interested in the educational process, and in educational research. The Center for Engineering Education (CEE) was established in January 2000 in response to that interest. The mission of CEE is to improve the learning of science and engineering, thereby increasing the accessibility of these disciplines. CEE's role is to act as a catalyst to bring together faculty who are interested in educational research, to disseminate the results of that research, and to provide professional development opportunities for CSM faculty, graduate students, and K-12 teachers.

In this article, we describe the factors at CSM that inspired the establishment of CEE, and the conceptual framework used to guide CEE's development. Finally, we discuss how the impact of CEE on CSM and the broader engineering education community will be evaluated.

II. Theoretical Framework

The late Ernest Boyer proposed a model that was used to organize the goals and direction of CEE. In *Scholarship Reconsidered*, Boyer[1] argued that an expanded view of "scholarship" was needed in academia. The intellectual rigor of scholarly activities should, he felt, extend beyond conducting original research and publishing results. Boyer suggested that the same scholarly rigor be applied in four inter-related activities: discovery, integration, application, and teaching. His ideas have since been given a great deal of attention.[2–4] In the paragraphs that follow, each of these forms of scholarship will be discussed as they relate to engineering education.

The scholarship of *discovery*[1,2] is the act of creating new knowledge within a given discipline. This is the traditional view of research on college campuses. Discovery is central to the advances of any given discipline, and is driven by what an individual investigator or team of investigators desire to know. Research that impacts society has been made in every discipline, including education. Discoveries in cognitive psychology and educational psychology have provided a foundation for understanding how learning takes place.[5] Efforts have also been made to unveil how learning occurs in undergraduate engineering.[6–8]

The scholarship of *integration*[1,2] connects or links information between different disciplines and areas of knowledge. Integration is the act of taking facts and concepts that emerge through separate investigations and linking these facts in a meaningful manner. Examining how the principals of cognitive psychology may inform engineering education (or vice versa) is an example of the integration of knowledge. Integration allows discoveries in one area to inform the discoveries in another area. This type of exchange increases the speed at which new discoveries are made across different areas of investigation.

The scholarship of *application*[1,2] builds upon the scholarship of discovery and the scholarship of integration. After new knowledge is discovered, the question becomes, "how can this knowledge be used?" The findings of cognitive psychology, learning theory, and engineering education may all inform the development of an effective undergraduate engineering program. In this example, it is the scholarship of integration that leads to the scholarship of application. The findings from each of these fields must be integrated before this information can be applied. Engineering courses may also be revised with the results of educational research in mind. Findings from individual studies as well as insights acquired through the integration of information across studies can be used to determine an appropriate structure for an effective engineering classroom.

The scholarship of *teaching*[1,2] puts the results of research into action. Effective teachers not only know what factors support the learning process, but also make an active effort to implement this knowledge in their classrooms. Quality teaching is an on-going process that requires the assessment and evaluation of the impact of new innovations on the learning process. Much like research, quality teaching requires the testing and verification of educational hypotheses. The laboratory for the teacher is the classroom.

The four forms of scholarship are not independent, but rather each type of scholarship overlaps and influences efforts within the other forms of educational scholarship. This framework for discussing scholarship was presented with respect to the discipline of education; however, the framework is equally appropriate with respect to any given discipline.[1] The scholarship of integration is the link between different disciplines. A given faculty member is likely to participate in all forms of scholarship to a different degree throughout his or her career. One manner in which to conceptualization the dimensions of scholarship are as four overlapping circles as is shown in Figure 1.

III. The Center for Engineering Education

CSM faculty members have diverse interests. Some faculty are deeply committed to the discovery of new knowledge within their fields, and others seek to integrate knowledge across fields and apply this knowledge to new situations. Still others are primarily concerned with improving the teaching and learning process within their discipline. The majority of faculty, however, cannot be categorized into a single form of scholarship; rather, most faculty lie in the intersection of one or more forms of scholarship. We recognize these differences and believe that given an appropriate structure, the diverse skills of the faculty can be assembled in a manner that improves the teaching and learning process.

A. History

The foundation for CEE was laid over twenty years ago. In the late seventies and earlier eighties, CSM sponsored a Seminar Series on Education.[9] Once a month, renowned engineering educators spoke to interested faculty about the challenges that were facing engineering education. These seminars, which were very popular, stimulated interest in both educational innovation and educational research. Many faculty members began to get involved in educational efforts.

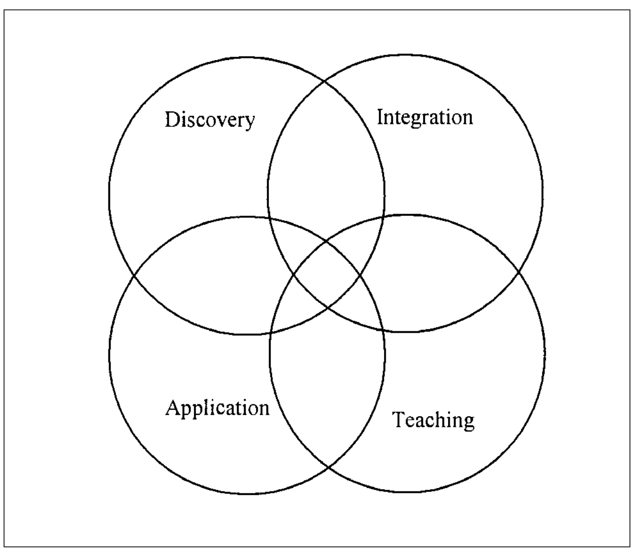

Figure 1. The overlap between the different forms of scholarship.

The fruits of these efforts may be witnessed today through the diverse educational topics that CSM faculty have addressed through presentations and publications.[10–14] Additionally, intellectual development models are now recognized as an appropriate tool for supporting educational reform at CSM.[15] Educational improvements have also been made. For example, as early as their freshman year, CSM students use teamwork to solve to real world problems in the Engineering Practices Introductory Course Sequence.[10] The current curriculum also includes a series of systems courses (e.g., "Earth Systems," "Human Systems," and "Engineered Systems") that encourage students to look at fields in an interdisciplinary manner. In the Engineering Division, the Multidisciplinary Engineering Laboratories (MEL) have replaced the traditional circuits, fluids, and strength of materials laboratories.[13] MEL requires students to work in teams and create their own steps in solving a problem, rather than having an instructor define the appropriate procedure. Thus, students practice solving the kinds of open-ended problems they are likely to face as working engineers and scientists. Mathematics and Physics courses also employ methods that require real world problem solving and group interaction.[16]

B. Purpose

In order to create and continually improve the educational innovations listed above, CSM faculty have engaged in an on-going, informal exchange of ideas about educational research. CEE was created with the purpose of recognizing and formalizing this collegiality. Faculty who are interested in educational research no longer have to identify each other by word of mouth, but rather CEE acts as a focal point for educational research at CSM. We believe that this will result in the rapid advancement of educational research and improvement.

Not all of the faculty members who are interested in educational research are trained in the appropriate methods and techniques. As is the case in any field, education has a rich and informative research base that has been established through the use of demonstrated methods. As has been argued before,[17–19] engineering education should be informed by the results of cognitive psychology, educational psychology, and learning theory. Many of our faculty have spent years completing research specific to their fields. Although this provides the opportunity to utilize discipline specific knowledge in the development of educational innovations, it also results in the challenge of updating faculty both on the educational literature and on appropriate methodology. CEE assists faculty members in establishing an educational research agenda, implementing that agenda, interpreting and using research results, and disseminating the results of their own research.

CEE is not intended to be exclusively for those who are interested in educational research. Many faculty members are not interested in completing educational studies, but they are interested in improving their instructional practices. To these individuals, CEE acts as a disseminator of educational knowledge. CEE provides workshops for both faculty and graduate students on the techniques of college teaching, and recent developments in the educational literature. CEE faculty also teach a graduate-level course called

"Fundamentals of College Teaching" for doctoral students contemplating a career in academia. CEE also promotes the expansion of educational research resources contained in the CSM library. Both the campus and the community have the opportunity to benefit from this resource.

Outreach activities, in which CEE works with local elementary, middle schools and high schools, are also anticipated. As educational research is undertaken at CSM, some of these findings may be applicable to younger students. Similarly, scholars in pre-college education are likely to offer knowledge and experiences that may be used to improve college level instruction. CEE will provide a forum to support the on-going exchange of information between these communities of scholars.

C. Anticipated Activities

Table 1 displays a sample of the anticipated activities of CEE. This table is loosely arranged by the form of scholarship to which it is most closely related. As we discussed earlier, there is no clear separation between the four forms of scholarship. Many of our faculty's interests can best be categorized as lying on the intersection of one or more of these forms of educational scholarship. CEE recognizes the importance of each form of educational scholarship and the positive impact that they are likely to have upon CSM. Additionally, due to the backgrounds of our faculty, CEE has the opportunity of combining discipline specific knowledge with educational advancement.

Technology is expected to play a central position in the efforts of CEE. The role of technology in educational research is expected to

Discovery	Integration	Application	Teaching
• Investigate why some science concepts are difficult for students to learn. • Examine the mental processes that take place when students solve open-ended engineering problems. • Study the mental processes that take place when students participate in multidisciplinary teamwork.	• Investigate how the results of cognitive psychology, educational psychology, learning theory, and engineering education may be used to improve the teaching/ learning process. • Synthesize the diverse literature on engineering education. • Investigate the impact of expert system software on the learning process. • Elicit feedback from industry on their expectations for future employees and examine how these expectations may be met through instruction.	• Apply the methods of cognitive psychology to better understand student learning. • Examine the educational impact of creating "virtual teams." • Examine how scientific concepts may be presented in a manner that improves learning in both college and K-12 instruction. • Assist college and K-12 teachers in using research to improve instruction. • Examine research on the assessment and instruction process and how this information may be applied to the college and K-12 classroom.	• Provide workshops for faculty and graduate students on the pedagogy of instruction and assessment. • Expand educational resources for faculty interested in educational research. • Provide courses on pedagogy to graduate students. • Disseminate information on new developments on teaching and learning. • Provide mentored teaching experiences to new faculty and to graduate students.

Table 1. Current and prospective activities of CEE.

increase in the next several years and CEE will provide the technological support that will ensure that CSM is on the cutting edge of engineering education research.

In the fall of 2001, CEE will be housed in the new Center for Technology and Learning Media (CTLM) at CSM. This building was designed with education in mind. The CTLM will be equipped with the hardware and software necessary to support mathematical and scientific simulations, virtual teams, and distance learning. The CTLM will also provide the ideal setting for educational research and collaboration. Outfitted with both classrooms and conference rooms, CEE will provide workshops, meetings and courses on how to use technology to improve student learning. The CTLM will have both a technology support staff, and a curriculum developer who will assist faculty in designing technology-rich modules for their courses. The combined expertise of these individuals will provide CSM faculty with the appropriate resources to increasingly use technology in both their classrooms and their research.

Of special importance to CEE is the role that technology may play in improving student learning of science and engineering concepts. The CTLM provides an ideal setting in which to conduct such research. A major research interest of CEE faculty is explaining why some concepts in science and engineering are so difficult for students to learn. Cognitive psychologists have proposed that students' misunderstandings about concepts as heat conduction, thermal diffusion, and chemical equilibrium, may arise when students misapply macroscopic models of the world to describe molecular-level processes.[20, 21] Key to repairing these incorrect models is allowing students to "see" molecular interactions though animation and simulations.[22] CEE faculty plan to conduct research in this area and to disseminate their results to the engineering education and K-12 communities. It is anticipated that federal, corporate, and private grants will fund these activities.

IV. Evaluation of CEE

CEE is still in an early phase of development. With this in mind, on-going formative evaluation is essential. CEE will rely on the newly formed consultation committee to assist in assessment efforts. The consultation committee consists of eight representatives from academia, industry, government, K-12 education, and teacher training (see Table 2). Each of these members has agreed to serve until May of 2002. The consultation committee will meet for the first time in March 2001 and will meet once each semester thereafter.

CEE has created three goals to support its stated mission: (Goal 1) to conduct world-class research on teaching and learning in science and engineering, (Goal 2) to disseminate the results of that research to the engineering education community to increase student learning, and (Goal 3) to support the educational needs of science and engineering instructors at both the K-12 and the college level. Evaluation of CEE will be based on these goals.

- Chair
- Representative of educational research
- Representative of university teaching
- Representative of industry
- Representative of assessment
- Representative of K-12 education
- Representative of K-12 teacher training
- Representative of government (ex-officio member)

Table 2. Roles on CEE consultation committee.

A. Evaluation of Goal 1

If CEE's first goal is realized, there should be an increase in faculty presentations and publications on educational issues, and an increase in external and internal funding in education-related projects. In order to identify changes in these activities, we will collect baseline data in May 2001 by surveying the CEE-affiliated faculty. This survey will be repeated at the end of each academic year. We expect that by May 2003, presentations, papers, and educational grants will have increased by at least 25%.

B. Evaluation of Goals 2 and 3

CEE is also expected to positively influence instruction at both the college and K-12 level. To examine this influence, we will survey the CSM faculty and students, and the surrounding K-12 community in May 2002. The information acquired through this qualitative survey will be used to evaluate and refine CEE's current efforts and to inform the construction of a future quantitative survey instrument. The quantitative instrument that results from these efforts will be administered to our constituencies every two years.

Educational programs that result from the efforts of CEE will also be carefully monitored and student performance will be directly assessed. The methods used to measure student outcomes will be dependent upon the purpose of the given program. The CEE consultation committee will review the appropriateness of the proposed methods for the given program's goals.

V. Concluding Remarks

Successfully educating tomorrow's scientists and engineers requires that we look closely at the educational process and the four forms of scholarship. We believe that engineering education will be most effective when educational research, informed by the principles of cognitive and educational psychology, along with the application of that research, and teaching, are linked and inter-related.[19] The methods that a teacher employs should be informed by the research that is available concerning the educational process. Content knowledge experts are also a valuable resource that may be used to improve the educational process. CEE hopes to effectively combine the diverse skills and interests of its faculty to support the common goal of improving engineering education. Furthermore, we expect to influence and be influenced by the efforts that are already underway in K-12 education. We invite each of you to follow us as we advance towards our goals by frequently visiting our expanding web site.[23]

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