Using Boyer's Four Forms of Scholarship to Advance Engineering Education

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Abstract

The Center for Engineering Education (CEE) at the Colorado School of Mines promotes both educational research and instructional improvement. In order to connect the potentially competing activities of research and teaching, CEE uses Ernest Boyer's model of the four forms of scholarship to describe and shape sponsored activities. According to Boyer, the word "scholarship" should not only describe the activities of those who conduct original research (which he called the scholarship of discovery) but also the activities of those who integrate and apply knowledge and those who teach. This paper describes Boyer's model and provides examples of how the four forms of scholarship display themselves in CEE sponsored projects and activities.

Introduction

This paper begins by briefly introducing the Center for Engineering Education (CEE) at the Colorado School of Mines and by describing CEE's mission and goals. Next, Boyer's four forms of scholarship are presented as the framework that was used to guide the development of CEE sponsored projects and activities. This paper concludes with a description of three projects that illustrate all four forms of scholarship. An earlier version of this paper was presented at the Frontiers in Education Conference (Streveler, Moskal & Miller, 2001).

The Center for Engineering Education

The Colorado School of Mines is the second oldest and one of the largest public research universities in mineral engineering and applied science in the country. Although the CSM does not have a School of Education, faculty at CSM have been interested in educational issues and have participated in educational research for over twenty years. To support educational efforts, a new entity was conceptualized in the early 1990's— the Center for Engineering Education (CEE). The purpose of CEE is both to provide professional development opportunities to faculty and graduate students and to foster educational research at CSM. After ten years of discussion, the Center for Engineering Education (CEE) was established in January 2000.

The first task for the new center was to articulate its mission and goals. The mission of CEE is to improve the learning of science and engineering, thereby increasing the accessibility of these disciplines. The goals of CEE are as follows:

(1) to conduct world-class research on the teaching and learning in science and engineering,

(2) to use the results of that research to continually improve instruction at the Colorado School of Mines to better support the learning process of our students, and

(3) to support the educational needs of science and engineering teachers and learners at the K-12, university, and continuing professional development levels.

For a more in-depth discussion of the purpose and goals of CEE, see Streveler, Moskal, Miller and Pavelich (2001).

Boyer's Model: Four Forms of Scholarship

In *Scholarship Reconsidered*, Boyer (1990) argued that the intellectual rigor that defines scholarly activities should 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. Boyer's framework was immediately recognized as an ideal structure to guide the development of CEE's projects and activities (Streveler, Moskal, Miller & Pavelich 2001). This section describes each of Boyer's four forms of scholarship. For greater detail concerning these forms of scholarship see Boyer (1990) and Glasic, Huber and Maeroff (1997).

The scholarship of *discovery* (Boyer, 1990; Glasic, et al., 1997) 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. Discoveries that impact society have been made in every discipline, including education. Research in cognitive psychology and educational psychology has provided a foundation for understanding how learning takes place (Bransford, Brown & Cocking, 1999; Marra, Palmer & Litzinger, 2000). Efforts have also been made to unveil how learning occurs in undergraduate engineering education (Atman & Bursic, 1998; Marra et al., 2000; Turns, Atman & Adams, 2000).

The scholarship of *integration* 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 the 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 the different areas of investigation.

The scholarship of *application* 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* puts the results of research into action. Effective teachers not only know what factors support the learning process, but also they 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.

As this discussion suggests, the four forms of scholarship are not independent, but rather each type of scholarship overlaps and influence the efforts within the other forms of educational scholarship. This will be further illustrated in the next section through the discussion of CEE sponsored projects. This framework for discussing scholarship was presented here with respect to the discipline of education; however, the framework is equally appropriate with respect to any given discipline (Boyer, 1990).

Scholarship at Work

CEE sponsors a number of different programs that support the four forms of scholarship: discovery, integration, application and teaching. The programs that will be discussed here were selected because they illustrate how all four forms of scholarship can be displayed within a single program or project.

Student Misconceptions in Engineering

Some CEE faculty members are actively exploring the question: “why are some concepts in science and engineering so difficult for students to learn?” Evidence from the literature in cognitive psychology suggests that science and engineering students do not conceptually understand many fundamental molecular-level phenomena such as heat, light, diffusion, and electricity (Reiner, Slotta, Chi & Resnick, 2000). These types of phenomena are examples of emergent processes or processes that involve uniform, parallel, independent events with no beginning or end.

It has been proposed that the conceptual misunderstandings arise when students incorrectly think of emergent processes as having the attributes of the causal processes that are seen in everyday life (Chi, in press). Causal processes involve distinct, sequential, goal-oriented events that have an observable beginning and end. Consider the example of adding a droplet of colored dye into a beaker of quiescent water. Visually, the dye appears to move through the water until the resulting dye/water mixture has the same color throughout the beaker. This point is called "equilibrium" and it visually appears that there is no further dye movement in the water. This experiment can be incorrectly described using a causal model. A student may explain that the dye molecules “want” to mix with water and that the individual dye molecules move with intent to create a uniform dye/water mixture. After this uniform mixture is created, the student may incorrectly believe that the movement of the molecules has stopped.

A correct conception of this process is that both the dye and water molecules continue to randomly move even after equilibrium is reached. Initially, the dye molecules are concentrated into a small region. As the molecules randomly bounce about, they become thoroughly mixed with the water molecules. This results in a mixture that is visually uniform, but microscopically the molecules continue to move. Students, who describe this complex, dynamic process using the causal explanation, possess a mental model that is fundamentally incommensurate with accepted theories of molecular motion. Since this causal model seems to describe the macroscopic behavior of the dye/water experiment, students are comfortable with this view and hold tightly to this misconception.

Many fundamental topics in science and engineering involve emergent processes, which are often incorrectly viewed by students as causal processes. Students describe molecular momentum transfer as faster molecules "dragging slow molecules along," heat as a "substance stored in hot objects," heat transfer as a "flow of hot molecules to cold objects," and molecular processes as "stopping" when they reach equilibrium (Reiner et al., 2000). None of these explanations are correct and each leads to incorrect explanations of other related phenomena. For example, the assumption that heat transfer is the flow of hot molecules to cold objects leads to the belief that there is an absence of a temperature effect on equilibrium processes. Similarly, the assumption that molecular processes stop at equilibrium leads to the incorrect belief that no molecular diffusion occurs in laminar fluid flow.

Studies are now being formulated at CEE to identify what concepts engineering students find difficult (i.e., scholarship of discovery), what makes these concepts difficult (i.e., scholarship of integration of engineering, engineering education and cognitive psychology theory), how assessment can be used to identify the existence of student misconceptions (i.e., scholarship of application), and what instructional approaches are necessary to correct these misconceptions (i.e., scholarship of teaching). CEE has received funding from the National Science Foundation for the study, *Developing an Outcomes Assessment Instrument for Identifying Engineering Student Misconceptions in Thermal and Transport Sciences* (DUE - 0127806), to support this research endeavor. Based on the results of this research, methods of instruction are expected to be created that will help students to better understand emergent processes.

Examination of the above identified project goals reveals the importance of all four forms of scholarship. The project's emphasis is upon the discovery of new knowledge (e.g., What concepts do engineering students find difficult to understand? What makes these concepts difficult to understand?). Responding to these questions, however, requires the integration of knowledge form the fields of engineering, engineering education and cognitive psychology. The results of this project will be applied to the development of assessment instruments to measure student misconceptions. Eventually, the knowledge that is acquired from this project will be used to develop instructional efforts that assist students in developing more appropriate conceptions, the scholarship of teaching.

Gender Difference in Engineering Design

Another CEE project that is underway and is sponsored by the National Science Foundation's Activities for Women and Girls in Science, Engineering & Mathematics program is the *Engineering Design Teams: Influence of Gender Composition on the Decision-Making Process* project (EHR-9979444). This project examines the team decision making process in the Engineering Practices Introductory Course Sequence (EPICS) using an observational protocol developed by Eberhardt (Eberhardt, 1987). EPICS is a sequence of required freshmen and sophomore courses at CSM in engineering design.

The purpose of this project is to examine the interactions that take place between men and women during team decision making and categorize these interactions using an instrument that was developed by Eberhardt (1987). This project seeks to address the following research questions: "1) How does the gender composition of a team impact the quality of the developed solution to an ill-structured problem?, 2) How do the roles team members play differ when gender composition of the team varies within the decision-making process?, and 3) How does the gender composition of the team impact upon the quality of the experience reported by team members during the decision-making process?" (Cheney, Lasich & Moskal, 1999, p. 3).

Early results of this project suggest that the gender of individual team members had little impact on the roles that team members played during the team process. This finding is in stark contrast to research in other fields (e.g., Wylie, 1996; Jones, 1999). An explanation for this difference is that women who select to participate in engineering may be different from women who select to participate in other fields. Therefore, it is reasonable to assume that women in engineering will respond to the team process in a manner that is different from women in other fields. An interesting finding of the current research is that whether a team consisted of more males than females, more females than males or was equally mixed between males and females did have an impact on the roles that team members played during team interaction. For example, male dominated teams were more likely to be witnessed encouraging other team members and clarifying information than were female dominated teams. Male dominated teams were also more likely to be witnessed setting standards than were female dominated teams (for more information concerning these results see Macdonell-Laeser, Moskal, Knecht & Lasich, 2001).

Based on the early results of this study and the research questions, this project appears to involve the scholarship of discovery. However, in order to pursue the research questions described above, an interdisciplinary investigative team was necessary. This team included specialists in engineering education, gender issues, assessment and communication. Each of these individuals brought to the project the knowledge from their respective field (e.g., the scholarship of integration).

One of the primary reasons for pursuing this research was to acquire information concerning team interactions that could be used to improve the Design EPICS sequence at CSM. In other words, the information that is acquired will be applied to the development of appropriate instructional methods for supporting the design process. This outcome requires both the scholarship of application and the scholarship of teaching.

Preparing Doctoral Students to Teach

A final example of a CEE activity that illustrates all four forms of scholarship is the efforts to educate engineering doctoral students in educational research. CSM has established a 2-credit hour course called "Fundamentals of College Teaching", which is offered to doctoral students who are contemplating a career in academia. Recent literature supports the importance of this effort (Wankat, 1999). This course is offered every year and is taught by three CEE faculty members. Table 1 contains a brief description of the course, a list of the course objectives, and an outline of the course activities.

Table 1
Description of "Fundamental of College Teaching" Course

Course description
The course, designed for graduate students planning to go into academics and for interested CSM faculty, will focus on:

- Principles of learning and teaching in a college setting.
- Methods to foster and assess higher order thinking.
- Effective design, delivery and assessment of college courses or presentations.

Learning objectives
The course will help students become better able to:

- Describe and apply the principles of learning and teaching in a college setting.
- Design, deliver, and assess a college course
- Apply methods to foster and assess higher order thinking.

Course schedule

Week 1	Introduction. How students learn.
Week 2	Models of intellectual development. Perry, King and Kitchenor. Students take the Kolb Learning Style Inventory, and the Myers-Briggs Type Indicator (MBTI).
Week 3	Learning styles. Interpret the Kolb Learning Style Inventory, and the Myers-Briggs Type Indicator. Implications for teaching and learning.
Week 4	Active learning principles and methods.
Week 5	Cooperative learning principles and methods.
Week 6	Cooperative learning principles and methods, continued. Preparation for classroom observations
Week 7	Discussion of classroom observations.
Week 8	Designing a course or a class presentation.
Week 9	Discussion of planned microteaching topic and final project.
Week 10	Microteaching presentations and critique. Collect journals.
Week 11	Assessment of learning. Creating and scoring exams.
Week 12	Alternate methods of assessment.
Week 13	Microteaching presentations and critique.
Week 14	Roundtable discussion of final projects. Turn in final projects. Turn in journals.

It is expected that students will:

- Keep a journal that records your observations and reflections about teaching and learning. (Questions to be addressed in the journal will be given each week.)
- Complete assigned readings before class. Be prepared to discuss those readings in class. Make entries about the readings in your journal.
- Complete the Kolb Learning Styles Inventory and complete and turn in the Myers Briggs Type Indicator.
- Observe a class session and record your reactions.
- Prepare and deliver two brief presentations to the class of topics in your discipline. (This is called "microteaching".)
- Create a detailed, written plan for a one-semester course. (This is referred to as the "project.")

Instructors: Dr. Ron Miller, Dr. Mike Pavelich, Dr. Ruth Streveler

At first glance, this course appears to focus upon the scholarship of teaching. Students learn about and practice teaching methods. They also read Wilbert McKeachie's classic work *Teaching Tips* (1999) and they practice teaching techniques through short presentations called "microteaching." For each microteaching presentation, faculty members provide the students with suggestions for improving their instructional techniques.

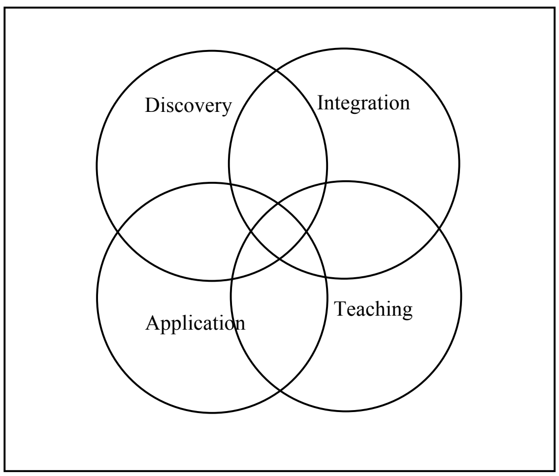
Examining this course beyond its surface features, however, reveals that all four forms of scholarship are at work. The students in this course are working on their doctorate and therefore, are deeply involved in original research projects. The course instructors encourage these students to develop their microteaching assignments around their own research results. Thus, the scholarship of discovery is brought into the course.

The initial topic discussed in the course is how people learn. This discussion is motivated by readings from Bransford, Brown & Cocking's (1999) book, *How People Learn*. Students in the course learn how knowledge is organized, how the organization changes as one gains expertise in the field, and the role of one's previous knowledge in the learning process. This information is drawn directly from the results of educational research and cognitive psychology and therefore, reflects the scholarship of integration. The scholarship of application is also an essential component. In order to give effective presentations, students need to apply the teaching principles that have been discussed throughout the course. In summary, the scholarship of discovery, integration, application and teaching are all part of this course.

Concluding Remarks

As the discussion above illustrates, the four forms of scholarship that were proposed by Boyer are not mutually exclusive. The scholarship of discover, integration, application and teaching can and do display themselves simultaneously within individual projects. Recognizing the presence of these different forms of scholarship provides a framework in which education and research efforts can be understood. A useful manner in which to conceptualize the four forms of scholarship is as overlapping circles, as is displayed in Figure 1. This model of the four forms of scholarship originally appeared in Streveler, Moskal, Miller and Pavelich (2001) and is reproduced here with permission. The circles within the model represent the different forms of scholarship and their intersections reflect the natural overlap that exists between them.

Figure 1. The overlap between Boyer's four forms of scholarship (from Streveler, Moskal, Miller, & Pavelich (2001), used with permission.)



The Center for Engineering Education at CSM recognizes and supports the important contributions that each form of scholarship makes to the educational process. In fact, the use of Boyer's four forms of scholarship assists CEE in reaching its goals: 1) to conduct world-class research on the teaching and learning in science and engineering, 2) to use the results of that research to continually improve instruction at the Colorado School of Mines to better support the learning process of our students, and 3) to support the educational needs of science and engineering teachers and learners at the K-12, university, and continuing professional development levels. The first goal requires the scholarship of discover, while the second and third goals require the scholarship of application, integration and teaching. As was illustrated here, some of CEE's sponsored projects reflect all four forms of scholarship. Other projects reflect a subset of the different forms of scholarship. The primary purpose of CEE is to provide a forum in which educational researchers at CSM may pursue scholarship, in a manner that is appropriate to their needs and interests.

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