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Preparing Engineering Faculty as Educators

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In *Educating the Engineer of 2020: Adapting Engineering Education to the New Century*, the authors ask, "What will or should engineering education be like today, or in the near future, to prepare the next generation of students for effective engagement in the engineering profession of 2020?" (NAE, 2005). To answer this question, we must look to engineering faculty—those who design the educational environment.

When engineering faculty members enter the academy, many—through no fault of their own—are not fully prepared for their role as educators. Although graduate schools have begun to focus more attention on developing teaching skills, the main focus continues to be on creating researchers. As a result, when most faculty members enter the academy, they are, as Kuh and associates note (2005), "well intentioned gifted amateurs" when it comes to teaching.

Furthermore, it has become increasingly clear that teaching and learning involve complex, interrelated intellectual, social, and emotional processes. Thanks to research in social psychology, the cognitive sciences, and education, we now know much more than we did 20 years ago about how cognition,

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motivation, and intellectual development affect learning and teaching. Unfortunately, universities have not successfully transmitted this information to faculty.

In this paper, we raise three questions germane to the task of preparing engineering faculty to educate students effectively. Our intention is to call attention to relevant findings from recent research to underscore the complexity and sophistication necessary for effective teaching and to argue for more recognition of teaching in the academic reward structure.

Overview

To improve engineering education, we must address three questions:

1. Is there a consensus among engineering faculty and administrators that faculty members need better preparation for their role as educators?
2. If so, what do they need to know, do, or understand to function more effectively?
3. How would academic institutions have to change for faculty to function more effectively as educators?

In this paper, we focus primarily on the second question. We address the first and third questions only briefly.

> *Improvements must begin with faculty members, the people on the "front lines" of education.*

Recognition of the Need for Change (Question 1)

Students would probably call this first question a "no-brainer." Over the past decade or two, leaders in the engineering community have identified shortcomings in engineering education and called for reform (ASEE Engineering Deans Council and Corporate Roundtable, 1994; NAE, 2004, 2005; NRC, 1995, 1999; NSF, 1995, 1996). In 1994, the Engineering Deans Council and Corporate Roundtable of the American Society for Engineering Education stated that, although engineering education has served the nation well, "there is broad recognition that it must change to meet new challenges." In 1995, the National Science Foundation (NSF) echoed this sentiment, and the National Research Council (NRC) Board of Engineering Education reinforced it: "In many areas, major change in the engineering education system is indeed necessary if it is to meet the needs of the nation and world in the coming century."

Organizations like NSF and the National Academy of Engineering (NAE) have led efforts to improve engineering education. An increasing number of centers at universities and elsewhere around the country (e.g., the NAE Center for the Advancement of Scholarship on Engineering Education) are researching issues in engineering education and implementing educational innovations. Similarly, the seven NSF-funded engineering education coalitions of the 1990s were charged with "stimulat[ing] bold, innovative, and comprehensive models of systemic reform of undergraduate engineering education." In fact, these initiatives have "produced significant reforms that have reinvigorated undergraduate engineering curricula . . . " (Foundation Coalition, 2006). Workshops on engineering education have focused specifically on preparing future faculty as effective educators, and prizes like the prestigious NAE Bernard M. Gordon Prize for Innovation in Engineering and Technology Education are now well established (NAE, 2006).

The question of whether engineering education should be improved and whether engineering faculty need better preparation, in other words, has been answered at the highest levels of the profession. Furthermore, a commitment of time and resources has been made toward meeting this goal. The larger question—*how* to prepare engineering faculty—remains to be answered.

Necessary Changes (Question 2)

Improving engineering education must begin with faculty members, the people on the "front lines" of education. At a minimum, they must (1) understand their students as intellectual-social-emotional beings, (2) understand basic principles of learning, and (3) understand the components of effective course design.

Understanding Students

Teaching requires complex human interaction. Students, like faculty, are social-emotional-intellectual beings, and all of these dimensions impact learning. Engineering faculty do not have to be social psychologists, cognitive scientists, or cultural anthropologists, but to design effective courses and implement effective classroom pedagogy, they must have a general understanding of the most relevant research findings.

First, educators must acknowledge the profound cognitive and emotional shifts experienced by 18- to 22-year-old college students. In a seminal work, *How College Affects Students*, Pascarella and Terenzini (1991) provide a synthesis of research on the influence of college on student development. They discuss not only learning and cognitive development, but also personal growth and changes, including changes in identity; relationships; cultural, aesthetic, and intellectual values; educational and occupational goals; political and social attitudes; and moral principles. The growth college students experience in a variety of ways every day impacts everything they do, and the better faculty members understand this, the better they can design learning experiences that can help students evolve into professionals. A few examples from four different areas of development highlight the types of information that can deepen our understanding of students as learners.

Intellectual Development

Ample research has been done in the past 50 years on how approaches to knowledge develop over time (Baxter-Magolda, 1992; Belenky et al., 1986; Perry, 1998).[1] Perry, for example, describes four stages of intellectual development. In the first stage, students have a dualistic view of the world; they perceive knowledge as clear and absolute and questions as having right and wrong answers. Students with a dualistic view believe that faculty know the right answers and that their role as students is to learn these answers. In the second stage, students recognize that there are multiple perspectives, but they may also believe that all opinions are equally valid or invalid. This is certainly not where we want our students to be at the end of four years!

As students gain greater maturity and experience and become more sophisticated intellectually, they reach the third stage, which Perry (1998) calls contextual relativism. At this stage "right and wrong, adequate and inadequate, appropriate and inappropriate can exist within a specific context and are judged by 'rules of adequacy' that are determined by expertise . . ." By the last stage of intellectual development, students are able to make decisions and understand the consequences of those decisions. At this stage, they have the ability, and the courage, to take and defend a position.

This brief description of Perry's work cannot capture the complexity of intellectual development, but it provides a context for thinking about how intellectual development impacts learning and teaching and raises a number of questions for educators. For example, if a first- or second-year undergraduate has difficulty with ambiguous or unstructured problems, should we push him or her to the next cognitive level, or will that happen naturally as the student matures? Can we assume that seniors have the ability to generate meaning and make choices among legitimate alternatives? Is it realistic to expect such intellectual growth in the four years of undergraduate education? If not, what are reasonable goals and expectations? The answers to these and other questions impact the way we design courses and the way we teach.

New knowledge is filtered through existing knowledge, whether or not it is accurate.

Intellectual Preparation

In addition to students' intellectual development, we would do well to focus on their intellectual preparation. We know that new knowledge is filtered through and interpreted according to existing knowledge, whether or not that knowledge is accurate (NRC, 2000). Consequently, we must assess students' prior knowledge and skills, correct inaccuracies, and identify gaps in their understanding or abilities in order for new knowledge and skills to have a strong foundation. We must assess not only *declarative knowledge* (i.e., knowledge that defines or describes), but also *procedural knowledge* (i.e., knowledge of how to use or apply) and *contextual knowledge* (i.e., knowledge of when to access and use certain principles, concepts, or procedures) (NRC, 2000).

The level of a student's knowledge or skills when he or she enters an engineering class depends to a large degree on what was learned in high school. Thus, it is important for engineering faculty to pay attention to what is happening in the schools that produce engineering students.

Given the increasing importance of high-stakes testing as a result of recent initiatives, such as the No Child Left Behind Act, and given the popularity of advanced

[1] For a synopsis, see Felder and Brent (2004).

placement (AP) courses in high schools, it is reasonable to question the depth of students' understanding. Do they enter college with a deep understanding of relevant material, or is their knowledge base superficial and fragile? Can they recognize when skills they have learned are applicable to new contexts, or do they only recognize their applicability in the context in which they were acquired? Finally, can they apply those skills appropriately? All of these questions warrant further exploration.

The childhood experiences of students differ markedly from those of their professors.

Generational Issues

A third body of information developed from studies of the "millennial" generation has identified traits that can be both advantageous and challenging to educators (Howe and Strauss, 2000, 2003). For example, many millennial students have older parents who are better educated than previous generations of parents. In addition, many students come from smaller families, in which parents have more time and resources to devote to each child. Some have called millenials the most protected generation ever, from prenatal classes and vitamins through childhoods with infant car seats, bicycle helmets, poison hotlines, childproof pill caps, and so on. Millennials have also lived highly scheduled and busy lives; structured play dates and after-school programs left them little free time. As a colleague likes to say, these young people are used to eating a sandwich in the car while doing homework on their way from soccer practice to piano lessons while listening to music on their iPods and text messaging with their cell phones! Current college students comprise "the most supervised and scheduled child generation ever" (Howe and Strauss, 2000).

What impact does growing up this way have on student attitudes, values, and behaviors? How do their experiences—which differ markedly from the childhood experiences of most of their professors—affect their interactions with faculty and their overall learning? Although it may be too soon to understand such complex sociological dynamics, we must start asking the questions now.

Cultural Issues

Faculty must understand not only generational culture, but also larger issues of cultural diversity among students. International students, for example, who constitute an increasingly large group on many campuses, come from a wide range of cultural and educational backgrounds. Their perspectives offer exciting pedagogical possibilities, as well as significant challenges. Communication skills, both written and oral, are an obvious area of concern, but less obvious cultural issues can also have profound effects on classroom dynamics, and thus on learning. The following examples represent just two of the many cultural differences that can affect interactions and perceptions in the classroom.

Differences in cultural and educational background can influence conversational styles, such as conventions regarding turn-taking during discussions; interruption techniques; pacing, pitch, and volume; and the number of people involved in a discussion at any given time. In the conversational style typical of certain cultures (Japan and Korea, for example), participation in discussions is orderly and characterized by polite turn-taking and deference to hierarchy. Linguist Deborah Tannen (1984) calls this "high-considerateness style." In the conversational style typical of other cultures (Latin America and the Middle East, for example), discussions are characterized by fast pace and high volume, frequent interruptions, and overlapping speech—"high-involvement style." Steinbach (1996) illustrates the difference between these two styles via a sports analogy. He compares high-consideration style to bowling; every player waits his turn, and only one player participates at a given time. He compares high-involvement style to rugby, which is characterized by loose rules and a great deal of movement. Rugby play does not stop when a player is tackled.

From an instructor's perspective, having students from both stylistic groups in one classroom can create particular challenges. Who will talk? Who will not? How do students perceive one another or the teacher? As instructors, how can we mediate and encourage a constructive level of participation for all? These questions become more complex when we consider that these are only two of many conversational styles and that there are many variations within and between cultures and contexts.

Many other cultural variations affect teaching and learning. In the United States, for example, students are generally expected to ask questions, indicate areas of confusion, and ask for examples to support their understanding. In some cases, students are encouraged to debate their peers, challenge their professors' ideas, and so on. Students who come from cultures where they are expected to maintain a respectful silence in class may be unaccustomed to asking professors for clarification or elaboration and may consider such behavior either disrespectful or personally embarrassing. Such cultural differences can lead to misunderstandings. If students do not volunteer questions, instructors may wrongly assume they understand the material. If they do not volunteer answers, instructors may wrongly assume they do not understand the material.

It may not be reasonable to expect faculty to learn all of the cultural differences that influence student thinking and behavior, but they must at least be aware of how differently students from diverse cultures can conceive faculty and student roles, conversational approaches, and the purpose of education. The better faculty understand the issues that impact classroom dynamics and student learning, the better they will be able to devise effective teaching strategies.

Understanding the Learning Process

In addition to understanding students better, we need a more thorough picture of how learning takes place. Educators today have the advantage of sophisticated research in the cognitive sciences and education to help them understand the learning process and design better instruction. Although we cannot do justice to the rich literature on learning here, two brief examples can suggest how engineering faculty might think about and foster student learning.

Organizing Information Effectively

Prior knowledge is the lens through which everyone views new information. If that lens is inaccurate, incomplete, or naïve, it can interfere with or distort the integration of incoming information (Clement, 1982; Minstrell, 1989; NRC, 2000). Research on cognition also indicates that the way this knowledge is *organized* determines its accessibility and use.

Students—like professors—create mental models that guide the retrieval and use of information; these models in turn shape further learning (diSessa, 1982; Holyoak, 1984; NRC, 2000). Effective mental models (clear causal relationships, accurately and logically categorized information, and evident relationships among concepts) enable students to retrieve information and apply relevant skills. Flawed or incomplete mental models lead to flawed and incomplete retrieval and application.

The challenge for faculty is to help students learn to organize knowledge the way experts do—"around core concepts or 'big ideas' that guide their thinking about their domains" (NRC, 2000). Core principles and concepts must be connected mentally to relevant pieces of information, and disconnected information and inaccurate links must be identified and corrected. In other words, to improve learning, engineering faculty must (1) assess (and sometimes correct) students' prior knowledge and (2) help students develop cognitive models for organizing prior and new information effectively. By making these goals explicit in the design of courses and classroom pedagogy, faculty can help students gain a deeper conceptual understanding of the material and thus enable the transfer of knowledge and skills to new situations.

Building Metacognitive Skills

To develop proficiency in an area of knowledge, learners must be able to select, monitor, evaluate, and adjust their learning strategies. In other words, students must become conscious of their thinking processes. This is called metacognition (Matlin, 1989; Nelson, 1992).

One way engineering faculty can help students do this is to "model" the way they, as experts in the field, construct intellectual problems, formulate questions, weigh alternatives, consider implications, and so on. An instructor might, for example, "talk through" a problem, identifying and putting into words the internal dialogue in which he or she naturally engages. This, of course, requires that the instructor become conscious of processes that have become so natural they may be barely conscious. By making "unconscious

Educators today can draw on sophisticated research in the cognitive sciences and education.

competence" conscious, the instructor (1) becomes more aware of the multiple subtasks and skills required to solve even simple problems, (2) helps students identify and address gaps in their understanding, and (3) models the metacognitive skills students are expected to develop.

Understanding Effective Course Design

Aside from a more conscious consideration of the learning process, instructors need a systematic approach to designing courses. Early in their careers, they often simply teach the way they remember being taught or adapt a colleague's course for their own purposes. They may also design courses based on a list of topics they think are important, rather than on learning objectives that indicate their expectations for student performance. If they do not clearly identify learning objectives, the activities they plan (lectures, discussions, in-class activities, etc.) may not actually teach the skills and knowledge they want their students to learn. At the same time, if assessments (exams, assignments, etc.) are considered an ex post facto means of measuring student performance, they cannot be used constructively to enhance learning.

Successful course design begins with asking who students are and using this knowledge to help design instruction. Designing effective courses involves three key components: (1) articulation of course objectives; (2) the creation of instructional/learning activities; and (3) the design of assessments. An instruction-design triangle (Figure 1), a simple illustration of a complex process, can provide a framework for thinking about teaching and support effective course design.

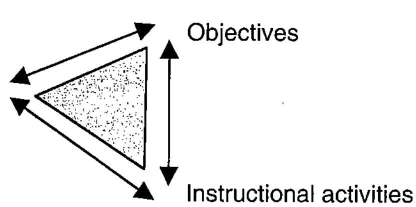

FIGURE 1 The instruction-design triangle.

Objectives refer to the knowledge, skills, values, and attitudes an instructor wants students to acquire by the end of the course. For example, an instructor might want students to be able to apply basic circuit laws to analyze simple circuits that include resistors and capacitors or to build Karnaugh maps and develop Boolean expressions. An explicit statement of these objectives, using active verbs and focusing on demonstrable skills, serves several purposes. First, it makes students aware of the goal of the course and the discrete skills and bodies of knowledge they must acquire to get there. Second, the identification of learning objectives helps the instructor design appropriate assessments and instructional activities that will help students realize those objectives.

Instructional activities include contexts and activities that encourage active engagement in learning. Research on cognition clearly indicates that students learn best by doing—by identifying types of data, formulating problems, discussing alternatives, weighing options, choosing among formulas and tools, justifying decisions, and so on. They do not learn as well passively. Successful instructional activities must be closely aligned with learning objectives, thus enabling students to practice the skills they are expected to master.

Assessments characterize the tasks and contexts that enable students to practice, demonstrate, and extend their knowledge and skills. Effective assessments provide both faculty and students with timely, systematic feedback on individual and group performance. Optimally, assessments not only measure student achievement (at the end of a learning experience), but also enhance student learning throughout the learning experience by enabling them to revisit concepts or practice their skills. Like instructional activities, assessments must be closely aligned with learning objectives so that the skills and knowledge students are working to achieve are reinforced simultaneously at multiple levels.

Each component of the triangle is directly connected to the other two; the relationships between them are direct and bi-directional. That is, each component should influence and guide the development and implementation of the others. The learning objectives guide what is assessed, and what is assessed guides the development and implementation of instructional activities. Many educational researchers agree that a close alignment of these three elements results in deeper and more meaningful learning (Gipps, 1999; Pellegrino et al., 1999; Snow and Mandinach, 1991; Stiggins, 1997).

Conditions Necessary for Change (Question 3)

For engineering faculty to become more effective educators, they must acquire skills and knowledge about students, learning, and effective instruction. At the same time, they must prepare students to function in a rapidly changing world. Students must understand global issues, function in interdisciplinary and cross-cultural contexts, engage comfortably with diversity, work effectively in teams, have strong written, oral, and visual communication skills, incorporate ethics into their professional lives, and so on. The only way students will be competent in these skills is if they are embedded in courses and curriculum in the context of engineering. In other words, faculty must change not only how they teach, but also what they teach. They must be committed to ongoing reevaluations of course designs as students change, the world changes, and our knowledge of learning evolves.

Clearly, this is asking a lot of faculty, whose time and energy are already stretched thin. In our experience, young engineering faculty genuinely *want* to improve their course design and teaching skills. However, because of overwhelming pressure to write grants and publish, along with committee responsibilities and other demands on their time, they often give teaching short shrift. The will is there, but the time, resources, and rewards are not.

Thus, improving engineering education will require not only a commitment on the part of faculty, but also significant support, resources, and recognition on the part of the university. First, engineering faculty members will need help to access the types of information discussed in this paper and support in adapting their courses to align with what we know about students, the learning process, and the changing world students will enter. Second, and perhaps most important, administrators must recognize the complexity and sophistication of good teaching, acknowledge the time and effort required to teach well, provide the resources necessary to prepare faculty appropriately, and give high-quality teaching greater recognition in the academic reward structure.

Conclusion

We can now review the three questions we initially posed. First, is there a widely perceived need for reforming engineering education? The answer is a resounding yes. Second, what would the necessary changes entail? We have provided a brief glimpse into the knowledge and skills necessary to create and teach effective, innovative courses. We hope we have conveyed that teaching is a complex process, learning is an even more complex process, and the human beings involved in teaching and learning are the most complex of all. Educating students is challenging, exciting, frustrating, unpredictable, and satisfying, often all at the same time.

Third, what are the necessary conditions for change at the institutional level? Faculty deserve to be better equipped to meet all of their responsibilities, and students have a right to expect their education to prepare them to function as effective engineers. If we expect engineering faculty to move from "well intentioned gifted amateurs" to expert teachers, we must recognize that expertise requires a large body of well organized knowledge and deliberate practice. Developing teaching expertise takes commitment, time, focused resources, and recognition in the reward structure. We know the conditions required for meaningful change in engineering education. The final question is: Will we provide them?

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