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Engineer Morphing: Bridging the Gap Between Classroom Teaching and the Engineering Profession*

AMIN ELSHORBAGY
Kentucky Water Research Institute, University of Kentucky, Lexington, KY, 40506-0107, USA

DIETER J. SCHÖNWETTER
University Teaching Services, Centre for Higher Education Research and Development, University of Manitoba, Winnipeg, Manitoba, R3T 2N2, Canada. E-mail: schonwet@ms.umanitoba.ca

Teaching engineering is a highly significant task. Engineering is not a self-taught discipline; it requires supervision, guidance, and instruction. This paper discusses some of the main features of current engineering education in many institutions and its challenges. A number of suggestions are provided to enhance the engineering education process. These include the importance of teaching communication skills, broadening the students' perspective with the ethical issues of engineering, and implementing the inductive instruction technique as an effective approach for teaching engineering. Suggestions are also given regarding assessment of the performance of engineering students.

INTRODUCTION

TEACHING ENGINEERING is a highly significant task. In fact, its significance has been documented over the last two or more decades by a number of new engineering journals that provide their readership with innovative ideas on the scholarship of teaching in engineering. These include the *American Society for Engineering Education*, the *Australian Journal of Engineering Education*, the *European Journal of Engineering Education*, the *International Journal of Engineering Education*, the *Global Journal of Engineering Education*, the *Journal of the Learning Sciences*, the *Journal of Engineering Education*, and the *Journal of College Science*. As noted by one of the leading journals, the *International Journal of Engineering Education*, topics cover a range of teaching issues, including developments in educational methods technology, case studies, laboratory applications, new theoretical approaches, and educational policy. Based on the volumes of literature dedicated to effective teaching strategies in engineering, teaching engineering has become an important task.

This paper discusses some of the main features of the traditional engineering education still common in many institutions and its challenges. A number of suggestions are discussed using Kolb's [1] learning styles and Bloom's [2] cognitive taxonomy as theoretical frameworks, to enhance the engineering education process in these traditional classrooms, specifically as it relates to developing critical skills that are relevant to the engineer's workplace. This includes the importance of implementing the inductive instruction technique as an effective approach for teaching engineering. Recommendations are discussed regarding the assessment of the performance of engineering students that more adequately reflects an engineer's mindset in the workforce.

Even though a variety of innovative teaching techniques are available to engineering instructors, the education of engineers in many colleges and universities still follows the traditional lecture format. Ironically, those who are adopting the new teaching techniques are the ones most likely to read the aforementioned journals, whereas those still following the traditional teaching format tend to be unaware of these resources or, even more disheartening, are not motivated to make changes to their teaching styles. Regardless of the reasons, more systematic attention should be directed toward the teaching and learning processes of engineers. Currently, a gap exists between the present education of engineers and the expectations of their roles in the engineering workforce [3]. Many engineering graduates have difficulty making the transition from school to employment. The roles expected in the workforce are often foreign to many recently graduated engineers.

CONNECTING LEARNING STYLES WITH ENGINEERING EDUCATION

Learning is a continuous process [1]. It is also the source of knowledge. Knowledge is the driving force behind the growth of sciences and intellectual endeavours, which in turn makes the development

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of modern technology possible [4]. The ability to learn may be one of life's greatest joys, fed by the inborn curiosity of the human mind. Schools should sustain, cultivate and enrich this invaluable feature of human nature. The ultimate purpose of most educational effort is to stimulate the desire to learn and to discover how to look for novel and original ideas to help solve the endless flow of incoming problems of modern life. The fulfillment of this purpose is essential in the training of future engineers. If academia does not fulfill this purpose, then the education system has failed engineers.

Cognitive value of the learning cycle should be carefully analyzed and the teaching techniques adjusted to suit the particular phases of the cycle. One such possibility is offered by the work of Kolb [1], who identified four principal learning styles or types. Kolb's theory has been developed for the purpose of teaching engineering and has been successfully applied to various engineering teaching situations [3, 5].

Creative versus passive learning. According to Kolb [1], the learning cycle consists of four quadrants, each addressing one of the four main questions that engineering students are required to apply to most engineering problems. These include *Why?*, *What?*, *How?* and *What if?* Each of these four quadrants is examined below and the learning cycle is applied to the teaching of engineering students.

The purpose of the first quadrant, or the *Why?* question, is to establish a 'feel' for the subject and its significance. Furthermore, it provides a foundation for the formal information about engineering concepts as they are presented in class. During this first phase of the learning cycle, students' motivation to learn about a new topic is critical. In order to accomplish this goal, instructors are encouraged to generate enthusiasm for the new material by modeling it during the presentation. Various techniques can be used. Probably the most effective strategy is to relate the new concept to an existing real-world problem. For instance, a lecture on the significance of the strength of steel is introduced by a 30-second highlight from the movie *Titanic*. The lecture might begin with the question *Why* the disaster? By doing so, the instructor's role is seen primarily as that of a *motivator* who personalizes the material, bridging a connection between the theoretical and the practical, and thereby inspiring the student to learn.

In the second quadrant, students find answers to the question *What?* At this stage, students are given an opportunity to familiarize themselves with the facts. The instructor ideally focuses on providing information to the student, organizing and integrating new material, and allowing time for thinking and reflection. Concrete examples should be provided to illustrate the abstract. Referring back to the *Titanic* example, instructors can initiate Kolb's second learning phase by asking students to reflect on the composition of the steel used in the *Titanic* and to compare it to the steel used in current ship manufacturing. This would be followed by the question, *What caused the demise of the* Titanic*?*

The third phase of Kolb's learning cycle is characterized by a search for answers to the question *How?* Students process information by applying it and, ultimately, by finding the answers to the question, *How does it work?* The objective at this stage is to gain some experience with the material being taught. Students might be encouraged to conduct simple tests on different types of metals to simulate the *Titanic* structure. Computer programs are also available whereby students can create simulated models and test them against simulated perils or disasters such as icebergs. Specific objectives include providing opportunities for students to apply the new information, helping them to develop problem-solving routines, and finally eliminating fear of failure by reassuring the student that the trial-and-error process is an essential part of learning, just as it is a vital part of any discovery. Unfortunately, teaching in this manner often runs counter to many well-established learning paradigms in academic institutions, where failure usually translates into penalization of effort through lower assignment or test scores. Despite the rigid requirements imposed by the traditional system, the student should still be encouraged by the instructor to look at his/her own mistakes as necessary 'stepping stones' leading towards mastering the material [6]. There is considerable value in going through the process of making a mistake, correcting it, and learning from the process [3].

The fourth and last phase of Kolb's learning cycle centers on the question *What if?* Borrowing from computer science, this part of the learning sequence could be re-labeled the 'post-processing' phase. Here the emphasis is placed on self-discovery, where students seek to apply the material and the acquired 'tools' to their own lives and to real-life situations. The students enter a realm located outside the formal world of education in which they themselves attempt to use the information and the procedures learned in the classroom. This is the point where students learn how to handle components as parts of a system [7]. To initiate such a self-discovery process, the ideal instructor provides space for students to share their discoveries and evaluate their performance. Using the example of the *Titanic*, the students would have the opportunity to create new composites of the steel and test them against the composite structure of steel used on the *Titanic.* Students could then transfer their findings to new problems associated with the strength of steel, as are frequently found in current news stories around the world. This process would begin to bridge the gap between the theories taught in engineering and real-life problem-solving, a crucial skill for engineers.

A natural progression from Kolb's self-discovery phase [1] is the process of sharing the findings with others. Dissemination should be encouraged as a vital part of an engineer's profession. Providing an opportunity for students to share their self-discoveries with others can potentially lead to further excitement in the process of learning. Not only is the student who is presenting his or her self-discovery excited, but also a degree of vicarious excitement may be transferred to the other students. In turn, this positive experience may enhance the student's confidence and help him/her conquer the fear of being ridiculed, which is common in many traditional schools of engineering. As a result, the student may enjoy the true rewards of the learning cycle [3].

If engineering students are taught according to Kolb's model, they will have the opportunity to develop what is called *creative learning* [1]. After receiving information, understanding it, asking questions, and going through the trial-and-error stage, students develop their own processed version of the material they have been taught. They are also more likely to take ownership of the learning enterprise and become more motivated to pursue engineering careers [8]. Moreover, students can retain this knowledge for longer periods of time and apply it to different cases and in different situations. This is ideal for the training of future engineers.

The outcome of such a system of motivational education will be different from the traditional, mostly passive, type of learning, where no rewards await the learner at the end of his/her tedious academic endeavours. Students should feel that sincere efforts to learn merit reward, rather than the current norm of *more thinking, more trials, more writing, more mistakes, and less marks*.

CONNECTING TEACHING TECHNIQUES WITH ENGINEERING EDUCATION

A variety of teaching techniques are used in the engineering classroom. These include the traditional lecture or deductive instruction, discussion or facilitative instruction, and the reverse lecture or inductive instruction. Each of these will be discussed in conjunction with impacting student learning.

Deductive instruction

The most prevalent form of teaching is still the traditional lecture, or deductive instruction, where the instructor is viewed as 'the sage on the stage'. Often seen as the most efficient method of communicating knowledge to a large number of students, this format of instruction is the least effective in promoting learning. According to research, students tend to remember 70% of the first 10 minutes of content, but only 20% of the last 10 minutes [9]. Although the instructor has control over course content delivery during the class period, this method results in the lowest retention of content material in comparison to the other methods of learning, as seen in Fig. 1 [10]. Students are not as likely to be actively engaged in this type

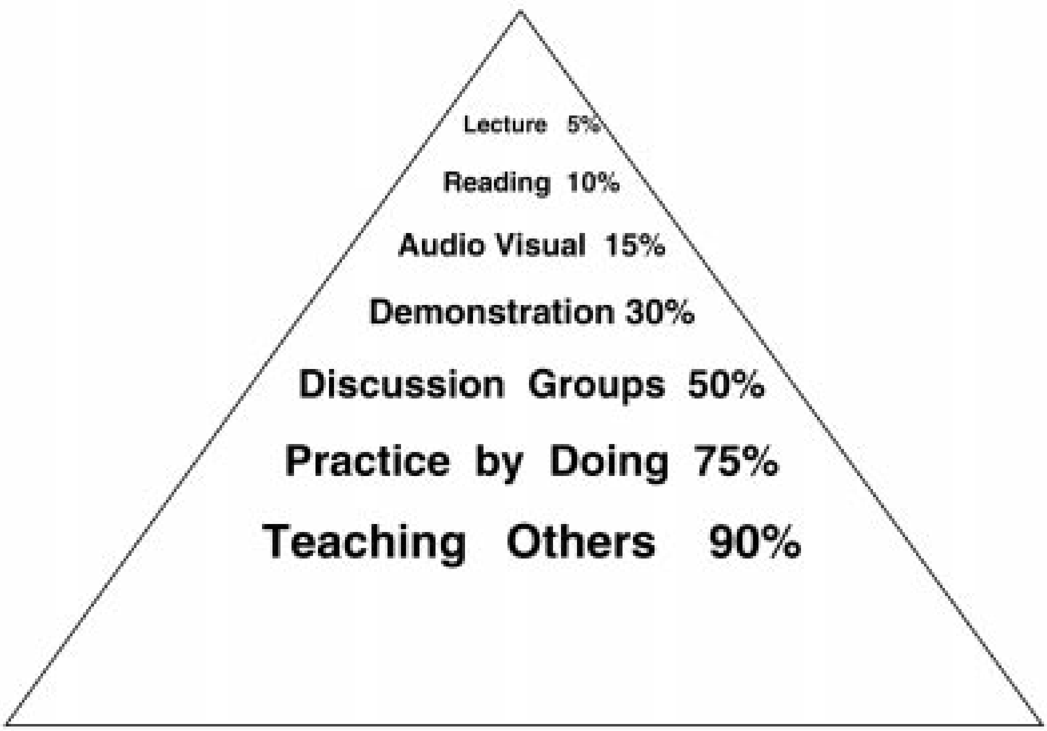

Fig. 1. Increasing student learning as a result of teaching technique (adapted from Biggs, 1999).

of learning, given the one-way flow of information, and are therefore less likely to benefit.

Facilitative instruction

Facilitative instruction requires the instructor to become 'the guide on the side'. The instructor facilitates the discussion while the students generate the content. Students are more engaged in this process and tend to feel more ownership of their learning. As seen in Fig. 1, discussion drastically increases the amount of content retention in comparison to lectures alone. Although very effective, this teaching technique is more challenging to adapt for engineering classes. Engineering education requires the learning of significant amounts of technical information, which often precludes the use of the discussion technique. However, this technique could be used in a few situations to generate interaction between students in the class and to help them express their understanding of a subject. For the instructor, this technique reveals the different capabilities and oral communication skills of the students.

Inductive instruction

The third type of teaching technique, inductive instruction, is highly suitable for teaching engineering. Grounded in the theory of constructivism [11–13], the learner is at the center of the learning process, developing his/her own understanding of the way the world works. The instructor assumes a facilitating role, assisting students in learning how to obtain knowledge, while students assume responsibility for their own learning [14]. The focus of classroom learning is on concept development, thorough understanding, and construction of active learner reorganization [15]. McDowell [16] demonstrates the effectiveness of this process when teaching engineering students about soil mechanics. As seen at the bottom of Fig. 1, this form of instruction substantially increases a student's retention of content material. The instructor guides the students to discovery of the abstract, such as principles, laws, theories, concepts, by providing and soliciting examples and asking probing questions. The process moves smoothly from the specific concrete example to the general abstract. For instance, the instructor begins with simple examples that students understand and discuss. The students are encouraged to build or develop the theory or the concept that is being taught gradually. Once students understand the abstract concept, the instructor can proceed by deductive instruction. This practical way of combining deductive and inductive instruction techniques has the potential to be an efficient way of teaching engineering.

CONNECTING STUDENT ASSESSMENT WITH ENGINEERING EDUCATION

Quizzes, assignments, term projects, and exams are the formal means of assessing the performance of engineering students. However, many of these are designed without any theoretical foundations. Thus, many instructors are unaware of what level of understanding or critical thinking students have attained in their classes. One of the best strategies is to develop assignments based on some sound theoretical framework that allows one to test the different levels of student cognition.

Bloom [2] provides one way to develop assignments, quizzes, projects, and exams that provide the instructor with a means of assessing varying levels of learning. According to Bloom [2], cognitive development spans across a continuum, beginning with the acquisition of new information or knowledge and ending with the evaluation of complex thought. As seen in Table 1, this process includes six stages. Students tend to advance cognitively from their very first class through to graduation, beginning with concrete ideas and ending with abstract ideas. For knowledge to be transferred from the instructor to the student, many instructors follow Bloom's cognitive taxonomy. They design their courses and even their assignment and test questions to reflect these developmental stages. For instance, many introduction courses in engineering focus on Bloom's first three stages:

- basic knowledge of engineering principles and facts;
- comprehension of the various theorems; and
- the ability to apply the material to various real-life situations.

As students progress in their training, they may be required to perform at higher levels of Bloom's taxonomy. A second-year student may be expected to analyze certain properties of a given alloy. A third-year student would be required to analyze two or more existing designs and synthesize them into a new structure. A fourth-year student would be able to evaluate the basic properties of a given compound. By structuring the assessment instruments on Bloom's cognitive taxonomy, instructors are able to determine the level of understanding that students have achieved as a result of completing the course.

SUMMARY

A number of important features of engineering education have been reviewed and presented in this paper. Kolb's [1] cycles of learning, along with the major questions that need to be addressed during the education process, have been discussed. Two important aspects of effective engineering education have been mentioned. Firstly, the inductive instruction (reverse lecture) technique has been highlighted in this paper as an effective method for teaching undergraduate engineering students. Secondly, the performance of engineering students

Table 1. Levels of cognitive development (adapted from Bloom, 1956).

Level	Process	Type of Performance
	Abstract	
6. Evaluation	↑	Capable of making a critical judgment based on internal and external criteria.
5. Synthesis		Capable of accomplishing a personal task after devising a plan of action.
4. Analysis		Capable of identifying the elements, relationships, and organizational principles of a situation.
3. Application		Capable of remembering knowledge or principles in order to solve a problem.
2. Comprehension		Capable of transposing, interpreting, and extrapolating from a certain body of knowledge.
1. Knowledge		Capable of recalling words, facts, dates, conventions, classifications, principles, theories, etc.
	Concrete	

should be carefully assessed in different ways, taking into consideration Bloom's [2] cognitive taxonomy to provide information about the different levels of learning that the students have achieved. By applying each of these ideas, engineering education can more successfully bridge the gap between the classroom and the engineering profession.

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Amin Elshorbagy is a postdoctoral scholar at the Kentucky Water Research Institute and the Tracy Farmer Center for the Environment, University of Kentucky. He received his B.Sc. degree in Civil Engineering from Ain Shams University, Cairo, Egypt, in 1989, his M.Sc. degree in Environmental Systems Monitoring and Analysis from ITC, the Netherlands, in 1994 and his Ph.D in Civil and Geological Engineering from the University of Manitoba, Canada in 2001. He has a Certification in Higher Education Teaching (CHET) from the University of Manitoba.

Dieter J. Schönwetter is the Associate Director of University Teaching Services, an adjunct to the Faculty of Education and the Department of Psychology, and is a faculty development specialist. As a social psychologist, he specializes in the social dynamic interactions between effective teaching behaviours and university student learning outcomes, particularly focusing on helpless and oriented students. Since joining the University of Manitoba in 1999, his primary responsibilities are for faculty development of future professorates, coordination of the first-year experience of 1,200 of the 4500 first-year students, graduate training, and research.