Experience-Based Instruction in Engineering Education

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Students mature during their engineering education moving from being a student of science and technology to becoming an apprentice engineer. This process will occur regardless of the practical experience held by the engineering faculty. However, maturation may be deepened by the apt use of experienced-based instruction (EBI). This paper examines the usefulness of engineering experience as a teaching tool.

Assessment of student readiness and receptivity should be considered in determining when to use experienced-based instruction. EBI can motivate the student by showing relevance of the topic and appealing to the student's sense of curiosity or adventure. EBI can broaden the topic by altering the "point-of-view" of the student. And last, EBI can allow the student to get a sense of what is expected from an engineer by his clients, employer, peers, and the public.

Deciding how to insert the engineering experience requires planning. Reading assignments, videos, web-based information, personal stories, role-playing exercises, simulations, games, and carefully crafted problem-solving exercises are tools that play a part in the delivery of EBI.

This paper discusses the use of EBI in a series of geotechnical courses offered to juniors and seniors at the US Air Force Academy (USAFA). The when and how issues are illustrated in four courses that include an introductory course, two required courses and a design elective. The success and limitations of EBI are examined with emphasis on when and how to insert meaningful, effective and appropriate EBI.

Introduction

A graduate of an engineering curriculum is expected to have the background, experience, and capabilities to begin a career in engineering. The new graduate will seek employment where he/she will work under the supervision of experienced engineers. The path to becoming an entry-level engineer is completion of an ABET-accredited curriculum. Within the curriculum a variety of opportunities such as lectures, labs, field trips, case studies, and projects are organized to permit the student schooled in the basics of science and technology to develop into an apprentice engineer. This paper focuses on incorporation of the teacher's engineering experience into his/her teaching style. The teaching style that is infused with lessons drawn from experience in engineering practice is called experience-based instruction (EBI).

All engineering instruction is to some degree experience-based. Experienced engineers know the skills needed by entry-level engineers. The engineering community influences the content of engineering curricula to ensure that necessary topics are addressed. The presentation of the instruction provides an opportunity to address more than facts, principles, and methods of analysis and design. The introduction of engineering practice experience into the delivery of engineering instruction can assist and enrich student development. The teacher should understand when and how to bring his engineering experience to bear on the teaching process.

Experience-Based Instruction (EBI)

Students hunger for real life examples. The examples are expected to entertain while carrying a useful message. Engineering is an apprenticeship profession. The student cannot attain licensure until sufficient experience is gained under the supervision of a licensed engineer. The immersion of the apprentice into the atmosphere of engineering practice will allow the apprentice to learn directly from his own experience and observe the actions of experienced engineers in the accomplishment of engineering work. This immersion can begin in the classroom.

EBI can provide a concrete example of the topic-at-hand which may ultimately be useful to the graduate engineer in the workplace. The selection of the example is based on the experience of the instructor. The instructor must create EBI that is relevant and introduce the EBI with appropriate timing to produce a memorable exercise for the student. Students are most likely to respond positively to EBI when they believe in the instructor's expertise and the setting, details, and the moral of the story are set forth in clear, concrete fashion.

EBI Topics

Teaching must aim toward giving students insight into the process of engineering and the practice of the profession of engineering. Process issues such as problem definition, selection of analysis methods, limitations of analysis, quantification of information, and consideration of societal values can be addressed through EBI.

Practice issues include expectations of clients, peers, the public and employers. These expectations are related to the concept of "standard of care" for the practice of engineering. The expectations can be illustrated for a variety of engineering tasks such as design, inspection, forensic analysis, and business practice. Ethical engineering practices relate to the duty owed by the engineer to each of the parties: clients, peers, the public and employers.

Discussion of EBI examples is essential to the development of engineering judgment. An adage states, "To the beginner there are many choices, to the master there are few." The master recognizes the fundamental issues at hand due to his experience whereas the beginners may not be able to formulate the problem, let alone proceed towards an answer.

Transforming Experience into EBI

How to create effective EBI is the subject of this section. The teacher recasts his engineering experience in an exercise that enables the student to live through, react to, and internalize the lesson. The engineer provides the content of the experience from his past. Placement of the content in an effective form to deliver as EBI requires that the engineer place the student in stage center.

EBI Tools (Re-creating a personal experience)

Effective EBI is largely dependent on two factors: (1) whether or not the learning activity is in the 1^{st} person, and (2) how much personal responsibility is tagged to the outcome of the activity. Experiences can be related to the "person," in which the experience was gained, i.e., 1^{st} person, 2^{nd} person (second hand), and 3^{rd} person (documentary).

The emotional impact of the experience is the aspect that makes it "real." Strong emotions produce strong memories. The further the experience is distant from the 1^{st} person, the more the impact of the experience is diminished. For example: I was in a car wreck (1^{st} person); I witnessed a car wreck (2^{nd} person); I read about a car wreck (3^{rd} person).

Traditional tools of experience-based education involve laboratory work, field trips, science projects, and experimental demonstrations. Each of these activities is strengthened by the emotional values associated with a sense of responsibility for the work and the physical nature of the work itself. Other EBI tools include role playing and topic-relevant games.

The role of the individual student in the activity determines the "person" of the experience for the student. A student performing a lab experiment, presenting a demonstration, doing field work, role playing, or playing a classroom game is participating in a 1^{st} person experience. A student listening to a classroom story or watching a demonstration is engaging in a 2^{nd} person experience. Reading a case study is an example of a 3^{rd} person experience.

A student functioning within a group activity may have any of the 1^{st}, 2^{nd}, or 3^{rd} person points-of-view depending on the role of the individual within the group. For example, the group leader is likely to have a 1^{st} person experience. A committed and involved group member may also have a 1^{st} person experience, while a pure observer may have a 2^{nd} person experience. Nominal participants may be so remotely involved that the exercise has the impact of a 3^{rd} person experience. An instructor can attempt to raise the overall level of commitment and involvement within the group by making the grade outcomes contingent on a summary or presentation that must be given by a group member who will only be chosen at the conclusion of the activity.

When and How to Use EBI

There are three setting for EBI, each with its own purpose. EBI can be used to create readiness, deliver content, and to summarize. The introduction of a topic must create interest and provide a setting for the presentation of content. EBI can effectively be used to introduce material. *Introductory EBI* can provide relevance and inspire curiosity, laying the groundwork for *content EBI*.

Content EBI allows the student to perform design or analysis in a setting where guidance and feedback can build student capabilities. And last, *summary EBI* can be used to conclude instruction and test student comprehension of material.

Each type of EBI must address the course objectives. Course objectives guide the instruction. Two guiding principles of EBI are to support the course objectives and aim to include 1st person activities. Second and 3rd person activities are worthwhile, but they are most effective when they serve as the basis for a follow-on 1st person activity. Examples of each of the three types of EBI are illustrated in the geotechnical courses taught at USAFA.

EBI in the Geotechnical Courses

EBI has been used in four courses that are part of the geotechnical sequence in our civil engineering curriculum. The courses are junior and senior level. The course titles are listed in the table. This section describes some of the EBI tools that have been presented in each of these courses.

Geotechnical Courses
Civil Engineering Practices
Soil Mechanics
Foundation Engineering
Pavement Design

Civil Engineering Practices

The civil engineering curriculum has a required course with a curious philosophy described by the course motto: BUILD FIRST -- DESIGN LATER. The course is composed of about 120 class hours taken in the summer after the sophomore year. Most of the instruction has been presented out-of-doors at a non-traditional field laboratory where the students engaged in a wide variety of activities such as wood framing, heavy equipment operation, surveying, concrete beam construction, and asphalt paving. The course is entitled civil engineering practices. Most of the activities involved 1st person "hands on" EBI. These activities introduced the students to a variety of construction practices, providing experiences that can be recalled when learning concepts in the design courses during the junior and senior years. Only the geotechnical activities are discussed. These field activities were held at a facility named the Field Engineering and Readiness Laboratory or FERL.

The geotechnical activities included soil exploration with a boring machine and hand auger, Proctor testing, sand cone density testing, earthwork operations (operation of a scraper and smooth wheeled compactors). As mentioned, these FERL activities formed the basis for instruction in follow-on courses. The students classified some soils during the soil mechanics course that they first worked with during the FERL course. Students that enrolled in the foundation design course returned to the FERL site to perform the Standard Penetration Test (SPT) with the drill rig that they saw demonstrated during FERL about one year earlier. These activities were 1st person EBI that are enthusiastically praised by our students. The EBI was primarily *content EBI*.

Soil Mechanics

Most students enroll in the soil mechanics course in the fall semester immediately following FERL. The students worked in the laboratory with the same soils that they had excavated, transported and compacted at FERL. Most students found the experience of using the FERL soil in the follow-on soil mechanics course helpful to the learning process.[3]

Compaction principles and specification of compaction were presented within the soil mechanics course. At the conclusion of the presentation of this topic the students were given a compaction curve and a set of compaction test results. They were asked to determine whether the compaction had been adequate or not in accordance with the specifications. The results showed that the compacted soil did not meet the required dry density and the soil was wet of optimum and close to the zero-air-voids line. Then, a role-playing exercise began.

The instructor posed as the earthwork contractor and asked the students if compaction passed. The students usually correctly evaluated the results and informed the instructor that the test failed. The instructor asked why and they explained that the soil needs a higher dry density to pass. Then the instructor asked what he, the earthwork contractor, should do. They thoughtfully provided the contractor with some well-considered advice. The contractor thanked them and promptly did as they suggested. The contractor asked them to test it again and the instructor provided results for another failing test. The instructor, resuming his role as contractor, asked if the second test passed and they informed the contractor that the test failed. At this point the contractor exploded telling them, "I did exactly what you told me to do. Why didn't it work? What am I supposed to do now?"

After a short period of tension, the instructor resumed the role of teacher and asked, "Should you, the inspector, have offered the compaction advice? What were your responsibilities and what were the responsibilities of the compaction contractor? After some discussion the instructor explained that the role of an inspector is limited to reporting the results of the testing. The inspector is not to offer advice or recommendations. The contractor has indicated that he was qualified to perform the work or he should not have been awarded the contract. Discussion continued about the responsibilities of contractors performing the work, quality control inspectors verifying the work, and the owner's quality assurance personnel executing oversight of the construction process. This *summary EBI* tested the students' understanding of the engineering practices of compaction quality control and quality assurance.

Near the end of the soil mechanics course the topic of bearing capacity was introduced and a homework problem from the text was assigned that had a footing installed at a depth 4-ft below the ground surface and 2-ft below the groundwater table. The students were asked to determine the allowable bearing capacity and they plugged-and-chugged an answer. The next question asked the students to describe how they would construct the footing. This construction question was not drawn from the text. Many students were confused and asked for additional guidance about the question. Others searched the text in vain to find some paragraph to quote. Some did not see the significance of excavation below the water table. Others who noticed the water table wanted to avoid the situation and either claimed that no one would place a footing in this position or else they wished to place the footing on the ground surface. The class discussion called on the experience of students who had observed structures that had been constructed on flood plain or coastal plain or other wet area.

The instructor explained that the nature of the soil determines the type of actions that are required to construct the footing. The instructor discussed the relative ease of creating a stable excavation in clay and the possible actions needed to cope with the instability of an excavation below the water table in sand. The student needed to view the problem as a practical exercise in problem solving rather than an exercise in algebra. The students had worked with both clay and sand in FERL. As with the compaction EBI, this *summary EB*I concluded the instruction and made clear to the student that analysis is intended to allow the engineer to make recommendations that support field activities such as construction, maintenance or repair.

Foundation Engineering

The foundation engineering class used *introductory* and *content EBI* to prepare students for every submission. The class was couched in a role playing environment. The students were entry-level geotechnical engineers and the instructor was the supervisor.

The instructor talked about the business of geotechnical engineering. The class was small having 10 students, and the instructor assigned each student a title such as supervisory engineer, project engineer, lab manager, engineering technician, driller, drill helper. Each student was allocated an annual salary appropriate to the title. The salaries were totaled and multiplied by a factor of 3 to represent the gross income that the firm required to stay solvent. The total was about 1.5 million dollars. We as a class observed that we had to bring in about $30,000 of work per week. We must prepare proposals for 2 to 3 times this amount of income. We discussed unit costs, the cost of an hour of engineering work or 1 day of drilling. We discussed the likelihood that our competitors have similar unit prices. We concluded that our costs are similar to our competitors and so our cost estimates will be similar to our competitors. The instructor asked, "How can we ensure that we will be successful in securing work?"

A student suggested that we do the work for a lower cost. How? The students usually suggest that we charge less – reduce our profit. We discussed the definition of profit and saw it as "return on investment." We recognized that profit was not merely difference between our income and the salaries or other labor, material, or indirect expense. We must always cover our expenses or we will not survive as a business for long. We eventually discovered "underscoping," that is, using fewer borings, less testing or analysis time or some combination of these items to allow our firm to complete the work for less cost than our competitors. The discussion continued into our responsibilities to our client. The instructor introduced the concept of "standard of care" and explained that failure to exercise the appropriate "standard of care" is negligence.

Pavement Design (Maintenance)

The pavement design course included a section on pavement management. The instructor had the students play a game in teams. The intent of the game was to provide an experience in management of a pavement network. A board was laid out with 3 sections. The board sections were labeled good, marginal, and poor. Ten plastic tokens representing road segments were distributed in the board according to the present condition of the pavement. The students were told that in a cycle each pavement segment will deteriorate one category; good becomes marginal, marginal becomes poor, and poor remains poor. The students were given ten gold tokens that represent money that can be applied toward pavement maintenance. A one token investment kept one segment from further deterioration for a cycle. Two tokens can be used to move a pavement section up one category; poor to marginal, marginal to good. Finally the students were told that at least 30 % of the segments must be in good condition, no more than 20% can be poor, and no particular segment can remain poor more than two consecutive cycles.

The students played the game for several cycles and then the instructor polled the teams asking if they were successful in their maintenance. The students very quickly discerned which strategies were successful and identified some actions that caused them to fail to maintain the segments up to the standards. The instructor asked if they could be successful if they had received fewer resources, that is, fewer gold tokens. Also, they were asked how many gold tokens would be needed to improve the system to have no poor segments. Again, the students quickly figured how to "game the system" to meet the minimum criteria.

Then the instructor asked the students to identify the key elements of the game. Here, the students needed guidance in recognizing that they needed an inventory of present condition, a deterioration law, maintenance repair cost schedule, and some criteria to define success and failure. Frankly, the students did not recognize the four elements were interrelated. A brief writing assignment was added to have the students explain and evaluate the interrelationships. The game was *introductory EBI* that was intended to stimulate interest in the topic and provided insight into the data needed to make maintenance decisions..

In summary, the geotechnical courses included *introductory EBI, content EBI,* and *summary EBI*. Often EBI could serve more than a single use rather than be purely *introductory, content*, or *summary EBI*. In the case of the maintenance game, the EBI served to introduce the issue of maintenance philosophy and the EBI provided content concerning the essential information needed to make maintenance decisions.

Effectiveness of EBI

Determining the effectiveness of EBI is important, but evaluation activities will only be discussed briefly. One measure of effectiveness can be taken through conventional testing activities. Another set of measures is the response of the students. EBI increases student attentiveness. The students ask more questions than they do during traditional lecture format and the questions are insightful. The students respond to the questions spontaneously or with minor prompting. The students ask questions about EBI after class more often than they do after traditional instruction.

EBI stimulates students to think in ways that bear on the development of engineering judgment. The educational domain terminology developed by Bloom[1] regarding the taxonomy of education is useful and now widely-used. The framework offered by Bloom consists of three domains: cognitive, affective and psychomotor. Traditional teaching methods emphasize the cognitive domain. Engineering judgment is high order thinking that includes application, analysis, synthesis, and evaluation, the highest four of the eight categories in the cognitive domain. EBI can be tailored to include strong affective domain and psychomotor domain components as well. Specific inclusion of these two educational domains makes for a more lasting impression than instruction that is limited to cognitive domain activities.

Student response to EBI is often in the form of questions and comments. The questions ask for clarification, additional information, or advice. Questions like "What do you mean by unsatisfactory performance?" Or, "How are we supposed to estimate the settlement?"

Sometimes the students appear visibly confused, so the instructor asks questions. Typical instructor prompts include, "Do we have enough information to define this problem?" or "What is the first thing we need to do?" The process of answering these questions calls on higher order thinking skills.

The questions sometimes continue within the classroom at the end of class or follow-up questions via email. Also, the students offer comments about the EBI topic that they have either read about or experienced in another class. The students will sometimes share personal experiences that bear on the EBI topic. Often the sharing takes place in class and sparks a discussion among the students. This involvement with other students and with the instructor both in and out of class is a positive indicator of effective instruction. The recent studies conducted by the National Survey of Student Engagement[2] use evidence of such questioning and interaction to create *benchmarks* of effective educational practice.

A list of higher order thinking inferred from student questions is presented in the following table. The items in the table each bear on higher-order thinking that we hope to develop in students. The students do not use these terms explicitly but the instructor can recognize the thinking behind the student question or comment.

Inferences of Student Higher Order Thinking Drawn by the Instructor from Student Questions During and After EBI showed that the student:
discerns issues recognizes the limits of knowledge judges the appropriateness of specific analysis methods evaluates consequences recognizes ethical considerations communicates engineering recommendations supports engineering recommendations evaluates decisions

Summary

EBI was used with four geotechnical courses to stimulate student thinking and enhance the learning process. The emphasis was placed on 1st person activities. EBI was placed in each course to support the teaching of important course objectives. Three types of EBI, *introductory, content,* and *summary EBI* were described and illustrated. The specific EBI tool for each occasion was chosen by considering the readiness of the student to formulate and consider significant questions regarding the course material. No formal procedure is suggested to determine choice of the tool but the instructor should consider the type of student questions that he would like to prompt from the EBI.

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