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A Student Teaching-based Instructional Model*

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The rapidly changing engineering profession demands the education of life-long learners, individuals who can adapt and thrive through change and evolving disciplines. This calls for a dual emphasis in engineering education on process (thinking, integration, discovery, communication) and product (knowledge). Furthermore, instructors of engineering curriculum understand very well the adage 'one never really learns a subject until one teaches it'. The perspective and preparatory effort required in teaching builds strong discovery, integration, comprehension, and communication skills. An instructional framework invoking this adage while building process and product skills is presented. The student teaching model (STM) is geared towards student interpretation, synthesis, presentation, and discussion of content material. This paper presents the development of the STM instructional framework, with particular emphasis on the underlying cognitive principles. The field of cognitive psychology provides the foundation for the STM, yielding insight into why 'one really learns a subject when one teaches it'. Student and instructor feedback from implementation in an upper level undergraduate engineering courses is also provided.

INTRODUCTION

ENGINEERING EDUCATION must embrace a rapidly changing profession. The emergence of hybrid disciplines, the growth of systems engineering and interdisciplinary design, and the swift evolution of technology have refocused attention on the need for new educational goals in engineering education. Such a dynamic profession calls for the education of life-long learners, innovators who can adapt and thrive through change [1]. As a consequence, a dual emphasis on product (i.e. content) and process (i.e. discovery skills, problem solving, thinking, communication) is warranted [1, 2]. Reform in this regard has begun within the classroom where historically the traditional classroom protocol of lecture-style material dissemination has pervaded [3]. With research indicating that lecture may not always be the most effective mode of education [3–5], numerous educators have introduced more active, discovery-based, group learning activities [6–9].

The motivation for the student teaching model (STM) described herein stemmed from instructor frustration with the traditional lecture approach and the adage 'one never really learns something until one teaches it'. The lead author found it impossible to reconcile the professional call for engineers who are adaptive thinkers, effective communicators, and life-long learners with an instructional design, i.e. traditional lecture, that leaves much of the thinking and communicating to the professor and creates a vertical rather than a horizontal relationship between teacher and student. The lead author's frustration led to a partnership with a colleague and a study of the cognitive sciences in an attempt to develop a learning paradigm where both process and product are emphasized. Cognitive psychology places much of its focus on the learner, attempting to explain the human mental processes of memory, thinking, problem solving and decision making. It seemed that focused facilitation of student thought, problem solving, and communication would better meet the call for life-long learners than would the more traditional lecture approach. Further, instructors intuitively recognize that one learns more completely what one has to teach rather than what one simply hears or reads [10]. Discussion and teaching of content material results in much greater content retention than is achieved as a result of traditional lecture [11]. We surmised that a shared approach to instruction and communication of ideas would provide students with the depth of learning instructors have experienced for centuries. This effort resulted in the creation of the student teaching model (STM).

What follows is a discussion of the STM instructional methodology geared towards developing both process and product in the engineering classroom through fostering of student interpretation, synthesis, presentation, and discussion of content material. The salient cognitive issues underlying

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the STM, namely (1) what the learner does while learning and (2) the social context of the learning environment, are discussed in detail. Student and instructor responses to STM implementation in an upper-level undergraduate course are presented.

STUDENT TEACHING MODEL

The learning model strives to empower and hold accountable each student participant through the employment of a student teaching methodology. The STM was developed for use in a 15-week semester course that meets for 75 minutes twice-weekly; however, the authors surmise that the STM could be adopted in many course formats. Each week in a semester course, each student prepares to discuss four to six related issues within a general topic (the issues are assigned at least two weeks in advance). For example, in a civil engineering soil mechanics course within the general topic of clay soil properties, assigned issues might include:

- Explain the difference in mineral composition between clay soils and sand soils.
- Elaborate on the nature of the differences between clay mineral types.
- Explain how the Atterberg limits relate to clay-water interaction and why they differ across clay types.
- Discuss the relevance of Atterberg limits to engineering practice.

Prior to the class period during which their assigned issues will be discussed, students are directed to develop a knowledge base to address these issues using multiple references (e.g. textbooks, periodicals, Internet). They are strongly encouraged to collaborate with their peers and to consult the instructor for feedback and clarification during preparation. During class time, students volunteer or are selected at random to *teach* and *lead* discussions with their peers on one or more of the assigned issues. Each student must be prepared to teach every assigned issue. 'Student teaching' involves communication and discussion of the principles and relevant examples to an educated audience of peers and the instructor. The classroom environment is designed to be informal and non-threatening. Student presentation and discussion in any effective manner is encouraged (e.g. seated, at a chalkboard or overhead). The presenter is encouraged to ask/entertain questions of/from their peers and discuss difficulties encountered with their own understanding. Classmates, who also prepare to teach, are instructed to foster a discussion by offering their questions, personal interpretations, and additional examples.

The STM does not promote a lectured effort from students; rather, it is an active and directed discussion of each assigned concept involving all students and the instructor. The instructor's role is one of facilitator and resource, guiding the dialogue and instruction in a positive direction. The instructor also serves as moderator and evaluator, insuring that each student exhibits sufficient knowledge of the issues at hand. As facilitator, the instructor assumes a perceptive position, able to evaluate student comprehension, inject poignant questions, direct discussion, and provide clarification. Based on the instructor's evaluation of classroom activity, he or she can create targeted mini-presentations, question/answer sessions, individual and group exercises, and design problems to further student comprehension and address problems that arise. Generally, the first 75-minute class of the week is dedicated to student teaching and discussion with brief instructor interruption to clarify issues. Student teaching and discussion is continued during the second 75-minute session interspersed with planned mini-presentations and exercises.

A clear goal of the STM is to have students complete the course with a better understanding of the material. Equally important, the STM aims to improve student ability to:

- discover and process information;
- generate meaning;
- communicate effectively.

With this format, we believe that success (i.e. practical understanding of the discussed engineering principles; improved processing and communication skills) lies in the efforts of the students. Their work in and out of the classroom dictates the pace of delivery and depth with which material can be understood. This format is designed to take advantage of the responsibility and initiative traditionally exhibited by engineering students, empowering them to push the envelope.

Motivation is evidenced in the grading process. The instructor grades individual students each week based on their preparedness, participation, and performance as evidenced during class activity. Consequently, it is critical that the instructor aim for equal participation from each student and moderate activity such that students reveal their knowledge or lack thereof, of each issue. The instructor-determined grade reflects both technical aptitude and communication skill of a student. Students receive their grade and an explanation for the grade weekly. The students also grade themselves on their preparation effort and knowledge of the assigned issues. The instructor-determined grade and the self-assessment grade are averaged and constitute a significant portion of each student's overall course grade (40 to 50 percent has been adopted by the authors). The remaining percentage of the course grade is allocated to exams, homework, and projects.

COGNITIVE BASIS

Educational psychologists have long focused their efforts strictly on content when considering learning. This conceptualization has resulted in instructor composition of specific behavioral objectives (e.g. the student will be able to distinguish between) and development of lectures to present the relevant information. Students in this model are passive participants in the educational process. The roots of the adage 'one never really understands a subject until one teaches it' and thus the foundations of the STM, lie in cognitive psychology, a theoretical perspective focused on human thought, perception, memory, and problem solving. The cognitive paradigm emphasizes both process (i.e. how teaching and learning take place) and product (i.e. content), both of which must be nurtured in engineering education to meet evolving global demands.

Cognitive psychologists argue that what a learner remembers depends on what she/he does during learning [12, 13]. Craik and Lockhart [12] proposed differing levels of information processing—from superficial processing (e.g. checking for spelling errors; counting the numbers of *e*'s in a passage) to deep processing (e.g. rating the pleasantness of words in a passage; determining if a passage describes oneself), and purport that the deeper the processing, the greater the understanding. Anderson and Reder [14] among others, theorized that knowledge is encoded as a set of propositions (i.e. the smallest units of knowledge from which truth or falsity can by determined) varying in richness and redundancy. At the time of recall, memory depends on the subject's ability to reconstruct the knowledge from the subset of propositions that remain active. Reconstruction, in turn, depends on the richness of the original set and hence the amount of elaboration fostered during study [14].

Researchers have found that students deepen their understanding if material is connected to prior knowledge [15] and placed in memory (i.e. encoded) in multiple ways. One way is to generate examples that apply principles in slightly different ways than were initially presented. Students in classes using the STM have a much greater chance to tap into their prior knowledge base and generate examples of application than do students listening to an instructor's lecture. The STM instructor, in turn, has a much greater chance of gauging student understanding and creating examples relevant to the particular classroom discussion if s/he is listening and shaping discussion rather than controlling it. Personalization of the material by relating it to one's experiences has itself been shown to increase the depth to which material is learned [16]. Recall of knowledge is improved when information is digested at the analysis, synthesis, and evaluative levels of Bloom's taxonomy [17, 18].

Metacognition, the thought process of an individual during learning, ties directly to the depth of processing theory and to the foundation of the STM [13]. Research in reading, for example, has shown that excellent readers do more than follow text left to right and from top to bottom [13]. Proficient readers monitor their own comprehension, comparing and contrasting with the author's message. Their effort is strategic and conscious as they question, summarize, clarify, visualize, and associate. Effective teachers engage in a similar effort during preparation of new material. Effective teachers establish the proper chronology to material, assess their understanding of the material, and develop practical examples to promote student comprehension. Extensive and comprehensive metacognitive monitoring takes place during teacher preparation. The STM aims to increase the strategic and metacognitive effort of students by having them prepare to teach, and by having them develop the life-long learning and communication skills necessary in the rapidly changing engineering industry. Using the STM format, students spend significant time preparing, building knowledge, and applying questioning, monitoring, and summarizing strategies. Their effort, along with a belief that they can succeed, helps students become self-regulated learners [19]. Further, we believe the STM creates students with an ability to understand and control their learning [20].

Researchers in the cognitive sciences are also recognizing the importance of social interaction. Learning does not take place in a vacuum. In classroom and work settings, more advanced thinkers act as models for peers, showing them more sophisticated ways of interacting. Instructors in the STM act as models, shaping and expanding student thought. STM facilitators, we believe, have the best chance to expand student knowledge bases by meeting them where they are intellectually. The late Russian psychologist Lev Vygotsky called the area just outside an individual's cognitive reach her/his zone of proximal development [13]. According to Vygotsky, teachers and students in the classroom must connect here in order for learning to take place. We believe that by having students externalize their understanding in the classroom through teaching and discussion, teachers can connect with them in this zone, shaping not only their grasp of the content but also their thinking process development. Teachers offer feedback on specific content knowledge as well as more adaptive thinking skills, more effective communication skills, and more efficient ways to work within a group setting. This process knowledge facilitates development of a more capable engineer for today's work place.

IMPLEMENTATION

The student teaching format was adopted in Advanced Soil Mechanics, an upper-level undergraduate and graduate course offered in the School of Civil Engineering at the University of Oklahoma. The format followed during the 15-week course that met twice per week each for 75 minutes, was detailed above. The findings reported below are limited due to the nature of the evaluation (student surveys) and the sample size (11 students); however, they do lend preliminary insight into STM effectiveness. Of the 11 students enrolled, five were undergraduates and six were graduate students. Student feedback was obtained through completion of pre- and post-class surveys. Prior to the course, students were asked to quantify the following, based on their experience in other classes:

- the percentage of time they came to class with some level of understanding of the material to be covered that day;
- the percentage of time they felt competent, involved, or 'not lost' in class;
- the amount of learning accomplished due to in-class activity;
- the amount of learning from peers.

At the end of the STM-based course, each student was asked the same questions based on their experience in the Advanced Soil Mechanics course. Student responses are summarized in Figure 1.

Student feedback

The reliance on student discovery and the need for a developed knowledge base before attending class in the STM is evidenced by student response in Fig. 1a. As a result of entering the class with a knowledge-base, the frequency of student-perceived competency increased (see Fig. 1b). Frankly, we were surprised by the high percentages of competency from experiences in other classes reported by the students. Nevertheless, we believe the amount of time in the zone of proximal development increased during the student-teaching format.

We also believe that productive in-class discussion promoted by the STM facilitated peer learning. The relationships developed within the classroom also extended to learning outside the classroom. As illustrated in Fig. 1c, which is based on a scale from 1 (poor) to 10 (excellent), the STM promoted an increase in peer learning. According to student responses, the percentage of understanding attributed to in-class learning remained virtually unchanged (see Fig. 1d). We believe that the extensive preparatory effort required in the STM was responsible for this finding. More comprehensive analysis using a control group and larger sample sizes is planned for further analysis. When asked if the STM provided a better learning experience compared with traditional methods, nine out of 10 students present responded 'yes' with one student responding 'maybe.' When asked to explain, the following comments were offered:

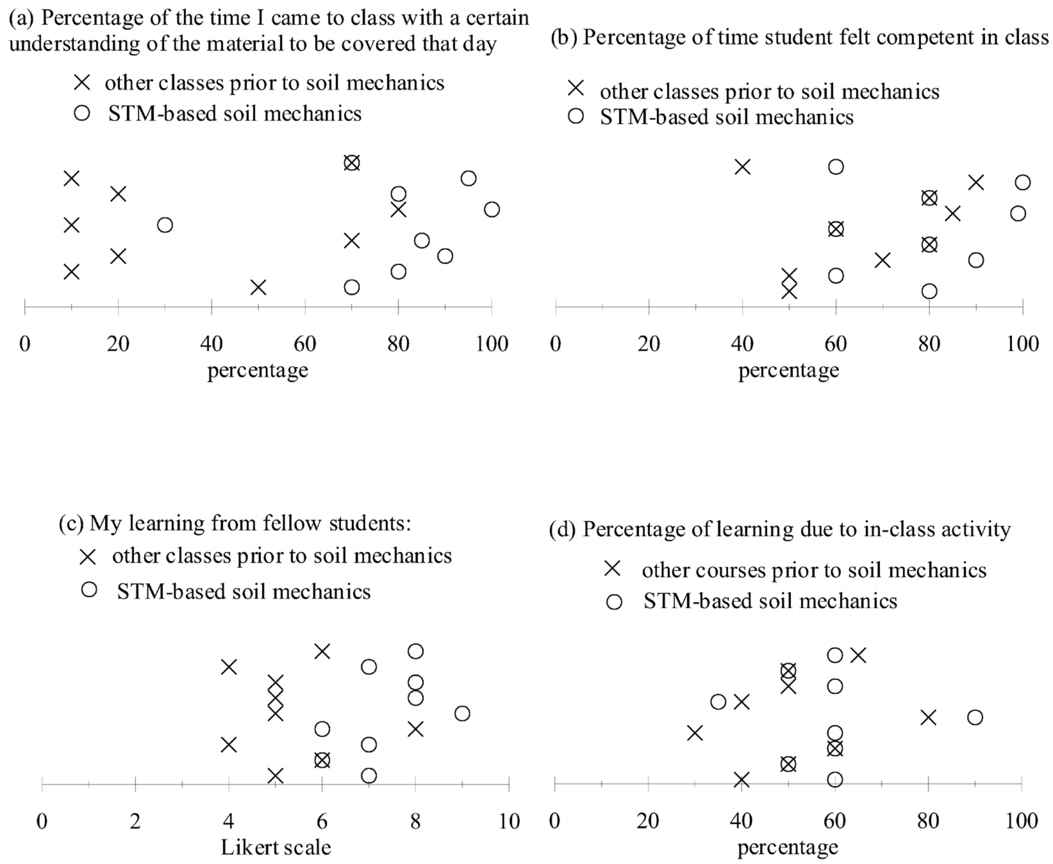

Fig. 1. Comparison of student response before and after STM implementation.

- 'With student teaching, you come to class prepared to teach but in other classes you don't worry about all this and you just go to class and take notes.'
- 'The encouraged self learning did help me to learn more, and made the material more interesting than the traditional lecture style.'
- '[Self learning/student teaching] does have positive results because it poses many questions in our own mind and we try to find answers on our own, and then finally discussing it definitely engraves it deep into our mind.'
- 'Coming to class with a good understanding of the material allowed me to absorb more during class and really strengthen my understanding of the material covered.'

The STM further allowed for slight improvements in student perceptions of oral communication and teaching skills from pre- to post-class surveys. Without a comparison control group it is difficult to quantify the improvement offered by the STM. As expected, understanding of specific soil mechanics concepts improved from beginning to end.

Students offered suggestions for future implementation of the STM format. One participant asked for more refinement:

- 'Often when students were asked questions or were asked to present a problem on the board, they looked to you (the instructor) for feedback instead of looking to the other students.'

The student added that the format did not always involve everybody. The comments speak to the importance of teacher facilitation. As the model is refined, it might be important to incorporate instruction in facilitation of group process. Training in leading counseling groups offers strategies for keeping the discussion relevant and allowing everybody a chance to participate.

Another student suggested that more 'complete' instructor notes be made available for study as part of the class. It is not known whether the availability of more detailed and pointed notes prior to class would promote or hinder meaningful student understanding. Student processing might be more focused, yet there is a danger of losing meaningful interaction with other resources (e.g. textbooks, periodicals, internet). We think that active and constructive involvement with course material may be diminished if students were handed detailed notes initially. Students may, however, benefit from notes between the time of student presentation and the follow-up sessions.

A final student comment involved the use of a format promoting 'depth' of processing:

- 'This course involves deep understanding. So, a self learning-student teaching and discussion-type class has helped us. But I feel this method wouldn't be successful in a vast and descriptive course.'

Interestingly, the instructor did not judge this course to be any less 'descriptive' than other courses offered in the civil engineering curriculum.

DISCUSSION

STM implementation in the Advanced Soil Mechanics course uncovered a number of important issues. Initially, the role as facilitator was uncomfortable for the instructor; relinquishing control of the classroom is dichotomous to an instructor's role during lecture. Students chosen to teach and lead discussion of a particular issue initially:

- took excessive time to teach points that were already clear to everyone;
- nervously fumbled through dialogue;
- struggled to both ask and answer meaningful questions of their peers.

Peers were initially shy to ask questions and probe in areas that were not clearly presented. Herein, facilitation of both the chosen student and peer actions was critical. After a few weeks of 'on the job training', each individual understood their role and felt comfortable with the classroom activity. The formulation of the pre-assigned concept issues was critical to the success of the STM. Issues that required higher level thinking skills, e.g. application, analysis, synthesis, evaluation, invoked far greater group interest, involvement, and discussion than issues that require recitation and paraphrasing. We found that the STM empowered the students and instilled a motivating sense of responsibility. Students were more engaged in their own learning, both in developing product knowledge and process thinking. The discovery learning undertaken before class promoted student collaboration, personal interest in the material, frequent questions, and, to our delight, greater student and teacher anticipation for class time than in courses where the STM was not used. Class activity involved valuable discussion, reasoning of unclear issues, and clarification of misconceptions that are often developed during discovery learning. It was important to provide incentive for the students. We found that attaching 50% of each student's course grade to his or her preparation and participation during class was substantive motivation. Allowing self-grading further empowered the students. We found that self-grading usually matched the grade assigned by the instructor.

We believe this initial implementation of the STM was a beneficial first step in our efforts to improve engineering education. It will be important to build on the cognitive principles of the model, develop relevant statistical parameters, and rigorously assess both product and process skill improvement. Although every instructor can attest to the adage one learns best when one teaches, it is imperative to thoroughly document process and product skill improvement. These efforts are planned for larger sample sizes in the near future. The STM has been used for classes with no greater than 11 students. We envision that the STM could be successfully adopted in classes of approximately 18 students or less with one instructor/facilitator. We further envision that with the help of trained graduate students or multiple instructors, the STM could be successfully adopted in larger classrooms. Efforts to adapt the STM format to larger classes are under way. The STM approach has been expanded in that the students in the Advanced Soil Mechanics course teach the concepts they have learned and facilitate group project meetings in an undergraduate Soil Mechanics course [20].

SUMMARY

The STM is founded on the cognitive principle that the learner's understanding is determined primarily by what she/he does while learning. STM promotes meaningful student interaction with material. Students are expected to interact with all forms of information from books and the internet to practitioners and peers. They are charged with understanding the relevant principles enough to communicate effectively with an educated peer group, be it through direct presentation or discussion with the presenter and/or facilitator. The expectation is for deep, elaborative, distinctive processing of material. The responsibility for generating meaning falls primarily on the student.

The STM is a new application of the old adage that one learns best what one teaches. The model is founded on principles of cognitive psychology. The teacher's role in STM is facilitator, moderator, evaluator, and master craftsman. The teacher's goal is to expand the learner's knowledge base through meaningful interaction in the student's zone of proximal development. The students' role is one of apprentice engineer, taking materials and resources accessible to him/her and shaping it into something meaningful within the context of an academic exercise.

The depth of classroom discourse will be determined by the quality of the students' understandings of the material and facilitation ability of the instructor. Student and facilitator alike will have the added burden of adapting to the particular classroom climate, the level of understanding of the group, and the interaction of the personalities brought together in the setting. Students and teachers who previously had experienced seminar class settings might have felt more comfortable, however, the process skills instilled by the teaching requirement and the focus on both product and process differentiate STM from seminar.

Bordogna [1] called for education that allows engineers to thrive through change. By promoting student understanding and meaningful strategic learning, students can take greater control of their own learning. Students, then, can become expert thinkers, better prepared to facilitate their own life-long learning. We are confident that the STM can contribute to the called-for emphasis on both product and process in engineering education, and can produce more effective graduates for the ever-changing engineering profession.

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