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Technical Note:

An Assessment of Practicing Reflection in Teaching the Concepts for Engineering Statics

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Note from the Editor: This paper shares the experience of Dr Ande in practicing reflection in teaching the concepts for Engineering Statics. His constant pursuit of being a reflective practitioner has made him more evolved as an effective teacher and made him more flexible in modifying his practice. It is interesting to learn from Dr. Ande experience.

Keywords: Reflection, concepts, engineering, learning.

Introduction

In my high school years, I used to be a below average performer in Math and consistently had to struggle even to pass the exams in Math. Since a lot of emphasis is given to Math at my home and in my family circle, a student who is poor in this subject is considered to be an under achiever and a failure. Hence, amidst this pressure to prove myself as a successful student, I struggled to do whatever I could to prove myself to get a passing grade in Math. On this insistence of my parents, in my ninth grade, I took tutoring lessons during which I was made to do at least fifty problems every day. The results were amazing as I found myself to be completely transformed. I scored second highest in Math test, surprising the entire school. Even now, my former classmates remain astonished that I chose to teach Engineering and Math. But a teacher of Engineering and Math indeed is what I have become, and my memories of those early troubles now guide my strategies to help my students to become better learners.

In high school, we were taught fundamental math principles in traditional lectures. The professor explained equations while writing them on the board, his back to the class, as we took notes in silence. After the lecture, we did the assigned homework, memorized formulas, and returned to class for the next day's lesson. My fellow students and I either "got it" or "didn't get it". If we had misconceptions, they were ours to discover and work out before an examination.

Later, when I began to teach Statics, I too followed the traditional teaching method, but I knew – and cared – that some of my students did not understand the concepts. However, I had already begun a practice of questioning and revising my teaching methods to emphasize a more interactive, student-centered development of conceptual knowledge. In my first Engineering Mechanics: Statics class in the Spring I semester, my students were well prepared and highly motivated, grasped fundamental concepts easily, determined forces with confidence, and asked impressive and spontaneous questions when critiquing solutions to design problems. But in the following semester, Fall I, my students, seemed to lose focus with each assignment in comparison to students from the prior Spring semester. Some students from Fall I solved the problems by just following the design steps; most demonstrated only the vaguest understanding of concepts basic to engineering, proof that the concepts had not been fully internalized to begin with. They were confused, for example, by the difference between internal and external forces, and seemed unfamiliar with the importance of applying conceptual knowledge to real-world problems. In the first few weeks of the fall, too frustrated to engage creatively with the material, the class moved slowly while I, growing anxious about coverage of material, reverted to the traditional lecture format. Listening passively, my students copied problems and formulas as I wrote them out on the board. Instead of transforming the traditional classroom, I was, to my chagrin, reproducing it.

What to do when there is not a perfect fit between our pedagogy and our students? My new class of students had underestimated the demands of the material, while my mistake had been to think that all students would be like those of the previous spring – eager, interested, and confident in their applications of conceptual knowledge. To understand the material and not be left behind, my new students

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needed skills more complex than the passive plugging in of numbers into equations. For me, the challenge was to modify my methods to deal with this unexpected deficit in student preparedness and, at the same time, cover a dense and demanding syllabus. Most important, I had to learn about my students' abilities and attitudes, and make teaching decisions accordingly and quickly, within the first weeks of class. In my second semester at a new college, I did not want my students to fail while I was figuring out how to teach them.

The teaching problem before me, then, was how to build acceptable levels of conceptual understanding and redirect learning habits. I needed to guide my students away from rote memorization and routine recitation of rules and formulas, toward active participation in their engineering education. I emphasized this as a crucial challenge in my teaching career as I am dealing with human resistance to change with respect to the students. Formally defined, resistance to change is any attitude or behavior that reflects a person's unwillingness to make or support a desired change. It is more helpful to view resistance to change as feedback that can be used to help accomplish the change objectives. The essence of this notion is to recognize that when people resist change they are defending something important that appears threatened by the change [2]. Fortunately, earlier that year, I had joined the Carnegie Seminar on the Scholarship of Teaching and Learning, a professional development opportunity to faculty interested in sustained and systematic reflection upon a single course, [3, 4]. I used the coincidence of problem class and professional development seminar opportunity to consider ways to adjust my pedagogy to accommodate varied levels of student readiness.

I found the seminar's consistent schedule of reading and writing, and the discussions with peers about teaching and learning to be a source of energy, allowing me to identify and resolve the contradictory elements between what I wanted my class to be and what this class actually was. The main seminar goals were to identify a line of scholarly inquiry into teaching and learning in a targeted course and to document pivotal points of that inquiry in reflective memos. My investigation was into ways to build acceptable levels of conceptual understanding, in order to redirect learning habits, and successfully guide skeptical students toward active participation in their engineering education. As I questioned my practice and looked for the causes of obstacles to learning, alternative approaches to the course began to emerge. With the development of disciplinary conceptual understanding as my goal, I decided to bring some of the Carnegie emphasis on reflection into my classroom, and turned my attention to increasing student awareness of their own learning processes. If I could question and reflect on my teaching, my students could also actively and profitably reflect upon their learning of primary engineering concepts.

Questioning as Reflection

Since Socrates, educators have stressed, directly or indirectly, the role of reflection in learning about the world and our place in it [5]. In my quest to model concept building, I restructured several learning activities to include sets of questions that called upon students to think systematically about engineering problems. I designed lectures that, depending on learning needs, could be accelerated or slowed down. I also assigned oral presentations and group work, activities perhaps less necessary among self-motivated students who engage each other and course material without prompting. The oral presentations and group work together demanded students to present in class orally the solution they developed for an engineering problem that I assigned to them. Taken together, these adjustments to my course would, I believed, clarify the understanding of real-world engineering problems, stimulate unexpected applications and solutions, and lead to the effective design of engineering projects. Discussed below are two strategies: (1) the use of question prompts to motivate reflection on previous solutions to problems, and (2) the use of concept questions to determine student's understanding of key ideas. As overlapping strategies, both are intended to stimulate purposeful dialogue, interactive critical analysis of problems, and alternative perspectives, [6].

Essential knowledge for anyone who wishes to pursue a career in civil or mechanical engineering, statics is a tool that, along with other theories, is used to predict the behavior of real objects. To avoid misunderstanding of statics, students must be able to distinguish the concept of moment (measure of the tendency for rotation about a point due to a force) and the concept of couple (two parallel forces with the same magnitude but opposite in direction and separated by a perpendicular distance), [7]. These two concepts form the basis for engineering design and practice, and lay the foundation for subsequent courses in the dynamics and mechanics of materials. Thus, exposure to the forces and moments that act between, or within, objects must be part of the student's introduction to the discipline. If the student is to interpret and apply the disciplinary concepts of "force", "moment", "couple", and so on, basic conceptual knowledge must be firm.

My inquiry into my student's learning began with my observing the extent to which they could internalize and apply key course principles to a range of design problems appropriate to their level of study. Uppermost in my mind was the objective of more intentionally and interactively teaching students to "think with" concepts. In its simplest sense, thinking conceptually in this course requires both familiarity with the language of statics and the ability to use disciplinary definitions with precision [8]. At the very least, command of primary concepts should reduce overdependence on the words "whatever" and "thing"! In planning my lessons, my first decision was to de-emphasize formulas in favor of concepts whenever possible. Second, in the belief that students needed more consistent hands-on experience with the course material, I assigned design problems to be worked out collaboratively in groups. In a typical class, students thought through and demonstrated their solutions together, and I moved from team to team, asking questions and listening for correct usage of engineering concepts. As students tried to justify alternative and diverse solutions, I could quickly and easily evaluate their progress away from the foggy language of "whatever" toward clear communication of the fundamental attributes and applications of the concepts of statics.

To generate interactivity as well as the more substantial and flexible conceptual understanding that I expected from the students, I set up three stages of solving real-world design problems "interpret, plan, execute", an approach that I have adopted for subsequent classes [7]. Connected to each other by a series of questions, the three levels of problem-solving progress from basic analysis to more complex reflections on actions [9]. The first and most straightforward learning stage requires teams of students to read the problem statement, break it down to its constituent parts, and demonstrate that they can identify and define its essential terms. Guided by the staged questions, the teams determine what information is provided by the problem statement, what remains to be worked out, and what assumptions must be made in order to reach a solution. In the second stage, students think about multiple approaches, looking for and, if possible, identifying more than one solution to the problem. As a team, they then choose and justify a "best" plan.

In the third stage, students describe possible relations of in-class engineering problems to real world industry. For example, shown a picture of a fracture in the concrete support of a bridge, the teams respond to a pair of cause-and-effect questions aimed at systematic reflection upon what may have gone wrong and why: "What has happened? Why has this happened?" Here students offer modify-cations, and begin to work out design steps.

In my Fall I class, several advantages to using such questions were immediately apparent, especially in relation to student attitude. The presentation of images attracted their attention which in turn excited their imaginations and motivated them to involve in further discussions with their peers. It also helped students who had formerly displayed lack of interest to know the purpose of learning an engineering topic, and to be curious about the relation of the abstract topic to real situations. No longer simply copying a problem while watching and listening to me work it out on the board, students now solved the problem in discussions with each other, providing immediate assistance and feedback. As team members, students participated more collaboratively in class discussions; as individuals, they were more confident and displayed more personal accountability when demonstrating a solution process before the entire class. By observing students as they worked and by asking them questions that required reflecting upon their solutions to problems, I could better evaluate weaknesses and strengths in conceptual understanding. I could see the degree to which students would persist in finding solutions, and, for their part, students could see their accomplishments or lapses and thus get a clear sense of their progress. The challenge, described above, to define terms and reflect upon solutions, out loud and in teams, improved communication within the class, reduced the fear of proposing incorrect answers, and minimized the number of conceptual errors students made. Overall, students worked with more conviction and approached problems with more success, improving their scores on homework and exams by an average of 40%.

A second method, the use of multiple-choice concept questions, helped me to assess my students' homework preparation, and their progress in defining and applying fundamental concepts. A pedagogical technique pioneered in the late 1980s by Harvard Professor of Physics and Applied Physics Eric Mazur, the in-class use of concept questions aims at assessing and improving students' abilities to "apply knowledge across a variety of previously unencountered instances" [10, 11]. In other words, strengthened conceptual understanding improves ability to work out solutions to new problems, and imagine and make predictions about the possibilities and consequences of future designs [10].

Practiced in class alongside reflection questions, and dependent upon completed homework assignments, concept questions replace memorization of definitions and formulas and prompt self-assessment and critical understanding. Drawing upon Mazur's pedagogy and Felder and Brent's application of

Bloom's theory of learning to the engineering classroom, I decided to align the first four levels of Bloom's taxonomy-knowledge, comprehension, application, and analysis-with concept questions [12, 13, 14, 15]. Classifying course content, I designed four levels or types of questions. At the first level, basic knowledge questions require my students to demonstrate their understanding of fundamental definitions such as vectors, forces, moments, product of two vectors, scalars, and so on. The next level of questions moves beyond simple memorization of definitions to comprehension of concepts, i.e., determining moment at a point due to a force or a resultant force at equilibrium. At a more challenging level, application concept questions involve making necessary assumptions and applying prior knowledge. Finally, analysis concept questions evaluate the degree of higher-level applications of content and design techniques. Of course, as suggested in the examples below, these four levels are overlapping and integrative:

Knowledge Question

For any two vectors A and B, where A = Ax i + Ay j + Az k and B = Bx i + By j + Bz k, which of the following is true?

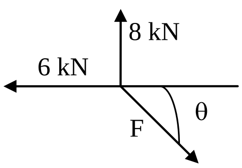
a. A · B = (Ax + Bx) i + (Ay + By) j + (Az + Bz) k
b. A · B = Ax Bx i – Ay By j + Az Bz k
c. A · B = Ax Bx + Ay By + Az Bz
d. A · B = (Ax + Bx) + (Ay + By) + (Az + Bz)

To answer successfully (choice c), students must know the definition of a vector and understand the differences between a dot product and a cross product. They should be able to show that the resultant of a dot product is always a scalar quantity and not a vector, and that the dot product of two vectors is A · B = Ax Bx + Ay By + Az Bz.

Students 's Answer–"c. Dot product of two Cartesian vectors are multiple of the corresponding x, y, z components and their algebraical sum. And it is a scalar quantity, as i.i = 1, j.j = 1, k.k=1.

Comprehension Question

The following force system will be in static equilibrium only if



a. F = 10 kN and θ = 53.13°
b. F = 10 kN and θ = 36.87°
c. F = 14 kN and θ = 36.87°
d. F = 14 kN and θ = 53.13°

After learning the fundamental definitions in statics, students demonstrate understanding of concepts both in class discussion and in quickly administered quizzes. In order to answer this problem successfully (choice a), not only must students be familiar with the definitions of the concepts of vector operations, resolving forces, and static equilibrium, but also, importantly, they must understand the implications of the interactions among them.

Student's Answer – "c. The force system will be in static equilibrium if the sum of the forces in the x direction are zero and the sum of the forces in the y direction is equal to zero. Since the resultant of the given forces is 10 KN we know that F must also equal 10 KN. The resultant of the given forces is located 36.87° use the vertical component of the given force. Therefore F must also be 36.87° in the opposite direction inorder for the system to be in equilibrium."

Application Question

If the moment of a force about a point A is M_A = {5 i – 6 k} Nm, its moment about line AB, whose unit vector is u_{AB} = 3 i + 0.2 j, has a magnitude of

a. –18 Nm
b. 15 Nm
c. –1.2 Nm
d. 1 Nm

In my Fall 2008 class, students experienced confusion when confronted with problems that required application of the concept of moment. To answer successfully (choice b), students must know the definition of moment and unit vector. But the complexity of the challenge here is that they must also be able to apply the concept of moment about a point in order to determine moment about a line. In our class, constant practice reinforced the concept that the moment about a line is calculated using a unit vector that is along that line.

Student's Answer – "b. $M_A = r_{AC}$ x F

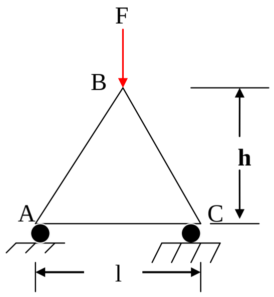
M_{AB} = $u_{AB} \cdot M_A$ = 15 Nm where, u_{AB} gives the direction of the axis.

M_A = r_{AC} x F = {5i – 6k}

M_{AB} = $u_{AB} \cdot M_A$ = {3i + 0.2j} {5i – 6k} = {3 · 5 + 0.2 · 0 + 0 · –6}

Analysis Question

Truss ABC is revised by increasing its height from h to 2h. Width l and force F are kept constant. For the revised truss as compared to the original truss, which one of the following statements is true if it is in static equilibrium?



a. Forces in all its members have remained the same.
b. Forces in all its members have increased.
c. Forces in all its members have decreased.
d. None of the above

To answer successfully (choice c), students must now demonstrate the ability to make predictions based upon sound assumptions. In addition, at this stage, their analysis should reflect the ability to apply content and design methods consistently. Here, students need first to apply equations of equilibrium for both original and modified truss and then analyze their calculations in order to conclude that forces in the members decrease.

Student's Answer – "c. $\sum F_y = A_y + C_y - F_y = 0$
$\sum Fy = 100 - 10AB/14.14 = 0$
$100 - 0.707AB = 0$
$AB = 141$
$111.8 < 141$"

$\sum Fy = 100 - 20AB/22.36 = 0$
$100 - 0.8944AB = 0$
$AB = 111.8$

It is not unusual for students to get lost sometimes in trying to find the right step to solve the above problems. At these junctures, they require additional assistance and continuous practice with similar problems to help them adapt to the learning challenges. Both weak and strong students benefit from working in teams on concept questions such as those explained above and reflecting upon and justifying their responses. Weaker students can more clearly reveal gaps in their understanding to stronger students; the latter may progress more consistently and, at the same time, justify their results by explaining approaches and processes to their peers.

Concluding Remarks

As a teacher, I did not want to fall into the traditional approach that had trapped me as a young student. By designing active learning strategies that reinforced continuous practice of statics concepts, I hoped to move my students toward a realistic awareness of the rigors and expectations of the profession they had entered into. To understand that sophisticated and effective engineering solutions rest upon firm conceptual knowledge [16], they had to first learn to speak the language of engineering and they had to demonstrate a disciplined approach to analysis and prediction, skills that were internalized through systematic questioning of theory and its real-world applications. Although the reflection and concept-based questioning techniques consumed a significant amount of instructor time in both their initial preparation and periodic improvement, I found that these lessons consumed less class time than lectures, and could easily be used together with my presentations and student presentations of their assignments. The combined methods of team reflections on problem-solving solutions and concept questions also helped me to assess quickly student understanding of the material, saving in-class lecture time.

Most important, these techniques significantly improved student scores on homework and exams. My end-of-term analysis indicates that the use of such in-class assignments helped increase student scores by an average of 40%. In their evaluations of the course, students commented that both reflection and concept questioning were useful in promoting their understanding of key engineering concepts and design steps. In addition, the use of these strategies made evident to me that students wanted to know not just how to solve problems mechanically: they wanted to know the purpose of learning a topic. The presentation of images of fractures in structures described above excited their imaginations and motivated discussions about causes, forces, resistance, and so forth. As I had hoped, these demonstrations and conversations brought home to my students the implications of their efforts to learn these concepts in our class.

In the words, "To think about one does and why - assessing past actions, current situations, and intended outcomes - is vital to intelligent practice, practice that is reflective rather than routine", [17] I had turned away from my lapse into the "back-to-the-class" pedagogy typical of the traditional engineering classroom to encourage active, visible, and "thinking out loud" learning. Facing each other, engaging in problems together, and reflecting on our practices, my students and I began to transform our approaches to teaching and learning. It is this potential to change, as I had done in my earlier years as a young student, as our students do every day that lies at the heart of the reflective classroom.

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