AC 2010-1818: EVALUATING INSTRUCTOR PRACTICES IN THE ENGINEERING CLASSROOM

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Evaluating Instructor Practices in the Engineering Classroom

The purpose of this study was to examine instructor practices in the engineering classroom especially with regard to students' 1) use of knowledge building and collaborative teaching strategies[1] and 2) perception of how their classes align with their future career paths.[2] Our results provide an initial qualitative description of how teachers promote constructivist, inclusive practices such as knowledge building and collaboration during instruction and how the use of these teaching techniques – such as activating student prior knowledge, engaging students in learning activities, and promoting reflection – might relate to students use of learning strategies and perceptions of a future career path.

Theoretical Framework

In the fall of 2009 we began an evaluation of a professional development program at a large southwestern university in the United States designed to promote constructivist teaching practices in freshman engineering classrooms. This program had the expressed purpose of improving engineering education for freshman students to "promote more effective learning and achievement" and to "act as a cultural bridge from high school to the university environment," which mirrors a larger trend in engineering education toward the use of collaborative, inclusive practices.[3-5] We have begun our examination by conducting research in eleven freshman introductory engineering courses, including gathering running records of instructor practices and surveying students 1) use of knowledge building and collaborative study strategies[1] and 2) perception of how their classes align with their future career paths.[2] Considering the expressed demand for improved instructional practices and a cogent philosophy of education for engineering educators, we hope our initial results can add to the growing body of knowledge regarding best practices in engineering education.

Research in education suggests that optimal learning experiences can be created when instructors provide educational opportunities for students that prompt them to activate their prior knowledge about what is to be taught, meaningfully engage them with new information, and help them to reflect on the new knowledge they have gained during a learning task.[6] Ideally, each lesson should begin with some activity or discussion that helps students access what they already know about a given topic, helping them to bring misconceptions to the surface and preparing them to build on existing knowledge – either through accretion or accommodation.[7] By accessing relavent prior knowledge and bring misconceptions to the surface, students are more likely to encode new information and revise misunderstandings after encountering new material. After this, a lesson should meaningfully engage students with new information, allowing them to actively construct new knowledge. Meaningful engagement is thinking deeply about alternative conceptions of a topic and "deep processing, elaborative strategy use, and significant meta-cognitive reflection." Many techniques can be used to facilitate high engagement including conducting experiments, reading refutational texts, generating explanations for strange data, and developing self-driven explanations. Many of these techniques lend themselves to collaboration and promote weighing alternative points of view, comparing prior knowledge with previously unencountered information, and contrasting ideas to resolve discrepancies.[8] Once new information is presented, students should reflect on what they have learned, a strategy that helps to encode new information into memory for later use.[6]

In order to navigate these three integral components of the learning process, students must 1) be motivated to consider and engage new information and 2) be willing to build on existing knowledge by making cognitive connections to new information and revising misconceptions and discrepancies. Though the field of motivation is vast, one important component of student motivation to learn at the post secondary level is their perceived instrumentality, or perceived utility, for new information.[2] Post secondary students who perceived new information to be useful to attaining a future goal have been found to be more likely to achieve at higher levels, both during in-person[9] and online learning tasks.[10] In general, students who are able to connect present learning tasks to future goals within the personal futures they envision for themselves are more likely to be motivated, engaged, and achieve.[11] Similar findings have been found in studies of post secondary engineering students. Engineering students who perceive information in their engineering classrooms to be instrumental to attaining a future goal have been found to be more meaningfully engaged in their learning and in some samples more likely to achieve higher grades.[12-14] Additionally, in order to learn new information effectively students must engage in knowledge building. A constructivist construct, knowledge building is the production of knowledge rather than the reproduction of knowledge. Knowledge production is accomplished by in-depth study of a topic that goes beyond simple factual or recall learning. It requires the construction of new knowledge, connection of new information to existing knowledge, integration of knowledge across topics and domains, and incorporates explicit recognition of the role of classroom factors such as asking questions and cooperation[1].

Purpose of the Study

The purpose of this study was to examine instructor practices in the engineering classroom, especially with regard to the three components of effective instruction: activating into prior knowledge, facilitating meaningful student engagement with new information, and encouraging reflection on what has been learned. Within this structure, we were particularly interested in examining 1) how engineering instructors attempted to help student make connections between present learning tasks a future goals (either academic or career goals) and 2) how instructors facilitated engagement with new information by promoting knowledge building and the production of new knowledge.

Method

To achieve the purpose of the study, preliminary observations were conducted in eleven freshman engineering classrooms at a large public university in the southwest. During the observations detailed, moment to moment running records and evaluations of the of the courses were taken using a modified version of the Reformed Teacher Observation Protocol (R-TOP), a research tool designed to evaluate instructor practices in the science classroom[15]. The topics of the courses included, Programming in C++, Introduction to Mechanical and Aerospace Engineering, Programming in Java; Informatics; Engineering Design; Digital Design, and Society and Technology.

Participants

Participants were eleven freshman engineering educators at a large public university in the southwest. Eight of the instructors were male, and three of the instructors were female. All of the instructors were experienced engineering educators at the university. Many of the participants have been at the university for many years. All of the participants agreed to participate in the study and were observed teaching typical lessons.

Analysis

During the observations, special attention was given to 1) teaching strategies (introductory activities, technology, etc.), 2) collaborative opportunities for learning (group work, whole class discussion), 3) knowledge building (connections to other course content, upcoming events, and future careers), and 4) teacher directed activity (giving instructions, guidance, and info about upcoming assignments and tests). After completing the running records, we followed Miles and Huberman's[16] recommendations for coding qualitative data. During the coding, special attention was paid to the structure of the lesson (activating prior knowledge, engagement, reflection) and how instructors encouraged perceived instrumentality and promoted knowledge building. Though many other observations were recorded, we were interested primarily in instances which reflected these constructs. Results revealed instances of exceptional teaching, as well as common teaching mistakes which, if avoided, can improve instruction.

Results

In the observations there were both positive instances where instructors facilitated knowledge building which helped students to understand how new information is connected to their personal futures and instances where improvement could occur. Below, these aspects of instruction are discussed within the three integral components of instruction – activating prior knowledge, facilitating meaningful engagement, and encouraging reflection.

Activating Prior Knowledge. Few instructors made an effort to activate into students' prior knowledge before beginning instruction. Instructors who did make an effort to activate into prior knowledge generally did so through verbal prompting. For example, one instructor began class in the following way:

> "Listen up," she says, "We need to take a look at our schedule because things are due shortly." They discuss some due dates. She displays a Microsoft Word document on the project screen. It is a syllabus. She points out the various components of the robot project and when they are due. She summarizes each component quickly and says things like, "Remember you need to make sure to fill out this status report professionally. On every status report you need to identify all members of the project, whose laptop you will use, and when the code will be written." She pulls up the report template and goes through each component. She says that each group member needs to fill out the status report on their own, so she can compare the reports for discrepancies.
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> She then puts up a slide about the importance of good team communication. The slide suggests using an agenda, having a facilitator, taking meeting notes, reviewing notes and making new agenda. She talks quickly, smiles a lot, calls on students even though they

> don't raise their hands, and uses their prior work and activities as examples. She clearly knows their names and uses them. For example, she points out Adam and says, "Adam, I know you are the president of a student organization. You might be a good team manager."

In another example, the instructor began class by going over a homework example. She notices that the students are sitting in groups discussing the homework before class starts. She takes advantage of this observation to activate into prior knowledge.

> The instructor begins by saying, "May I have your attention, please! I see that many of you are working on the assignment. That is good." Immediately there is a question from one of the major groups of students. The professor replies, "Imagine I have a function where . . ." and she goes on to describe that you don't write a function for the sake of writing functions. Some students want to come by for office hours. She gives them the times and encourages them to come. She tells the students that they are going to work on a handout. She lowers two large projection screens, one on each side of the three large white boards at the front of the room. She opens Textpad and puts some c++ code on the screen. She says, "Okay, we are going to see a sample of functions and we are going to go over overloading."

None of the instructors we observed began class with an introductory activity that employed collaboration or experimentation to help students bring their existing knowledge to the surface. Most of the instructors neglected to activate student prior knowledge and instead simply began instruction abruptly and without introduction. For example, the following observation was recorded in a running record.

> The professor jokes and chats with students while he brings up the classroom materials. Their banter is funny. The professor improvises jokes and moves quickly from topic to topic. Some of the comments include:
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> > Instructor: "Did you guys see that a professor from our school was in the news?"
> > Students: "Yeah, but we thought he was from IU?"
> > Instructor: "I think he has a joint appointment?"
> > Students: "What about Obama's prize . . . .?"
> > Instructor: "Yeah, that is a good question . . . hey, do you all know what all professors have in common?"
> > Students: "Selling their souls for research money?"
> > Instructor: "Well, yes, that, and absent-mindedness."
>
> The professor moves on and discusses forgetting their homework. The professor transitions easily into the topic for the day, which he announces rather regally as, "The problem solving heuristic." He pulls up a Microsoft Word document which has a graphical representation of a series of problem solving steps.

Though it appeared the students had a comfortable relationship with the professor, no effort was made to help students access relevant prior knowledge before presenting new information. Instructors who do not activate student's prior knowledge before present new material may be overlooking an opportunity to address student misconceptions and neglecting to help students to understand how new information is interconnected with their existing goals. Those instructors who encourage students to access prior knowledge help students to create perceived future pathways for learning, where past, preset, and future are cogently interrelated, with new information building on old information, and learning in general being connected to existing knowledge of a career in engineering.

Engagement. All of the instructors, in some way or another, made an effort to engage students in learning new information. Along a continuum from low to high engagement, instructors on the low end used power point slides or white boards to present main ideas and graphical models. Instructors on the high end used group activities and collaborative experimentation to teach new concepts.

In one instance an instructor wanted to help students review for an upcoming test covering multiplexors and decoders. He began class by proposing some group work, but wound up lecturing for most of the period. The situation was captured in the running record.

> He begins by saying that he wants to cover the material in the text. He is going to propose an example problem and have the students solve it in groups. A student asks, "Can you explain multiplexors and decoders?" He says yes. Another student asks if we can go over the homework. The instructor says yes. So, what they decide to do is go over problem 15 on multiplexors and decoders.
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> The instructor abandons the group work and begins drawing a problem about decoders on the white board stands with his back to the class, and says out loud each number and symbol he is writing and why. His voice is directed to the white board. He is hard to hear. He constructs a lengthy equation on the board, while talking at the board, and students copy what he writes.
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> He continues with the explanation and then says "This is what you will need for your midterm." He says, "You will also need to be able to use this information to make a truth table. See you simply copy the information from here," at which point he directs the student attention to the board, and begins to construct a table. He continues, "See, like this." Most students copy while others just watch.
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> It is quiet as he makes the table, with a few minor comments directed toward the white board. "See, zero one, zero one, one one, zero zero one, one one zero zero. See I have to jump around. And finally, I just circle the yeses. I have four circles for the four product terms. But I have to be careful about what I can share between the different functions. And so finally, to write it all down," and he continues with the explanation directed at the white board.
> Three large white boards are full of a lengthy problems now – all color-coded with different dry erase markers. It is actually quite impressive with many tables, matrices, symbols and arrows.

Although the activity implicitly communicates to the students that homework problems are related to future success on the test and they were given accurate, detailed information, students were not meaningfully engaged in solving the problem on their own and simply observed the instructor diagramming procedures and calculations on the board. Interestingly, after the review session, students approached the instructor for additional help. It was recorded in the running record:

> There is no formal announcement that class is over. Students just begin to leave when the clock hits a quarter after, and the professor continues to answer questions. At this point, he has a crowd of students around him at the front of the classroom with their notebooks open, all asking clarification questions. There are also more questions from the same female student. He talks with her for awhile, while others listen and nod their heads. She leaves as another student meanders up and begins asking questions. They talk and look at the diagrams on the board.
>
> Students leave leisurely as other students come in and take their seats for the next class. The instructor stays after class for nearly 45 minutes, working with students around the white board, going over sample problems as answering questions.

The instructor stayed after class for 45 minutes helping students in this fashion. In many respects, it would have been more beneficial to organize classroom instruction to look more like the after class instruction rather than carrying out lengthy explanations facing the whiteboard.

In another instance an instructor had students engaged in an ongoing project to build a robot. Students were situated in groups in the classrooms. After beginning class with some discussion about upcoming assignments and their progress on building the robots, the students were given 30 minutes to continue working on the project. Students worked collaboratively on the project, with some students building the robot and others working to isolate problems with uploading important software to their laptops that would allow them to program their robots.

> She transitions into the group activity for the day by saying, “I am about to hand you a robot build and code sequence. I am going to go through this at lightening speed, so you can figure out the details in your groups.” She stops and uses Pig Latin to chastise a group for talking. They are thrown off guard, smile, and stop.
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> She says, “Shawn, you see this code? I want you to use this code for the robot.” She goes through a list of procedures on a slide that she has in a handout on her desk. She goes very fast. “We are going to do this a little bit at a time,” she adds. She begins to circulate the handout. Immediately, she is talking with a group about their questions. She hands the handouts to another student, with no words, and the handout begins to circulate while she answers questions in an animated way.
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> Students pull out tubs of materials. The tubs are made of plastic with plastic lids. They are about a foot and a half in length and three quarters of a foot in width and six inches tall. The tubs contain wires, electrical equipment, circuit boards, instructions, and other tools such as markers and scissors. The students are all engaged in what I know to be building a robot, though I wouldn’t be able to tell at this stage if I wasn’t listening to the professor. Things are scattered all over the tables. Students have the web browsers on

> the computers pointed at the Blackboard website, with the instructions pulled up on the web. Laptops are open, and the room is bustling with students. Students wander from team to team, switch positions at their tables, stand over the tables and reach around the computer components to get materials, leverage, or a better view.
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> In the teams, division of labor is apparent. The teams are divided in groups of four, and at many of the tables the teams have split into two groups of two. In the group near me, two students stare at a laptop and simultaneously pour over an article while the other two appear to be wiring up some device that will go into the robot. This type of division is common in many of the groups, although some have not divided and are working as a whole.
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> The teacher circulates the room, moving from table to table asking all types of questions and giving advice. "Whose laptop are you going to be using? Who is going to save the codes? You will want to back that up. What type of error are you getting? Hmm, never seen that one. Try this. Ok, now try." She and the student both stare at a laptop. She continues, "Keep trying different numbers." She wrinkles her brow and puts her hand on her chin while she stands behind the student. She asks more questions over his shoulder. They figure out the problem. She turns to the class and exclaims, "Attention! Once you install the run software for the robot, you have to shut down the computer before trying to use it, or you will get a run time error." Many of them nod, one student says, "That is a deceptive problem." The student then gets up from his seat, walks over to the other side of the table, and sits down in front of the computer.
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> As the students settle into the project, the classroom quiets. Work is getting done. Student approach the teachers with materials in their hands, asking questions. She goes from group to group, answers questions. "Yes sir, what do you need?" She laughs loudly at the student's question, and the student seems pleased.

Students worked collaboratively in conjunction with the instructor and other students to solve novel problems and work toward completion of the project. The instructor regularly reminded them how components of the project carried over to both success on classroom assignments and tests, as well as how the project was reflective of realistic work in the field.

In other instance, the instructor did not use a long term group project, but rather developed a short term collaborative problem solving activity to illustrate engineering design principles. In the course the instructor was discussing engineering design. He outlined engineering problem solving heuristics using power point slides. After reviewing the principles, he engaged students in an activity to help them understand how to employ the hueristic. During the activity the instructor continually reminded students how the problem related to both class material and the type of work they would be doing as engineers.

> He points out that the pursuit of a solution can be ill-defined and the problem solving heuristic can help to maintain focus and to help wade through "infinite possibilities."

> The professor goes on to explain to the students that in the industry, engineers often use the problem solving heuristic to do things like improve existing products. He gives a lengthy example about the need to improve air conditioning units when Freon was banned. In this example, he says, “The problem space has well defined parameters.” He says, “Often times, the problem space simply requires replacement, no need to reinvent the wheel.” The professor continues, “So even in problems with well defined parameters, how do I define and explore a solution space? How can I look at an infinite number of solutions in a reduced fashion?”
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> He then puts a “concept generation map” on the projection screen. It is a flow chart that can be used to define potential solutions to further define a problem space. To explain the flow chart, he tells the students that he wants to develop a device for signaling people when their basement is flooding. He says, “As an engineer, if you were to solve this problem, you might begin thinking about it along the lines of this chart. You would want to 1) locate technology for the device, 2) find an appropriate energy source, and 3) devise a method to attach the device.”
>
> He tells the students that they are to spend the next few minutes working in their “teams” to solve the “flooding basement” problem. He wants them to fill in the flow chart for the problem and make a few drawings. He says, “Look at this for about five to six minutes and then we will come back together as a group.”

In the first example the instructor neglected to adequately engage students during the exam review. As a result, the instructor stayed after class for a long period of time engaging students in the problem solving task to account for the low engagement. Though it is commendable that the instructor was willing to put the time and effort into the instruction, the other two examples illustrate how to more effectively engage students during class activities. In the first example, the instructor developed a long term project that was used to engage students with new information throughout the semester. Because the project was carried out collaboratively and the instructor continually reminded students how the project was related to upcoming information in class as well as how the project was reflective of actual engineering work the students were engaged in the active construction of new knowledge. The same can be said for the third example. Though this instructor did not develop a long term project, the instructor did create a novel, collaborative problem solving activity in which the students were free to experiment with the application of the new knowledge they received. The students played with experimental and sometimes silly ideas, but in the end gained valuable experience using design heuristics. Research in education suggests that active engagement in the classroom is beneficial to learning for many reasons. Future analysis of these running records in conjunction with surveys administered to students in the classroom many provide valuable information about the relationship between these types of practices and student motivation.

Reflection. None of the instructors we observed asked students to reflect on the new information they had learned during their classes. All of the instructors in the sample ended class abruptly with little or no attention to promoting reflection. For example, one instructor ended class in the following way.

> The instructor goes back to the slide show and begins pointing at a new slide. He asks another vague question that gets no response. He answers his own question quickly. At this point, more students are on the internet.
>
> He advances the slide. He asks another rhetorical question and gets no response. The instructor tries to raise his energy to get the students attention but it doesn't seem to be working. He ends class abruptly and says, "Okay folks, have a great week!"

Though this type of instruction was not typical, it was typical for instructors to end class abruptly without any review of course material. Encouraging students to reflect on new information helps them to cognitively access newly learned information immediately after instruction, helping to encode it into memory and making it easier to access for future use.

Discussion

The running records allow for a number of conclusions. First, only a few engineering instructors were observed helping students to activate relevant prior knowledge. Instructors who engaged students in this type of activity may have been better able to motivate students by helping them to see how new information builds on old information and is related to future goals such as completing a class project or learning how to solve engineering problems. This observation is in-line with future time perspective research that suggests instructors should help students understand how present tasks are related to existing future goals.[11] However, none of the instructors activated prior knowledge by using a structured introductory activity that allowed students to review old information. Even simple activities such as a think-pair-share, collaborative answering of open ended questions, or listing important main ideas from previous classes could help to improve instruction in this regard.

All of the instructors engaged students with new information, but this engagement existed on a continuum from low to high. On the low end, instructors simply talked about new ideas, presented power point slides, or drew diagrams on the board. In these classrooms, students were not required to solve problems, critically consider new information, or discuss ideas with classmates during classtime. In one instance, the instructor stayed after class to engage students after spending the entire class period lecturing. Other instructors avoided these difficulties by creating long- or short-term collaborative learning opportunities for students. During these learning opportunities, students were actively engaged with solving novel problems and applying information they learned in class to realistic engineering tasks. Though oftentimes playfully, students in these classrooms were motivated and engaged in the production of new knowledge. The instructors made a special effort to explain to students how the knowledge they were gaining in class was related to future assignments and their careers, as well as to show them how by engaging them in activities that were reflective of actual tasks they would encounter in future careers.

Though instructors who simply presented new information via whites boards and power point presentations may be liked by students and may be having a positive impact overall, they may want to consider using simple instructional techniques to promote novel problem solving and group activity to communicate to students how new information applies their future careers –

both as students and engineers. They may also want to consider devising ways to activate student prior knowledge and create opportunities for reflection after learning has occurred. Introductory activities that help students to activate relevant prior knowledge help students to integrate new information into existing knowledge structures. Reflecting upon newly learned information facilitates cognitive activation of new information and helps to encode information into memory. Future research will further demonstrate how engineering professors successfully create these types of opportunities for students, as well as what influence these instructional strategies have on students self reported engagement and motivation.

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