

Active Learning Exercises Requiring Higher-Order Thinking Skills

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Abstract

As active learning becomes accepted in engineering classrooms, more and more faculty members are using in-class exercises. While these exercises are instrumental in helping students gain experience with concepts and processes covered in class, they typically allow students to perform satisfactorily while thinking and working at the lower levels of Bloom's Taxonomy (e.g. knowledge, comprehension, application). Term projects often are used to help students develop higher-order thinking skills and to bring design concepts into engineering courses. However, because projects have greater scope and larger work requirements, it is difficult to fit more than one or two projects into a semester-long course. Further, most students and many faculty view these longer-term assignments as mostly out-of-class work. While comprehensive and very worthwhile, these term projects are both burdensome to complete and cumbersome to grade. Hence, neither faculty nor students would relish increasing the number of these all-encompassing design projects attempted per semester. This paper describes efforts to develop and implement in-class exercises that encourage students to engage in higher-order thinking skills. The in-class exercise developed required only 10 to 30 minutes of class time, was easy to grade, and required meaningful work from the students. The exercise was developed for and implemented in an upper-division course in biological and agricultural engineering at Texas A&M University. Methods used to develop the in-class exercise, the specific exercise used, and results of implementation are discussed.

Introduction

Often faculty complain that students do not adequately learn the material without realizing that they are meeting their expectations. This is illustrated by a real classroom scenario: "I use Bloom's Taxonomy, and I point out the lowest level. That level is knowledge: it's memorized facts... I put up a slide, and it says, "How many of you will be successful if you attain this level of learning?" They don't know where I'm going with this, and ninety-nine percent of them will say, "That will get me an "A" or "B," if I can do that in class.'" (P. K. Imbrie, Purdue University as quoted on <http://clte.asu.edu/active/consistent.htm>). Clearly, engineering faculty would not be satisfied with

students merely recalling the facts we present in class; however, many of our students feel that they have done a good job if they can repeat the examples from class on the test.

Bloom presents cognitive learning as the recall of information and "the intellectual skills: comprehending information, organizing ideas, analyzing and synthesizing data, applying knowledge, choosing among alternatives in problem-solving, and evaluating ideas or actions."¹ Typically these intellectual skills are referred to using the hierarchy presented by Bloom and his colleagues:

1. Knowledge (least complex)
2. Comprehension
3. Application
4. Analysis
5. Synthesis
6. Evaluation (most complex)

Obviously, faculty and employers want students who can perform at all levels listed in Bloom's Taxonomy, yet our classes often allow students to survive and succeed by memorizing and repeating facts (and examples from the book or lecture). There is a significant amount of information that has been presented on measuring higher levels of learning on tests^{2,3}; however, little of it has been in an engineering context. The purpose of this paper is to present a convenient method of encouraging students to develop their higher level thinking skills.

Active Learning

The research is clear: students need to do more than just listen to learn.⁴ Despite this widely held and strongly supported belief, a survey of U.S. professors found that lecturing is the mode of instruction in 89% of math and science teachers.⁴ One of the underlying ideas of the Foundation Coalition (FC) has been to advocate active/cooperative learning as a pedagogical approach to be used in conjunction with lectures. Bonwell and Eison⁵ describe active learning using the following: "When using active learning students are engaged in more activities than just listening. They are involved in dialog, debate, writing, and problem solving, as well as higher-order thinking, e.g., analysis, synthesis, evaluation." This means that active learning would be an ideal environment to promote higher level thinking skills.

Johnson, Johnson, and Smith⁶ define cooperative learning as "the instructional use of small groups so that students work together to maximize their own and each other's learning." Groups are not cooperative just because we (or they) form them. There are essential ingredients needed to encourage and promote the cooperation needed to meet the operational definition for small-group learning to be truly cooperative. Reference 6 lists the following as essential components:

1. clear positive interdependence between students
2. face to face interaction
3. individual accountability
4. emphasize interpersonal and small-group skill
5. processes must be in place for group review to improve effectiveness.

The authors and many of their colleagues have adopted an active/cooperative classroom as the environment of choice. It is in this active/cooperative classroom that we have undertaken development, implementation, and evaluation of a short-duration, higher-order thinking activity. Details regarding the development of the activity, its use in the classroom, student work and evaluation follow.

Developing the Activity

A higher-order thinking activity was developed for use in a senior-level, elective engineering design course entitled Water Quality Engineering. The focus of this course is nonpoint source pollution mechanics and selection and design of pollution abatement strategies. Course prerequisites include fluid mechanics, introductory hydrology, and introductory soil science. The course attracts upper-level engineering undergraduates from Biological Systems, Agricultural, Civil, and Chemical Engineering. Typically, about 20 undergraduate students take the class each year.

The overall goal of the course is to prepare students to select and design best management practices for controlling pollution generated by storm runoff. Specific course outcomes include:

- Understanding how hydrology impacts transport of pollutants in surface flow,
- Understanding the behavior of pollutants in the environment and synthesizing behaviors to predict pollutant transport mechanics and losses,
- Using information regarding pollutant transport mechanics to appropriately evaluate and select best management strategies, and
- Designing best management strategies.

The goal of the higher-order activity described here was to increase student understanding of how individual concepts covered in the class and in some prerequisites worked together to achieve the overall course goals and outcomes. The activity description as given to the students is shown in figure 1.

Implementing the Assignment

The activity was administered on the first day of class before any technical content of the class had been undertaken. Students were given approximately 10 minutes to develop the concept map. Students were informed that the assignment would not be graded, but that they might be called upon to share their work. After students finished the activity, but before solutions were shared, students were asked to predict their performance on the activity.

Listed below, in random order, are concepts covered either in this course or in the prerequisites. Arrange the concepts and connect them with arrows as appropriate to indicate how these concepts work together to achieve the end result of selecting and designing best management practices for abating stormwater pollution. For example, if you believe an understanding of hydrology is important for understanding water erosion and sediment transport, draw an arrow to indicate that linkage. For each arrow you draw, be prepared to explain why that linkage is important.

Your work on this assignment will not be graded, but you may be called upon to share your concept map with the class. When you have completed your diagram, answer the self-assessment question at the bottom of the page.

- Contaminant Transport (movement of water quality constituents in runoff)
- Fluid Mechanics
- Introductory Soil Science
- Behavior of Chemicals in the Environment
- Water Erosion and Sediment Transport
- Hydrology
- Selection and Design of Best Management Practices (pollution abatement strategies)

Self-Assessment: On a scale of 1 (not so hot) to 5 (very well), how well do you believe you performed on this activity?

Figure 1. Higher order thinking activity used in a senior-level water quality engineering course.

The instructor's diagram is shown in figure 2. Sample diagrams generated by students during the activity are shown in figure 3. Figure 3a shows a well-conceived student response while 3b shows some conceptual flaws. Both the instructor's diagram and the well-conceived student response show a high degree of non-linearity in concept organization. These diagrams also demonstrate a more logical progression of concepts. For example, fluid mechanics, introductory soil science, and hydrology are prerequisites for the water quality engineering course. In figures 2 and 3a, these concepts appear near the beginning of the concept map. By comparison, figure 3b is considerably more linear in its construction with more simple linkages between concepts. In addition, some prerequisite topics, particularly soil science, do not necessarily appear at the beginning of the concept map.

As previously described, students were asked to self assess their performance on the activity before any discussion about the concept maps was undertaken. Performance was rated on a scale of one to five with one indicating "not-so-hot" and five indicating "very well." The average student self-assessment ($n = 19$) ranged from 1 to 4 and averaged 3.1. There appeared to be little correlation between self-assessment values and actual performance on the concept mapping activity. After discussion of the concept maps, most students still believed their earlier self-assessment to be appropriate.

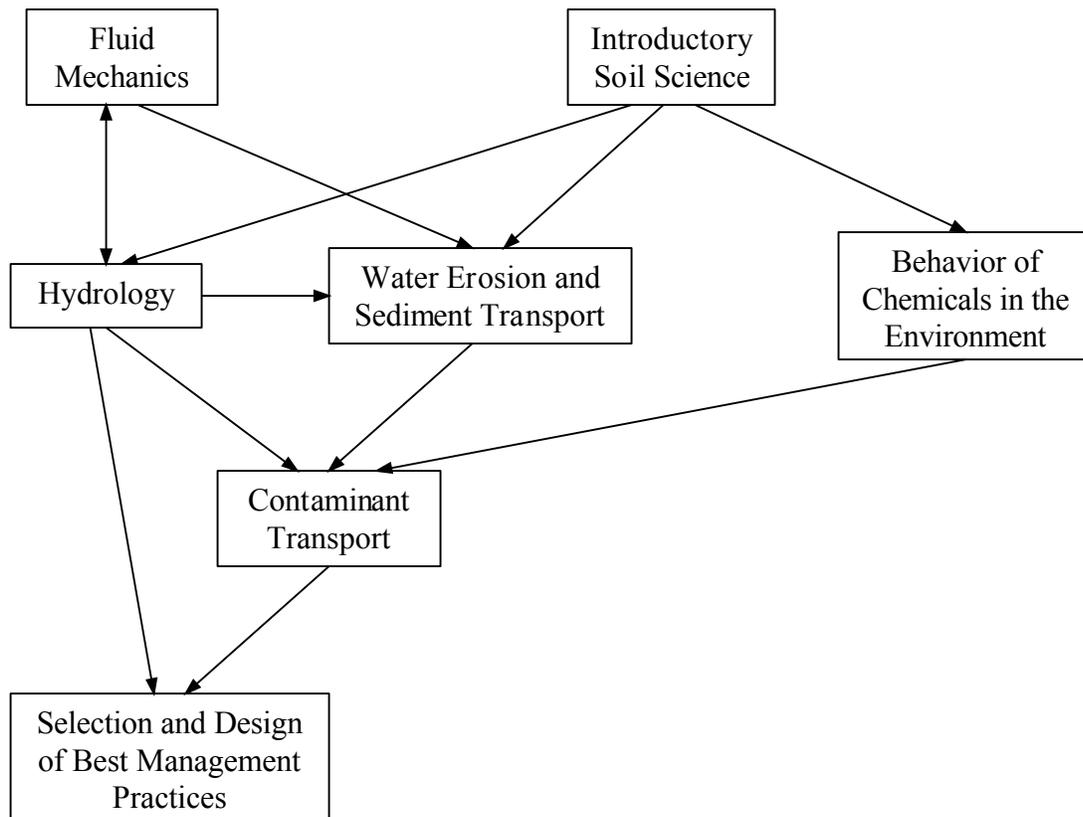


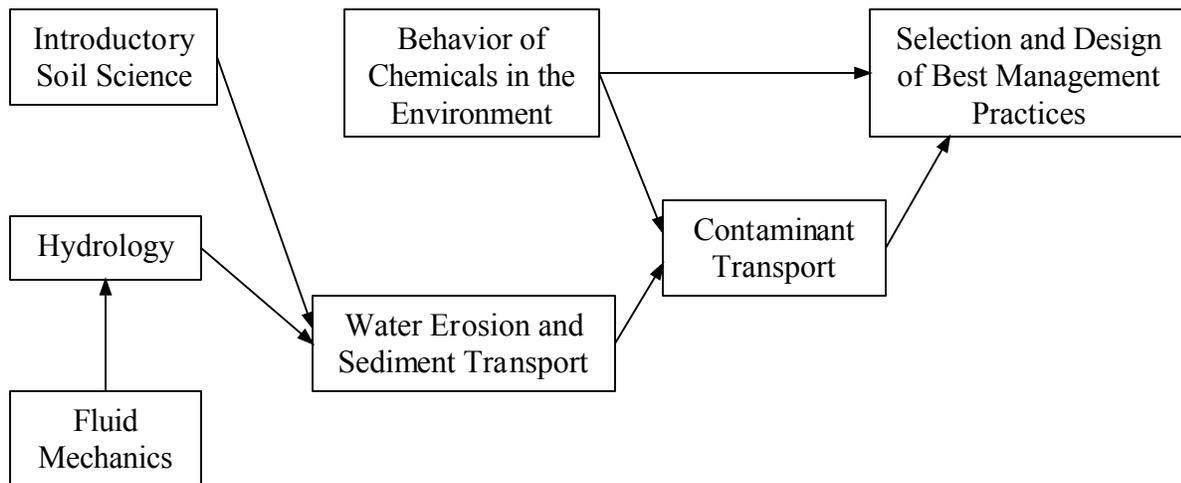
Figure 2. Instructors concept map.

Student Response to the Activity

Following the activity and discussion, students were asked to evaluate their experience. Questions used for the activity evaluation are shown below:

1. On a scale of one to five (one being very easy and five being very difficult), rate the difficulty of this assignment.
2. What aspects of the assignment, if any, did you find easy? Why?
3. What aspects, if any, of the assignment did you find difficult? Why?
4. On the assignment sheet, you ranked your performance on the activity on a scale of one to five. How did you rank your performance earlier?
Do you still agree with this performance rating? Why or why not?
5. Do you believe this activity helped you understand how the concepts covered in this class or its prerequisites fit together?
6. Would you like to see more of this type of activity used in this class? Why or why not?

A.



B.

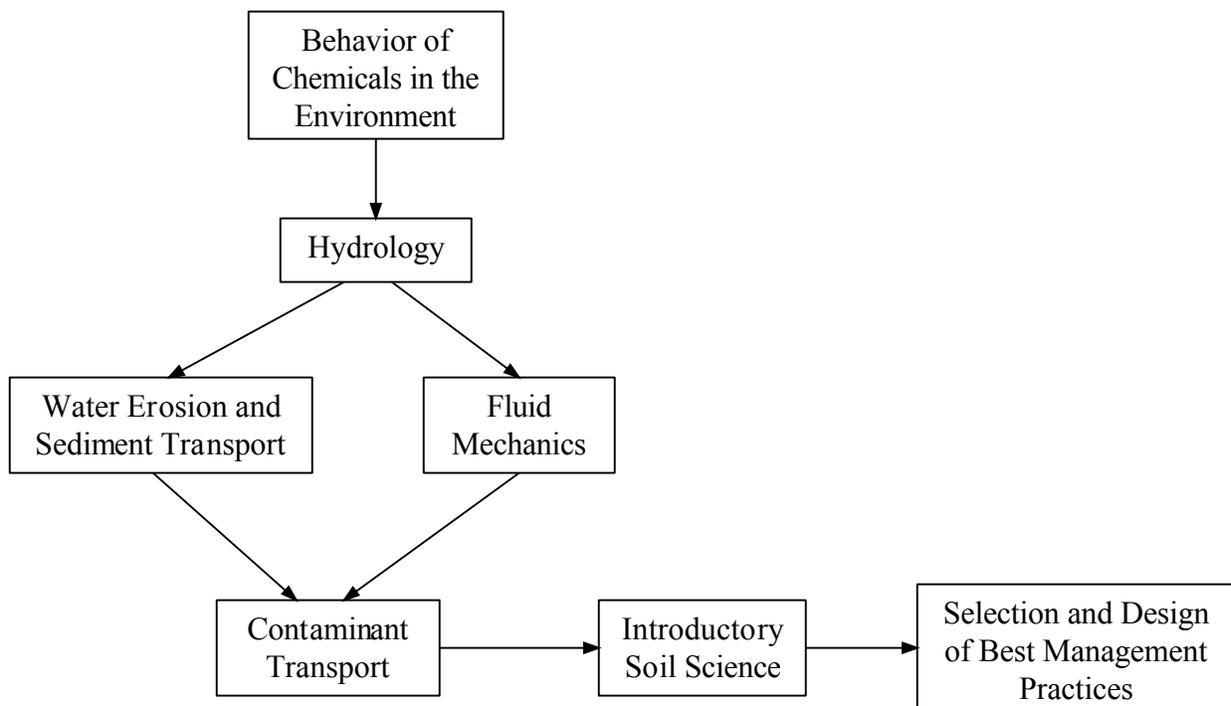


Figure 3. Examples of student work on the higher-order thinking activity. Figure 3A depicts a well-conceived concept map while figure 3B demonstrates some conceptual errors.

Student ratings of difficulty (scale of one being very easy to five being very difficult) ranged from 2 to 4 and averaged 2.9. Overall, students provided relatively little response when asked about the part of the assignment they found easy. A few students responded that they found the beginning of the concept map, which focused on prerequisite topics, easier because they were familiar with

those concepts and how they linked together. When students were queried about difficult aspects of the activity, two common topics emerged. First, many students found linking unfamiliar concepts to be difficult. One student summed up this difficulty by stating, "I found (it) difficult to make the chart because some of the subjects were unknown to me." The nonlinearity of the concept map was also a difficult aspect for many students. They were aware of multiple relationships between the concepts, but were unsure of how to illustrate those complex relationships in their map. One student commented, "It was difficult to place some of the concepts because all of the topics are fairly closely related. Some of the concepts seemed to fit in several places."

All students found the activity to be at least partially helpful to their understanding of how course and prerequisite topics fit together. Many students further indicated that discussion that followed the activity also facilitated their understanding of concept linkages. In addition, all students indicated that they would like to see similar activities used again in the class. While not specifically addressed in activity assessment questions, a number of students commented that the exercise required them to think. A selection of such comments are provided below:

- "I liked that this assignment didn't have an absolute answer be required some serious thinking."
- "...it makes me think about the concepts"
- "I ranked this assignment (more difficult) because it required me to think about the class structure instead of someone just dictating it to me."
- "I like this way. It encourages thinking and conclusion."
- "I enjoy reasoning through a problem then having the solution explained. I learn the material better this way. It is a refreshing change from simply restating facts the instructor gives you to show understanding of a concept."

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Biographical Information

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