Pedagogical Advantages of a Multi-phase Undergraduate Laboratory Project

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Abstract— **A four phase laboratory project has been developed and used in an undergraduate environmental engineering and earth sciences soils course. The project provides both independent and peer learning through the process as students work together and in teams in the different phases of this tiered approach. The project begins as students choose a unique facet of soils science to learn about as an individual and evolves into a group project where students create a laboratory exercise, evaluate a hypothesis and ultimately analyze the results and share them with their peers in a group presentation. The students are guided through this project by their instructor and they create written presentations, oral presentations, experimental designs and final conclusions from the work. Each step increases the depth of student understanding in an area where they expressed an initial interest. Students have responded very positively about the experience and reflected that it provides a unique learning opportunity. The framework can be adapted to a variety of disciplines.**

***Index Terms*— soil, environmental factors, Engineering Education, Student Experiments**

I. Introduction

In an effort to improve undergraduate engineering education, we use a variety of approaches including establishing assessment techniques, setting up outcome based objectives and focusing on student centered learning. Our goals in using these techniques are to provide practical problem solving strategies through our undergraduate engineering programs that develop lead our students into a successful engineering career. Techniques that carry student through several levels of learning are valuable from the educator's perspective because these techniques allow us to more closely observe this growth and development in our students.

Many techniques exist to define the level of learning and the development of thought processes in our students. These techniques start with the fundamental applications like Bloom's Taxonomy which was developed by Benjamin Bloom in 1956. He identified a pyramid of intellectual behavior that helps to establish different levels of learning [1]. In the 1990's this pyramid of taxonomy was revised from a 'noun' and idea based syntax to a 'verb' and action based [2]. The ideas can be applied to different disciplines and even to specific development within one discipline.

The new pyramid begins with a foundation level that requires learners to remember facts. Bloom defined this level as the *Knowledge* base and as undergraduate students explore new areas of their engineering discipline, *Remembering* the basic facts is essential. Learners in an electrical engineering program must learn the basics of current flow, mechanical engineers must learn the basics of stress application, Environmental engineers must learn the basics of natural system interactions. These foundational tools provide students with the information that is necessary to move forward to the second level of the taxonomy which focuses on *Comprehension* by Bloom or *Understanding* as defined in the revised taxonomy. If students can explain concepts, the ideas are clearer to them.

The taxonomy then moves to levels which use the information by applying information. This level is fundamental in the sophomore level foundational courses that are prevalent throughout many engineering programs. Many approaches work to take the 'textbook' approach out of the problems, working to develop more design style problems. The goal of these problems is to take students to the next level of the taxonomy which requires analysis of the information. Design problems may require students to define the problem that needs to be solved, not just work through textbook equations. This approach is sometimes successful, but many students are still working to master some of the fundamental information at the base of the taxonomy and are not quite confident enough with the material to analyze the information or move to the higher levels of learning while they are still mastering the fundamentals.

As students enter their junior level in an undergraduate engineering program, they still have many fundamental pieces to learn in their chosen discipline yet they must develop the higher level skills that are important for practicing engineers. The students must continually revisit the base of the taxonomy as they learn new concepts, but should be climbing to higher levels of learning through their work. As engineers, we are working to help individuals develop the creative skills necessary to design different treatment schemes or product models or building designs. These designs require all the upper levels of Bloom's Taxonomy to be a part of the process including creating

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designs as well as analyzing the design and evaluating alternative designs. Incorporating these skills into a one semester course in a new focal area within a discipline can be a challenge.

A practical laboratory project that assists in the transition between the base levels of learning and the upper levels of learning as defined by the traditional Bloom's Taxonomy has been developed and used for several years in an Environmental Engineering undergraduate curriculum. The goal of the project is to allow the students to be a driving force in the topic of interest as they move from layers of basic knowledge and understanding, through levels of applying and analyzing to the creation of a laboratory exercise which they evaluate during the process. The work also emphasizes the cooperative nature of engineering work in having individuals begin the work and then, based on their interest, be coupled with peers to complete the final components of the project. The project carries all students on the journey through the learning levels as the students interact in the lab and when they make their final presentations to the class. A peer review process requires students to evaluate their colleagues and the results of their work. The process allows students to learn about a variety of topics through the exercise. It allows the students to initiate some of the content for the laboratory course, it allows new perspective and ideas to develop and plant the seeds for future design work for these students.

II. Student Project Description

In the Environmental Engineering Program at Wilkes University, students in their junior year are transitioning into design work for their engineering discipline. The transition is challenging for students as they move from the classic problem solving approach that is found in many undergraduate engineering foundation courses into the more advanced design course and design work in their upper level courses. More than that, the focus of the junior level courses are more specific to sub-disciplines in the field. Students must learn background information in soil science, water quality and air quality so that they have the information necessary to design treatment systems in solid waste systems, water and wastewater treatment systems and air pollution control treatment systems. In their junior year, students need to develop the skills obtain foundation pieces but still need to develop the higher learning levels that require creative, evaluation and analytical skills. To achieve that transition, a phased project has been developed that carries students through the phases of learning so that they are ready to address the engineering design problems creatively and with developing confidence.

The handout that describes the project is provided with the course syllabus and the work is carried through until the final lab exercise in the course. By beginning the project at the start of the semester students can bring in their fresh ideas for the topic of the course and develop these ideas prior to being swayed by the context of the course. New ideas and approaches to problem solutions sometimes come with those who have little background information but creative approaches to problem solving.

Most projects start as complex problems which requires students to go through several steps to solve. Through the four phases of the project the students move into all levels of learning through the several steps needed to define and develop a clear statement of the complex problem.

A. Phase 1

The first phase of the project requires the student to identify an issue in the course field of topics. It is recommended that they chose a topic that is interesting to them, currently being developed and perhaps not reviewed in detail in the course. Students are provided with some suggestions, but many come into the course with an interest in a specific sub-discipline of the field that may not be covered in depth in the course. The first phase requires a short written document that describes this issue and a short virtual presentation on the issue. The presentation is placed on the class website so that all students can review all the topics. There is limited restriction on the topic students can choose. The first phase is exploratory and individual work. The students explore topics and are at the lowest two level in Bloom's Taxonomy focusing on increasing their *Knowledge* and *Comprehension* of the topics. Students are asked to review all the phase 1 project presentations online and are not required to keep to their initially selected topics as the project develops.

B. Phase 2

The second phase of the project asks students to delve deeper into a chosen area of interest. They may use their initial topic as a baseline or may build on a topic suggested by another student. The focus of the second phase is to identify the problem or concern with the chosen area. The second phase takes students from the two baseline levels in the taxonomy and requires them to move toward the *applying* and *analyzing* levels.

Considering an example of a student topic may help to illustrate the development of the project. A student who has chosen erosion as their phase one topic needed to define the term and understand where it was relevant. For their second phase, they need to identify a specific concern with that topic. The student would need to choose an area where erosion creates a concern or illustrate how different soil types present different levels of erosion concern. These ideas are a part of applying the information learned in the first phase that defined the topic of erosion and also brings information from the course into the topic by considering different characteristics of soils and how they may be relevant. The second phase also asks students to write an action plan to address the topic of interest. They must move toward analysis of the concern in a more real and tangible way by presenting suggestions of laboratory work that can test a hypothesis that addresses the concern. This carries them into the analysis area where they question, compare or contrast different situations that will help them to more clearly understand the problem they have defined he work is still by the individual and the output includes a short written report and short virtual presentation which are again both placed on the course webpage for the class to review.

C. Phase 3

In the third phase of the work, the students no longer work individually. The instructor takes an active role in the third phase of the project. Upon review of their phase one and phase two work, the instructor groups students with similar interests into working groups. The topic sometimes is slightly redefined to allow for a more practical development of the laboratory work. Students are assigned a topic which may include elements of the work of all the students in the team or may focus more closely on a facet of their work. The work carries students to the peak of the updated verision or Bloom's Taxonomy by requiring students to formulate a hypothesis, develop an experiment and assemble the appropriate equipment to execute that experiment. The third phase proves to be very challenging for many students and requires multiple discussions with the instructor. One of the challenges is to design an experiment that can be accomplished in the allotted time with the available resource. The third phase is the design phase of the work and takes several weeks to develop. Developing a good project requires the instructor to be clear on what the students are doing and requires the students to design an experiment with measurable outcomes

The third phase also includes the execution of the experiment. Two lab weeks are allotted for the lab work. The better prepared students are for the work, the more significant the results. The instructor must sometimes work in creative ways to assist the students in designing experiments to meet the time and results criteria.

D. Phase 4

The final phase of the project requires the analysis and evaluation of the experiment created by the students. This actually steps back down the pyramid defined in Bloom's Taxonomy by focusing on the *Evaluating* and *Analyzing* steps. The thought process during this phase also carries students through the engineering design loop where the created design is reevaluated and perhaps redesigned to improve the overall product or results from the work.

Students are required to create a final project report that is evaluated by the instructor. They also create a ten minute presentation that is provided to the class during the final lab session. Specific information is required in the final presentation so that all students see the development of the project including minimal background information, clear description of testing, graphs of laboratory results, and conclusions drawn from the laboratory data. The goal is to help the students be as clear as possible in the presentation of their results, being quantitative rather than qualitative.

Visual information is required for the final presentation and students must work to present conclusions that are as clear as possible. Students evaluate their peers on the presentation and the development of their project. This again has students revisit the taxonomy as objective reviewers of the information that is presented.

III. Student Response

Students have found the project engaging and a good learning process. Some have comments that they have not been a part of this kind of experience in the undergraduate work. In our curriculum, the course falls after the fundamental engineering and science requirements and begins to provide students a chance to be creative and explore hypothesis through their own work. The junior year placement allow it to serve as a good foundation to their senior project capstone work. Students have the have the opportunity to design and execute a larger project with fewer boundaries. Students have been very positive about the results they have seen. Not all students perform the same tests, so that the final presentation is interesting because the students spell out their process and share how their project has developed.

IV. Instructor Response

The project does make an interesting facet of the course from the instructor point of view. Because the students initiate the topics, the instructor must work to keep up with their ideas and work to encourage them to develop those ideas. Students set the bar for the laboratory project and the instructor must work to keep them grounded and help them to identify the right questions to ask. The instructor acts to facilitate the project by helping the student to take their ideas and develop the testable components and coordinating and ordering supplies to accomplish the purpose.

The students have been empowered during the work and some have been amazed at their own findings. In an undergraduate education, this is a valuable piece. Participating in the process of discovery with the students keeps the motivation of the students high as well as the faculty. The faculty has the opportunity to get to know the students better and to more clearly see their interest in a facet of the subject area. Through the process, their interest in the field or their personal history becomes a part of the project. It offers an opportunity for students to become involved with some cutting edge ideas through a relatively simple laboratory protocol. It is valuable to the students and provides a new way to learn the material.

The project also provides a way to help students interact and work with other students based on their interests and moves students out of the typical groups they fall into when working together. The mix of lab partners creates a good opportunity for learning new ideas and creative thought and hearing information from another person's perspective.

V. Continual Development of project

The project has been used for four years in its present format. The opportunity exists to improve the project by adding an additional phase or striving to encompass some additional levels of learning as defined by Blooms taxonomy or the engineering taxonomy. One distinct advantage of the project is that as the students move through the course, new ideas move with them. This new exchange of ideas keeps the course material current and developing.

VI. Application to Other Disciplines

This specific project has been applied in a soils science that focuses on undergraduate environmental engineering students. The idea of a multi-phased developmental project can be applied to any undergraduate engineering discipline. The project design works more effectively in a course with a laboratory format so that students have the time to work on the hands on activities that connect ideas with practical situations. Many approaches to engage students in active learning have been developed and shared. This example has provided valuable results from the perspective of both the instructor and the students who have participated.

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