



Bringing Creativity into the Lab Environment

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Bringing Creativity into the Lab Environment

Introduction

In a day and age where much of our nation's infrastructure continues to erode and degrade at rates much faster than we are able to maintain and rebuild,¹ civil engineers need to be creative problem solvers more than ever before. This means that both the civil engineer of today and especially those of tomorrow need to be innovative, creative, inventive, inspired, and original in learning how to do more with less. It is not any surprise then that the American Society of Civil Engineers (ASCE) is also simultaneously pushing to see these types of skills integrated into academic curriculum. ASCE has indicated that one of the attributes that should be embraced by the Civil Engineer of 2025 is creativity, leading to "proactive identification of possibilities and opportunities and taking action to develop them."² ASCE has further indicated that civil engineering students need to also develop the ability to critically think.³ If our civil engineering students are to achieve success in professional engineering practice, they must develop the ability to both think critically and be creative. One specific location that civil engineering curriculum can be appropriately targeted for strengthening the innovation and creativity skills within students is within the laboratory setting.

A colloquy held in 2002, established thirteen different fundamental objectives of engineering instructional laboratories.⁴ Of these, several specifically feed into the notion of students learning and exercising innovation and creativity in the lab, including learning about appropriately using experimental approach, collecting and analyzing data, designing and building experiments, learning from failure, demonstrating independent creativity, selecting and appropriately using engineering tools, and making sound engineering judgments in formulating conclusions about real-world problems.⁴ In the Civil Engineering Body of Knowledge for the 21st Century the rationale for including experiments as a civil engineering outcome includes the following statement: "inquiry-based learning emphasizing the method of discovery helps to develop the critical thinking skills necessary in learning the experimental process."³ In addition, critical thinking helps "develop engineering judgment, necessary in interpreting and analyzing results of experiments."³ Lau explains that critical thinking in essence promotes creativity.⁵ While laboratory experimentation is indeed a critical component of a civil engineering student's undergraduate education, there is a need for civil engineering programs to place more emphasis on inquiry-based learning within the laboratory environment to foster critical thinking and creativity growth within students. The primary purpose of this paper is to present one program's efforts in establishing inquiry-based lab experiments and likewise fostering student creativity within the laboratory environment.

Implementing Creativity in Lab Experimentation

One of the key elements in inquiry-based lab experimentation is to allow students to formulate their own lab experiments and exercise creative thought while developing their own ideas, applications, processes, and analysis techniques. A traditional lab setting often includes having the students follow step-by-step procedures as outlined in the lab manual. However, it is typically not the intention of the laboratory exercise to train the students to become lab technicians. Rather, the principal purpose in putting our students in the laboratory setting is to

enhance and supplement their understanding of the concepts and principles being taught within the classroom. However, students should also begin to strengthen their understanding of how and why experiments are conducted, and think “outside of the box” on possible ways to conduct experiments. The laboratory environment should be a place where students can experiment and take risk,⁶ reinforce conceptual understanding, cultivate professional and social skills, develop abilities towards scientific inquiry and engineering design, and through these processes, refine their epistemological beliefs about engineering.⁷ Designing laboratory experiments that can meet all of these end results can be challenging and faculty often simply establish course goals as opposed to student learning objectives.⁸ With this in mind, this paper was put together to demonstrate a variety of ways in which inquiry-based experimentation can be implemented within different civil engineering laboratory courses and to provide ideas for other programs seeking the same efforts.

There are numerous examples within the literature of efforts to improve the undergraduate engineering lab environment and generate more meaningful educational experiences for students.^{9,10,11,12,13,14,15} It is beyond the scope of this paper to provide a summary of these experiences, but the authors do note that they exist. Rather, it is the intention of this paper to illustrate specific examples of ways that creativity and innovation were implemented within pre-existing laboratory courses and discuss how this has strengthened the laboratory experience for the civil engineering students. Furthermore, it is not the intention of the authors to provide this information expecting that other programs will make immediate drastic changes within their curriculum to introduce similar assignments (although readers should obviously feel free to utilize any of the ideas provided), but rather to use these examples as a means of identifying potential for implementing more creativity and innovation within their own existing laboratory classes. The following represent a brief description of laboratory assignments that include a specific creativity aspect in the civil engineering program at the University of Texas at Tyler (UT Tyler). It should be noted that creativity within the laboratory environment does not have to be exclusive to lower division coursework, but rather creativity should be included throughout the entire undergraduate curriculum. Finally, the examples contained within this paper don’t represent every attempt in implementing creativity within a laboratory course that has been made, but rather some of our more successful ventures.

Introduction to Engineering (Freshman Level)

The introduction to engineering type course is often one in which instructors do attempt to implement creativity within a laboratory setting. These types of classes tend to include a definite “hands-on” component, often as a means of strengthening retention.¹⁶ The University of Texas at Tyler Introduction to Engineering course includes a laboratory component where students must utilize innovation and creativity to solve problems in multiple engineering disciplines. Although most of the lab assignments contain some aspect of creativity, the following are the principal laboratory exercises that fit this description:

Truss lab assignment: The truss lab assignment is a civil engineering specific assignment. Students are tasked with using K’NEXTM elements to construct a bridge that meets certain dimensional constraints and can sustain a pre-defined load (typically four very large textbooks). Students are given a brief introduction to truss behavior, including the concept of tension and

compression members and the use of triangular truss elements, and then student groups are set free to design and construct a bridge on their own. Generally speaking, students are allowed to stumble their way through the exercise, but the occasional reminder of general truss principles or other tips on bridge behavior may be provided to a group completely drifting in the wrong direction.

Motor lab assignment: The motor lab assignment is a mechanical engineering specific assignment. This assignment is similar in scope and purpose to the truss lab assignment, except that torque and power principles are explored as opposed to basic statics principles. Students are tasked with constructing a motor, using LEGO® motor components that can lift a specified weight. Once students are able to accomplish lifting the specified weight, they are challenged to work on producing a more efficient and/or quicker motor.

Final project: For the final laboratory project students are tasked with incorporating civil, mechanical, and electrical engineering disciplines into a single design project. Student teams are assigned to design and construct a given structure (such as a drawbridge, elevator, or crane) using K'NEX™ elements for the structure and LEGO® motor parts to perform a specified mechanical task (such as lifting the drawbridge). Figure 1 shows a drawbridge constructed by one of the student groups. Students also integrate an electric circuit to control the specified mechanical task. The premise of the final project is for students to implement skills learned in earlier laboratory exercises, and integrate them into a functional working multi-disciplinary structure. Students must be creative in designing each of the individual components. Since the components don't directly work with each other (LEGO® and K'NEX™ don't readily "connect" together) students have to be creative in anchoring their device, securing the different components, and in general getting the task to work. This particular set of lab assignments has proven to be fun, educational, and has even helped retention of freshman engineering students at UT Tyler.¹⁶

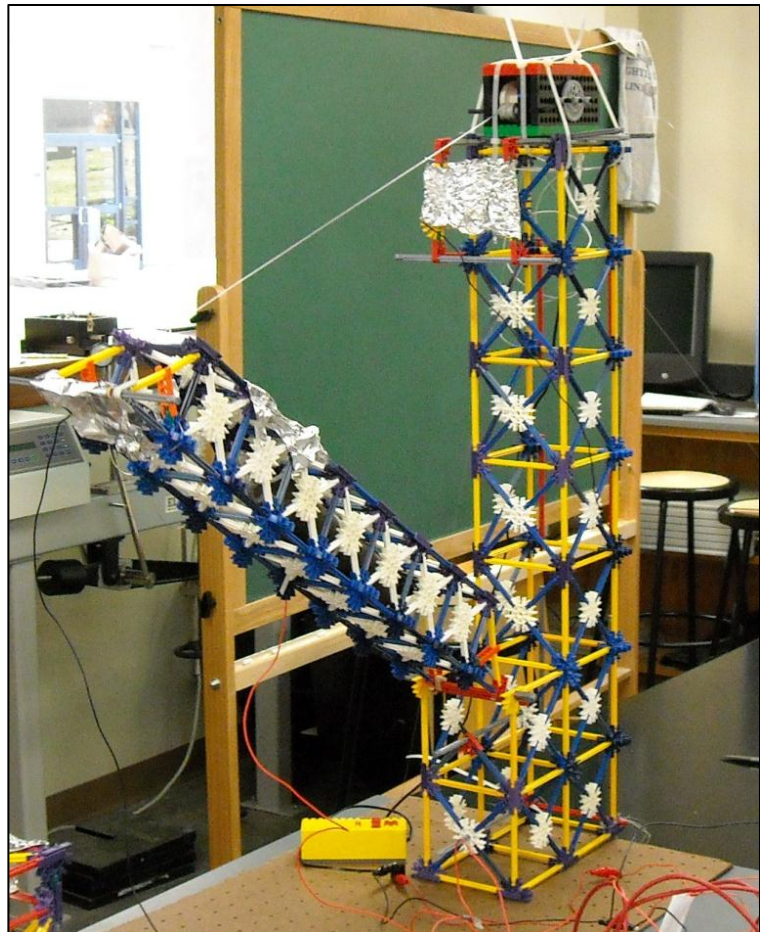


Figure 1: Final project in Introduction to Engineering course - drawbridge design.

Civil Engineering (CE) Measurements (Sophomore Level)

One of the principal course objectives for the CE Measurements course is for students to develop an organized approach to designing an experimental measurement system and conduct a physical experiment to solve civil engineering system analysis and design problems. This class includes a weekly lab session in which creativity and experimental design are a significant element. Several lab assignments were developed with student creativity and innovation in mind, but many were simply pre-existing laboratory assignments modified to include the creativity component. The following include a brief description of the principal labs that include a student creativity element.

Estimation lab: This is the introductory lab for this course and the two principal objectives include 1) students generating accurate estimates of civil engineering systems and 2) communicating their methods for estimation (through demonstration of field sketching/notes and adequately explaining assumptions and techniques used for estimating). In this exercise, students are asked to estimate the height and weight of the UT Tyler bell tower as well as the current surface area of a campus pond, volume of water within the pond, and the potential maximum storage capacity of the pond. To assist students in developing their innovation and creativity skills, students are not given any specific directions on how to do the estimation, nor are they given any tools with which to do so. Rather student teams have to develop a methodology for doing so. The purpose of this laboratory exercise is to instill within the students the importance of estimating measurements. Although there are many different ways to take measurements precisely, as an engineer they must be able to quickly make accurate estimates and recognize whether or not the magnitude of an estimate appears reasonable. The term estimate does not have to mean sloppy, inconsistent, nor inconclusive, but rather, the term estimate should mean “best approximation with the tools at hand.” Additionally, communication is important in explaining how the student’s estimates are gathered. Field sketches and notes should be clear and legible and as accurate and to scale as possible. Therefore, in addition to developing realistic results, emphasis in this laboratory exercise is placed on having students explain the process that they use to establish their estimate (not just pulling the number out of the air). In essence, students are asked to assess and justify their creativity in this exercise.

Developing experiments: The two primary objectives in this lab include 1) having the students develop and set up an experimental laboratory procedure and 2) explain their experimental process and results. In this assignment, the students are simply asked to develop and conduct a design experiment to determine the weight, volume, and density of an ordinary U.S. penny. Students are given the following tools with which to work: K’NEXTM pieces, a wooden dowel, string, full and empty 0.5 L bottle of water, \$2.00 in pennies, a graduated cylinder, and a tape measure or ruler. Students are also given a hint that pennies after mid 1982 weigh less than those produced before then, with a ratio of these penny weights being 1.244. Students are allowed to look up the weight of water if they do not know it. The purpose of this laboratory exercise is to demonstrate to the students the importance of utilizing creativity and resourcefulness in setting up and conducting a design experiment, since in the real world they are not always given specific experimental directions or the processes required to take an engineering measurement.

This lab exercise is intended to help the students explore their ability to “think outside the box” and become problem solvers. Furthermore, this lab tests their ability to achieve accurate results using non-typical methods. As in other labs, communicating their process and results (both verbally and graphically) is as equally as important (if not more) than conducting the experiment itself. Students are asked to submit a group report that included an explanation and theory of their procedure, an explanation of results (including calculations), a discussion on accuracy, and their conclusions. They are also asked to include a diagram or clear photos of their experimental setup and to clearly identify and explain any assumptions that they may have made. An important final component of this lab includes asking the students to provide an assessment of their experiment, explaining how they felt that they did, what they would change if they were to do it again, and what they learned from this experience. This step is important in helping students assess their creativity and learn to acknowledge both strengths and weaknesses in their efforts.

Introduction to Visual Basic for Applications (VBA) programming: This particular topic consisted of several different lab exercises, intending to explain basic VBA language elements and then using VBA programming within Excel to perform basic functions and decision making. Although there are a number of preliminary tasks associated with understanding how to interpret and write VBA programming constructs (in other words, teaching fundamental VBA programming), the final task allows the students to exercise their creativity in utilizing their freshly acquired skills in writing a small computer program to explore available options in fixing

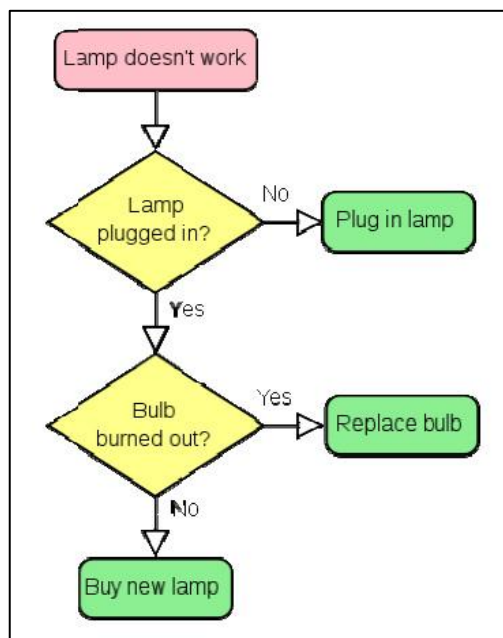


Figure 2: Lamp assignment.

a broken lamp. Figure 2 is given to the students and they are asked to develop the code that provides input boxes to address the questions, and provides corresponding message boxes with the appropriate user response. The earlier tasks (included within the initial VBA lab exercises) provide the students with a sufficient knowledge base to develop the final code themselves. Generation of computer code inherently requires that students be creative problem solvers and apply their programming skills in doing so. The purpose of the programming labs used in this course is not to help the students by any means become fluent in a programming language (since this was not the scope of the class), but rather to help them understand basic programming principles and how they can be utilized in solving problems. Students are also asked to submit a self-assessment of their program by explaining what process they used to write their code, what they learned from the exercise, and the value of using VBA programming in their spreadsheets.

Direct current (DC) circuits: The principal objectives of this lab are to 1) have students learn how to set up simple DC circuits, 2) measure and calculate resistance, voltage drops, and current in a DC circuit, and 3) explain how a Wheatstone bridge works. The creativity component is in the latter part of the lab. Instead of students being taught the theory behind how a Wheatstone bridge works, students are simply asked to take measurements and then to deduce how it works from

there. This includes asking students to develop the circuit math to support their measurements. Students are given an overview of voltage drop and resistor math in the classroom, and therefore have the foundation that they need to perform this task. All too often students are simply given all the theory they need prior to performing a lab experiment, and then set free to verify their results. In this case, the final task includes allowing the students to have the results and then develop the theory themselves. Using this technique allows the students to explore the concepts and exercise inquiry-based experimentation.

Cantilever flexure: The principal objectives for this lab include 1) measuring the strain of a cantilever beam with a strain gage, 2) calculating the corresponding stress applied to the beam, and 3) plotting and interpreting the stress-strain curve. This lab had formerly been prescriptive with students following a specific set of procedures and all lab groups getting “the answer.” However, to incorporate a creativity component within this lab and to help the students better understand some of the other foundational principles behind stress and strain, an additional objective was added requiring students to experiment with load and deflection for various shaped beams. Students are provided three different rubber beam shapes (rectangular, I-Beam, and circular) and measure the cross sectional dimensions of each with a set of calipers. These beams are ordinary rubber beams and students have to utilize their creativity in setting up an experiment to measure the deflection for various loading scenarios. Students are asked to make every effort to utilize accuracy and precision in their experiment. Using a simple set of hanging weights, rubber bands, and a ruler, students perform five different cantilever tests (including both cross-sectional directions for the rectangular and I-beam) and measure the corresponding deflection for each applied load. Students are provided a hint to ensure that the cantilever lengths are the same for each beam so that a true comparison of deflection for the different shapes can be made. Students are then asked to calculate the moment of inertia for each shape so they can discuss bending resistance appropriately. The students are finally asked as part of their assessment to comment on the importance of utilizing accurate tools in performing an experiment.

Velocity lab: The single objective in this lab is for students to design and conduct their own experiments to measure velocity for different civil engineering applications. By this point in the semester, the students have become quite skilled in the art of designing and conducting experiments. This lab continues to build upon those principles, but also places an emphasis on thinking through the approach utilized in gathering the measurements. Students are asked to really think about the variables (controlled and uncontrolled) that might affect the results, attempt to minimize error, and consider replication and randomization of their results. Each of these is to be addressed in their assessment. There are three different tasks assigned; the first task is to measure the average stream flow velocity of one of the campus water features; the second task is to measure the average traffic velocity on an adjacent campus roadway known for cars often traveling at a higher than allowed rate of speed; and the third task is for students to measure soil seepage velocity in one of the many grassy areas around campus. Students are allowed to utilize materials, equipment, and tools that they personally have available and as an added incentive, teams are awarded points for creativity and uniqueness to be awarded at the discretion of the instructor. It should be noted that students are cautioned to obey all safety rules and to not leave any trace of their testing behind.

This lab assignment is more about procedure than it is about results and serves as a direct assessment of the student's abilities to be innovative in setting up their own experimental procedures. The following questions are assigned to be addressed in the lab submittal: What was the student's approach to their experimental setup and procedure? How was the experiment conducted? What equipment was needed? How did their actual experiment compare to their original experimental concept and design? What adjustments did they have to make during experimentation? Students are also asked to discuss the controlled and uncontrolled variables considered, their approach to replication and randomization of their testing, what they learned from this exercise, and to provide a general assessment of their laboratory experience.

Friction experiment and presentation: The culminating project in this particular course (as far as creativity is concerned) requires the students to design and conduct an experiment to measure friction of different walking surfaces. Students are assigned to work in teams of three, and tasked with designing and implementing an experiment to measure the wet and dry coefficients of friction on three different walking surfaces, including concrete flagstones, tile hallway floors, and the surfaced pedestrian walkway bridge between two adjacent campus buildings. Students are given the assignment sheet a week prior to the lab period, in order to prepare to actually perform the experiment during lab time. Student teams present their results as a formal presentation to the entire class, the week following their experiment. Students are only allowed to use materials, equipment, and tools that they personally have available, and as with other lab assignments, teams are awarded points for creativity and uniqueness. As part of their project report and submittal, students are asked to provide background regarding the purpose of the project, issues involved, locations tested, their experimental setup and procedure, include their approach, how they conducted the experiment, equipment that was utilized, how the actual experiment compared to their original experimental design, and what adjustments they had to make during the experiment. Students are also asked to consider and explain the controlled and uncontrolled variables that were encountered, their process for minimizing error, their approach to replication and randomization of their testing and to show results supporting this claim, a discussion of what they learned from the exercise, and an overall assessment of their laboratory experience. Furthermore, students are asked to explain their creativity process and what it is that makes their experiment unique.

This particular lab exercise is utilized as a tool for measuring the CE program outcome at UT Tyler that "students can design and conduct experiments, as well as analyze and interpret data in more than one civil engineering discipline." After working to develop and strengthen their abilities to be creative in developing and performing earlier lab experiments, this assignment then allows the students to pull it all together into a single challenging task that allows them to use their creativity in designing, conducting, and reporting their results for an experiment testing the friction of three different walking surfaces. The students are not given specific instructions on how to perform the experiment, but rather only considerations that the students should implement during their test. Students generally do well on this assignment. The most common solution that students utilize is using spring type force gages (see figure 3), some being commercially purchased (fish scales) or creating their own force gage by calibrating a spring. There are two essential considerations that the students have to account for; first, they have to find some way of measuring the reactive force along the surface, and second, they have to consider what type of material to use as their frictional surface acting in contact with the concrete

walkway. This assignment has become a faculty and student favorite, because of the allowance for exercising creativity in solving the problem. The students generally approach this assignment with an open mind, and put forth an honest effort. Having the students consider controlled and uncontrolled variables, as well as



Figure 3: Experiment developed to measure friction.

randomization and replication during the design experiment, also forces the students to really put forth an effort in the development of their experimental design and implementation therewith.

Preliminary civil engineering (CE) design: The final lab session of the semester is used to incorporate what students have learned about creativity throughout the semester and apply it in a general sense to civil engineering design. This lab session is a good fit for this class, and after having had the students “practice” their creative skills the entire semester, it seems prudent to begin to bridge the general idea of creativity with the reality of implementation in engineering design. The students really enjoy this final preliminary design project. For this lab assignment, students are tasked with putting together a preliminary civil engineering design of a new hospital. Students are given a fictitious piece of property (see figure 4) and told that the hospital can be located anywhere on the property map, with the exception of displacing the neighborhood farm house. The only other general considerations given are defining power and sewer lines running adjacent to the highway and vectors shown on the map indicating general slope and drainage of the area. There are a number of basic constraints that the students are provided (such as size, parking, and roadway considerations, as detailed below) and the students are set loose. Students are also told that “Farmer Brown” is not happy that a hospital is being built adjacent to his home, and that students should do their best to minimize the impacts to this family.

The given hospital constraints include the following: the hospital is required to have a minimum of 50,000 square feet of floor space, can be no more than two stories tall at any given point, and must be located a minimum of 500 feet from the river. Students must estimate the size of a standard parking stall, include parking for at least 300 vehicles, and consider driving lanes in the parking areas. Students are asked to design the layout dimensions and parking for their hospital, and include a sketch with the layout map (figure 4). They are also asked to explain why they chose their specific location, dimensions, and their considerations for access to the hospital based on their parking scheme.

Constraints are also provided for highway conditions. Traffic on the highway runs around 180 cars per hour per direction during peak times, and students are asked to provide an estimate of how much the traffic volume would increase for the hospital and the rationale behind that decision. Students are further asked to design a roadway system to connect the main highway with the hospital, including safety features for traffic exiting and entering the highway and appropriate roadways for parking, emergency access, and other features as deemed necessary.

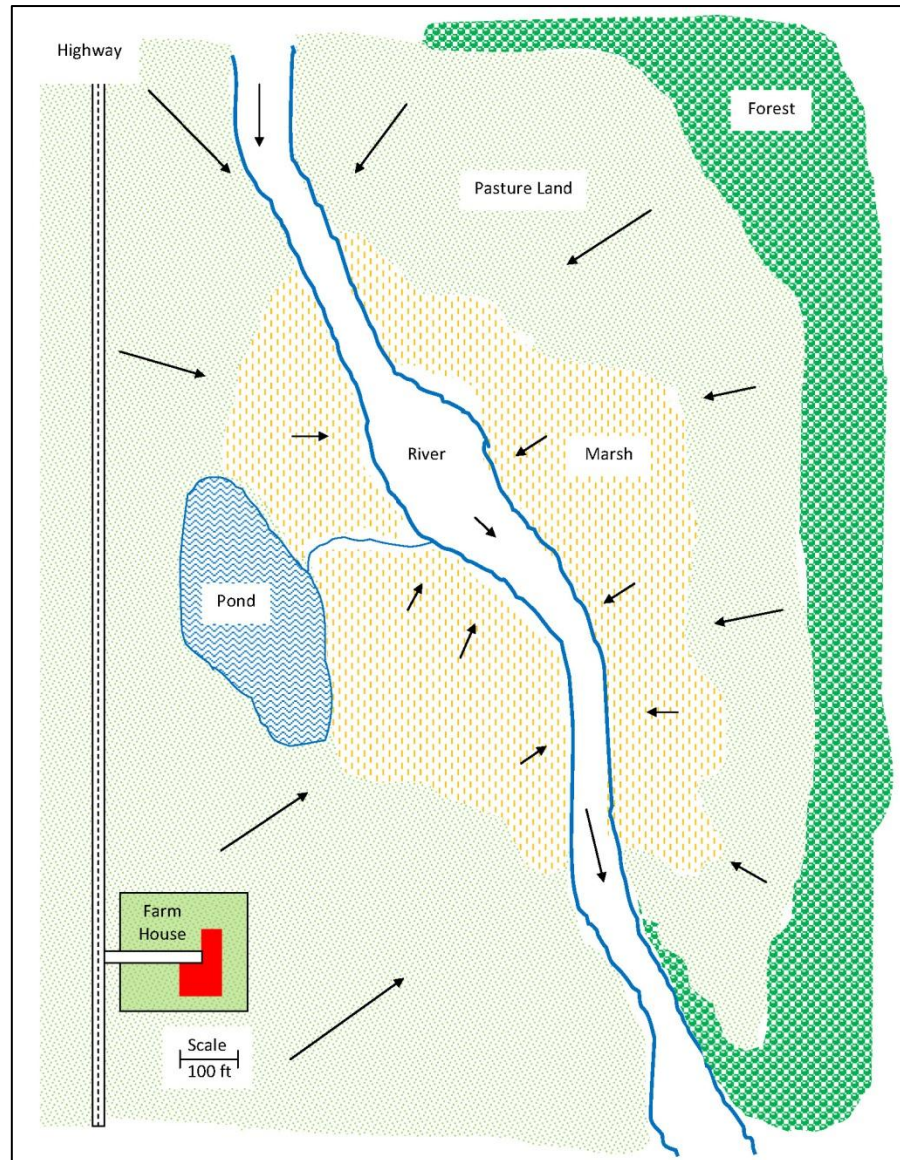


Figure 4: Generic layout map for CE preliminary design assignment.

These too are required to be sketched onto the layout map provided. Power and sewer constraints are given in that students are asked to consider how to get electric power, as well as water and sewer lines to and from the hospital. As for aesthetic constraints, students are asked to try and minimize the impacts of the construction to the surrounding landscape. Therefore students should attempt to incorporate the natural features of topography and nature into their hospital layout, while maintaining the natural beauty of the area. Since this is the culminating lab exercise, students are asked to identify and consider any potential measurements that must be considered for the principal civil engineering disciplines. Other constraints, including environmental or sustainability, could also be easily added to this assignment.

This particular assignment includes explanation detailing the constraints explained above, but students are also given a series of blank pages to explain their considerations and provide

additional design sketches for the hospital dimensional layout and parking lot diagram, roadway design, power and sewer constraints, aesthetic constraints, and any other considerations that might have been explored. As sophomore level students, they have very little specific design knowledge, and will probably not get things correct according to appropriate CE design standards. However, the point of this exercise is not to get a correct design, but simply ask them to be creative in their preliminary design. It is surprising just how much a little creativity helps the students come up with some very good assumptions. Although this particular lab exercise as described above is performed in a single session, the general concept behind this type of lab is powerful, and can easily be broadened to suit the needs of any program.

Soil Mechanics (Junior Level)

In the junior level laboratory classes, the lab exercises tend to become more prescriptive and many programs simply have students follow set procedures based on specific laboratory testing standards. It is not the intention of the authors to discredit lab testing procedures or standards. However, it is common for instructors of junior level laboratory courses to exclude the creativity and innovation element. These lab courses are typically used to supplement principles and concepts taught within the classroom, and provide a hands-on approach to demonstrating such. With a little bit of creativity, it is still very possible to utilize creativity and inquiry based learning techniques in a junior level laboratory course. The following examples include junior level experiments that integrate student creativity with student learning centered principles. As mentioned earlier, there are a number of laboratory classes at UT Tyler that have experimented with integration of a creativity component, but these are the more successful assignments that have been developed thus far.

Constant head permeability test: The constant head permeability test is a laboratory test that utilizes very straight forward theory integrated with fairly simple laboratory testing equipment. Having the students develop their own constant head permeability test is one of the simplest applications of integrating a true design experiment into an introductory geotechnical engineering course. The parameters that the students need to obtain during the experiment include the volume of water for a certain amount of time, the change in head (gravity fed water of course using elevation differential), and the volumetric dimensions of the soil specimen (length and cross sectional area of the soil specimen). Ideally the students simply need to come up with a chamber for the soil specimen (it doesn't really matter what shape the chamber is, so long as the students know the cross sectional area and it remains continuous throughout the length of the sample) and design the means of providing constant flow of water through the specimen. The design can be approached in a couple of different ways. Students can be provided a box full of assorted plastic bottles, tubing, or other miscellaneous items and the groups have to develop their experiment with the materials provided (analogous to the NASA engineers in the movie Apollo 13). Another approach is to have the students brainstorm ahead of time and provide their own test apparatus. This is most effective if a dollar limit (no more than \$5 or \$10) and/or other constraints are imposed on the supplies that students can use. Because the input parameters within the experiment are straight forward and the test is easily run, the students can actually still get very good results. A follow up exercise is to have the students run a similar test using professionally produced equipment (ensuring soil density is the same) and compare results.

Rammed earth challenge: Another student favorite lab exercise that has been used at UT Tyler is the “rammed earth challenge.” In this laboratory session, the students don’t design the experiment itself, but rather the soil specimen that is tested. The students are asked to investigate and develop their own “secret recipe” for strength. Students are asked to use only natural soils (meaning no cementitious materials allowed) and then construct a cylindrical specimen in a standard proctor mold. They are allowed to use whatever lift heights they want and apply as much energy as they want, so long as these values get reported as part of their submittal. After the lab groups have made their specimens, the rammed earth specimens are extruded and left to cure (air dry only) for one to two weeks. On testing day, the students gather around the Tinius Olsen compression machine where the specimens are tested. The stress-strain behavior of the soil specimens is recorded and provided to the students to analyze as part of their submittal. Figure 5 shows the results of the nine specimens tested during the 1st annual rammed earth challenge, including the highly suspicious group 8 results, which group promptly confessed to using synthetic modeling clay as a binder in their “secret mix.” Of course bragging rights go to the group that carries the largest load. Students seem to thrive on competition in the classroom, and creative lab experiments can be a great source of competitive learning. As with all of the other laboratory assignments discussed within this paper, students are asked to assess their experience and indicate what they did well and could do differently if they were to perform the experiment over again.

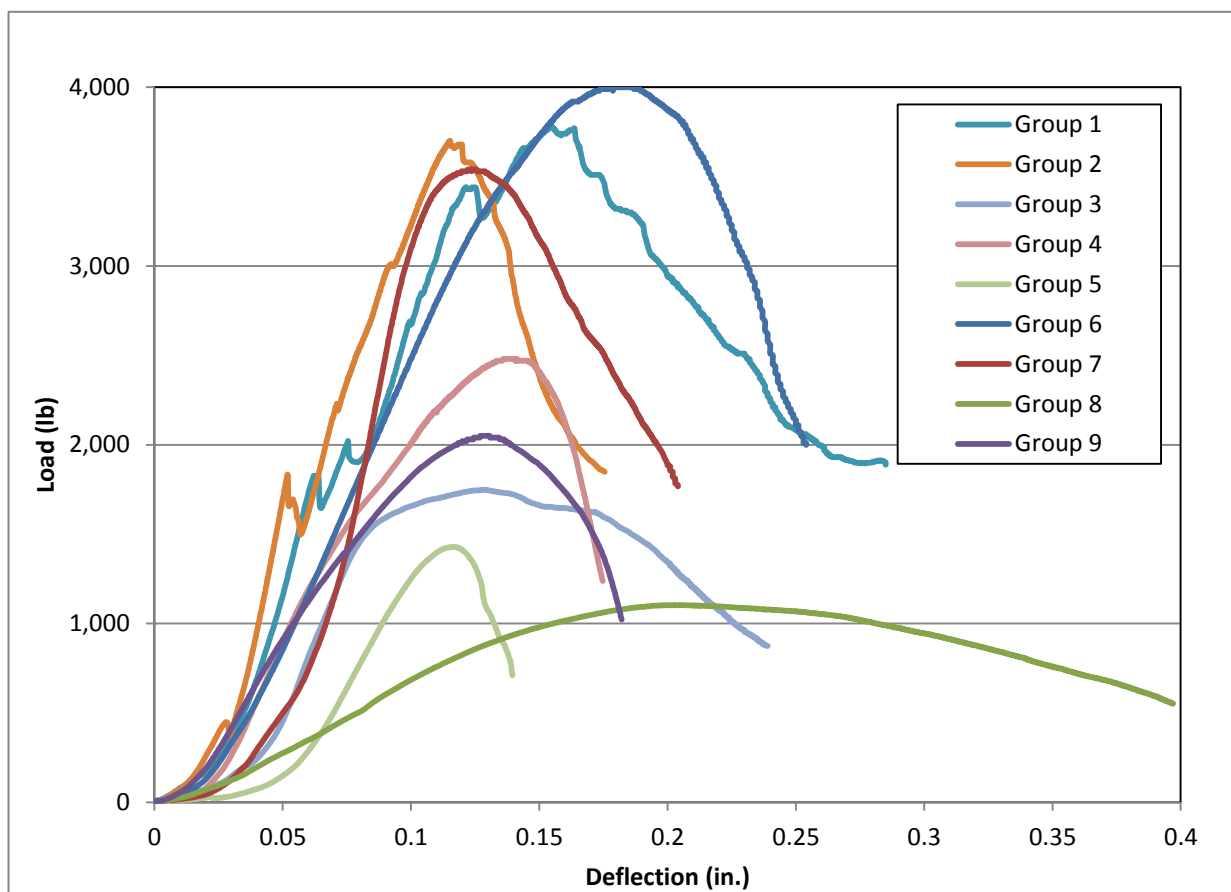


Figure 5: Results of the first annual rammed earth challenge.

Running trail project: The running trail project was initiated within the junior year curriculum, where all junior year courses with a lab component included a piece of preliminary design for a running trail on the UT Tyler campus. The point of this exercise was to help students identify how the different civil engineering disciplines interrelate, as well as begin to introduce the students to the engineering design process. For the soil mechanics class, the students went out and took basic bulk soil samples on campus. They had to think through the process of where to take samples, how to collect and take care of their samples, and then design what geotechnical laboratory tests they would need to perform to have the necessary data for their design. This project allowed the students to utilize their creativity and innovation in having to perform a geotechnical investigation, much like it would be performed in the “real world.” This was very different from students being given a specific soil sample to run. They had to actually prepare the samples themselves, and make decisions about what was representative soil, and what could be utilized effectively. Students enjoyed this exercise, in that they were given the freedom to perform the entire process themselves.

Senior Level Courses

The UT Tyler civil engineering curriculum does not include many full laboratory classes at the senior level, where traditional lab sessions supplement course content. However, that does not mean that creativity within the laboratory has to be disregarded. Rather, instructors should look for opportunities to allow students to continue to exercise and strengthen their creative skills, especially when so much effort goes into having students utilize creativity in their prior coursework. It is at the senior level when civil engineering students truly begin to see the fruits of their “creative labors” and begin to become more heavily involved in performing design. Many capstone courses emphasize student creativity, and by exposing students to creative processes throughout the curriculum prior to that experience they are better prepared to “think outside the box” and truly practice problem solving akin to what they will see as practicing engineers. The following is an example of the type of exercise that can still be performed at the senior level (or any level for that matter), even if the course does not happen to have a specific laboratory component:

Foundation design: In the foundation design class at UT Tyler, students are taught the basic principles behind mechanically stabilized earth (MSE) wall design. Many programs are good about performing in-class demonstrations¹⁷, but in many cases a simple hands-on experience would be even better at helping students visualize the principles being taught. In this course, prior to the students being taught any principles about an MSE wall, students visit the laboratory and teams are tasked with competing to build the tallest soil structure out of everyday newspaper and soil. The in-class MSE wall challenge pits the students against one another, to see which group can build the tallest structure and which structure can sustain the largest load. A variation of this activity is used in the ASCE sponsored student Geo-Challenge, and Evans and Malusis also detail their experience using an MSE wall competition as a regular curricular assignment.¹⁸ Students love competition! They love to be challenged, to work together to solve problems, and even to exercise some “good old fashioned trial-and-error.” Even senior level students can enhance their learning by using a little creativity in the laboratory, even if the class does not have a specific laboratory component.

ASSESSMENT

In the University of Texas at Tyler Civil Engineering department, assessment of program outcomes is taken very seriously, both to satisfy ABET (Accreditation Board for Engineering and Technology) accreditation requirements as well as to simply improve the teaching and learning that occurs within the program. One of the key mechanisms for performing this assessment process is the collection of embedded indicators, a graded event or a portion of an assignment that directly demonstrates student accomplishment of a program outcome.¹⁹

Embedded assessments are more efficient than many other methods because they rely on data that already exists within the academic program.²⁰ Embedded indicator collection begins by identifying assignments or portions of assignments that appropriately and directly demonstrate program outcomes.²¹ The topic of this paper has been introducing inquiry-based experimentation in the laboratory, which is directly associated with UT Tyler CE program outcome #2 – “can design and conduct experiments, as well as analyze and interpret data in more than one civil engineering discipline.” For each embedded indicator the following are collected: the assignment, solution, grading rubric or cut scale, an assessment of the student performance, and three examples of student work (high, average, and low performance).¹⁹ The assessment of the student performance should include how to adjust the course content to improve performance or how to adjust the assignment to better assess the students understanding.¹⁹ An example of an embedded indicator assessment is shown in Appendix A, which is an assessment for the friction lab described within this paper.

Numerous assignments are selected to serve as embedded indicators for each outcome every semester, each specifically chosen for its abilities to meet the respective program outcome. Embedded indicator collection in the UT Tyler CE program is performed by all faculty members, with shared distribution of assigned workload. Embedded indicators are stored in hard copy in a central binder and each spring a two member faculty team evaluates the embedded indicators that were collected,¹⁹ as part of the annual “fast-loop” process.²² Each embedded indicator is given a ranking on a 1-5 scale, indicating its effectiveness in demonstrating the outcome, and recommendations are provided for strengthening each. Finally, a recommendation is provided as to whether or not the indicator should continue to be collected. Indicators collected that do not appropriately demonstrate the outcome are dropped and replaced with other assignments that can achieve the goal. An example of this process is shown in Appendix B, specific to the team assessment of UT Tyler CE program outcome #2 described above, and pertaining to the content of this paper. As shown in this example, two assignments with a low ranking and not satisfying the intent of the outcome were dropped. The other assignments will continue to be collected and reanalyzed the following year, as part of the “slow-loop” process of continual improvement.²² In order to “close the loop” on the annual embedded indicator assessment, a memorandum discussing the evaluation results is generated and becomes part of the accreditation documentation, as shown in Appendix C. It should be noted that the five indicators shown in this example represent the current collection strategy. This does not mean that these are the only assignments demonstrating the outcome, but rather a minimum number of indicators that appropriately demonstrate the program outcome. Of the five indicators seen, three are directly associated with inquiry-based experimentation and students exercising creativity in their laboratory assignment. Most of the assignments included within this paper could be utilized as

embedded indicators for this program outcome, because of the nature of inquiry-based experimentation.

One specific feature that the faculty in the UT Tyler CE program have strived to do as part of this assessment process is ensure that there are embedded indicators collected from Freshman through Senior level. This means that first each outcome must be integrated within the curriculum throughout each level, before appropriate indicators are assigned. Many of the lab activities contained within this paper continue to be strengthened through multiple iterations as part of this assessment process. It is this process that has led to the integration of inquiry-based lab experimentation and attempting to foster student creativity in the lab environment. Many of the assignments identified in this paper are a direct result of faculty simply attempting to find multiple ways to demonstrate the program outcome and likewise strengthen the course content and student learning opportunities. The faculty members in the CE department at the University of Texas at Tyler have been open-minded about thinking outside of the box and attempting innovative lab exercises. In some instances, attempts at integrating creativity into a lab assignment have not worked. However, by simply being willing to attempt to integrate more creativity into the CE labs, the successes have far outweighed the non-successes. The CE faculty members at UT Tyler have made it a personal goal to have at least one creative component in at least one lab session for every lab class, and in many instances continue to add creativity components as opportunity develops.

An important part of the creativity process is having students evaluate their lab experience and assess their own creativity. Having this self-assessment is a valuable asset in demonstrating that students can design and conduct experiments and utilize creativity in their efforts. Students are also routinely asked as part of the course evaluation at the end of the semester to provide feedback about their lab experience. Students historically have liked the hands-on feel of the lab sessions anyway. However, since implementing more creativity into the labs, student comments tend to show even more positive response to their experience. Examples of common student responses when asked to identify one thing that they liked about the labs in the course include:

“They were interesting and kept me thinking”

“Being able to use our creativity”

“They allowed us to go out and make-up our own experiment”

“In most labs we had to think of how to do the labs on our own”

“We had to figure out most of it for ourselves”

“Freedom for creativity in experimental procedure”

“Fun yet enlightening”

Students have had very little negative to say about the creative lab assignments. When asked what they would change about the labs, many responded that they would have actually liked to have seen even more designing experiments. Even with such simple feedback, it has been clear for us to see that the students have really appreciated their experience in being able to utilize creativity in the laboratory session. In general, we feel that the quality of creativity in design and problem solving has increased in the upper division courses, primarily due to creating a culture of creativity within the curriculum, and especially in the laboratory components of the coursework where students can work freely to solve problems.

Conclusions

This paper provides a general overview of how student innovation has been performed during lab sessions within multiple lab courses in the CE program at the University of Texas at Tyler. Creativity within lab classes has not only helped the program achieve their program outcomes, but has proven to benefit the student's abilities as they have progressed through their undergraduate education. Laboratory courses are a great resource for developing student innovation, creativity, inquiry-based learning, and problem solving skills. However, programs and faculty have to initiate activities and exercises that allow these skills to be utilized. This paper serves as a means of sharing specific examples of ways that creativity has been implemented into a variety of lab classes. Our program has already seen success through these types of lab exercises, and other programs can benefit from utilizing these ideas to strengthen their own lab courses and develop similar ideas of their own to suit their own needs. Our number one perceived benefit from this type of laboratory approach is seeing that our students are now able to think more critically. Student feedback also supports the idea that students really appreciate the open nature of this type of lab environment and the positive effect that it has had on their learning. The annual assessment process utilized in evaluating embedded indicators at UT Tyler has also improved the level of creativity being implemented within lab exercises.

Acknowledgements

We would like to acknowledge our colleagues in the Civil Engineering Department at the University of Texas at Tyler, and the collective efforts of the entire CE faculty in development of creativity within the laboratory components of the curriculum. We thank each of them for their efforts and contributions in helping establish the labs mentioned within this paper.

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Appendix A: Example of embedded indicator collected for the program outcome notebook.

CENG 2353 – Civil Engineering Measurements
Faculty Name Withheld
Spring, 2010

Embedded Indicator

2: Can design and conduct experiments, as well as analyze and interpret data in more than one civil engineering discipline

Assignment: Laboratory Exercise #12: This assignment was given to the students to allow them to use their creativity in designing, conducting, and reporting their results for an experiment testing the friction of three different walking surfaces near or in the engineering building. The students were not given specific instructions on how to perform the experiment, but rather considerations that the students should consider during their test. The students were then asked to prepare a 10 minute oral team presentation.

Assessment: The students in general did well on this assignment. The students all elected to use spring type force gages, some being commercially purchased (fish scales), borrowed from the statics professor (actual spring-force gage), or creating their own force gage by calibrating a spring. There were two essential considerations that the students had to account for. First, they had to find some way of measuring the reactive force along the surface. Second, they had to consider what type of material to use as their frictional surface acting in contact with the concrete walkway. The instructor was pleased with the creative effort that went into the project. The students in general like this assignment, and typically approach it with an open mind, and put forth an honest effort. The instructor placed more emphasis this year on consideration of controllable and uncontrollable variables, as well as randomization and replication during the design experiment.

This assignment meets the intent of the embedded indicator for designing and conducting an experiment. This is actually one of the primary purposes of this class, and so this class in and of itself serves to fulfill this embedded indicator. Most of the points missed by the students were simply because the students failed to address all of the requirements within the assignment submittal. This assignment should continue to be offered, and the indicator continued to be collected.

Score: Assignment worth 70 points... High 97.1%, Average 90.4%, and Minimum 71.4%.

Appendix B: Example of annual program outcome evaluation.

Table 1: Annual evaluation for program outcome #2: can design and conduct experiments, as well as analyze and interpret data in more than one civil engineering discipline.

Course	Item	Item Description	Rating	Comments	Suggested Changes	Continue Collecting
CENG 4351	Lab 1	Spot speed study, determining roadway speeds.	5	Students design an experiment by selecting site location, data collection time and procedure.	None	Yes
CENG 3361	Lab 8	Measure the flow passing through a series of weirs located within hydraulic structure	4	Although the experimental techniques are specified by the instructor, each group must select their test site and determine the most accurate data collection approach	Although it addresses the indicator, the hydraulic structure design/prototype project is better suited for this indicator.	Yes
CENG 3434	Lab Report 6	Design problem	2	Involves pavement design through the use of design software and manuals. Does NOT deal with experiments or analyzing and interpreting data in more than one discipline.	Remove indicator	No
CENG 2353	Lab 6	Construct basic circuits: voltage and current laws	3	Performing current and voltage measurements does not constitute a design component nor addresses more than one civil engineering discipline.	Remove indicator	No
CENG 2353	Project 1	Design and conduct experiments for the friction of a concrete walkway.	5	The entire project is based on the students having to develop and perform their own experimental design.	None	Yes
CENG 3336	Lab 9	Perform the consolidation test on a clay specimen in the lab	3	Consolidation test does requires use of analysis and interpretation of data in geotechnical engineering. Originally intended to be a hydrometer test by previous reviewers.	None	Yes
CENG 3325	Mini Project 2	Find the weight of \$2.00 in pennies	5	Students are provided with basic materials and must design their own experiment	None	Yes

Appendix C: Example of memorandum discussing annual program outcome evaluation.

MEMORANDUM

To: *Faculty Name Withheld*
Professor and Chair, Department of Civil Engineering

From: *Faculty Name Withheld*
Assistant Professor, Department of Civil Engineering

Re: Assessment of Program Outcome 2

Date: May 13, 2009

An assessment of program outcome 2 “Can design and conduct experiments as well as analyze and interpret data in more than one civil engineering discipline” was conducted on May 13, 2009 by:

- *Faculty Name Withheld*, Assistant Professor, Department of Civil Engineering
- *Faculty Name Withheld*, Assistant Professor, Department of Civil Engineering

Having reviewed the program outcome notebook, the reviewers have the following comments regarding the data collection and outcome accomplishment:

Were previous recommendations implemented and evaluated successfully as an indicator?

The previous assessment recommended tracking seven indicators, of which five were tracked as per the recommendation. One indicator in CENG 3336 was swapped for another, the indicator from CENG 3371/4371 was not tracked at all, and an indicator from CENG 3434 was added.

Did the department demonstrate accomplishment of the outcome?

Yes

What improvements are needed to better demonstrate accomplishment of the outcome?

The reviewers feel that this outcome really covers two different aspects: designing and conducting an engineering experiment and analyzing and interpreting data in more than one civil engineering discipline. The current indicators include courses from sophomore through senior year from seven different courses. It appears that designing experiments is adequately addressed. It is important to ensure that the different Civil Engineering disciplines are being covered.

What are the minimum items needed to demonstrate accomplishment of the outcome?

Five entries for this indicator are needed and should cover multiple academic levels as applicable.

What items should remain the same tool for collecting data?

The current indicator for CENG 3361 should be swapped from weir flow measurement to the detention structure design/prototype. Although the CENG 3336 indicator does not include a design component, it

does involve analyzing and interpreting data. The remaining indicators that should continue to be collected are shown below:

Course	Item	Description
CENG 2353	Project 1	Design and conduct experiments for the friction of a concrete walkway.
CENG 3325	Mini Project 2	Find the weight of \$2.00 in pennies
CENG 3336		Consolidation Test
CENG 3361		Detention structure design/prototype
CENG 4351	Lab 1	Spot speed study, determining roadway speeds

Recommendations for improving data collection and demonstrating accomplishment of an outcome:

There are no additional changes beyond those indicated above for these indicators. These five indicators provide the design aspect of the lab as well as the analyze and interpret data portion of the lab.