# Evolution of an Undergraduate Probability and Statistics Laboratory

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## Abstract

An interactive laboratory that combines experiential and cooperative learning is used as part of a probability and statistics course for undergraduate civil engineering students. The goal of the laboratory is to help students see how probability and statistics are used in real civil engineering problems, reinforcing lecture topics and giving practice in recognizing and managing uncertainty. In the laboratory, computer simulations of civil engineering problems are performed, with students working in groups to collect and analyze data. During the four years that it has been used, the laboratory has changed in response to student surveys and instructor observations. The laboratory has been successful in helping students to understand probability and statistics concepts and their application to actual civil engineering problems. The students have also seemed to develop an understanding of uncertainty in engineering practice. Cooperative learning has been a valuable addition to the laboratory, since it fosters discussion and interaction in solving problems and allows students to learn from one another.

## Introduction

An interactive laboratory has been used in a probability and statistics course for undergraduate civil engineering students for four years. The laboratory is designed to reinforce topics taught in lecture by providing examples of how the concepts are used in real-world civil engineering problems. More importantly, the laboratory provides students with practice in recognizing and managing uncertainty in these engineering problems. While homework problems allow students to practice the computations involved with probability and statistics concepts, the laboratory allows students to use the concepts to design civil engineering systems, making decisions based on performance and cost.

The first year of the laboratory was described and evaluated in Yarbrough and Gilbert[1] and Yarbrough[2]. The laboratory has evolved in the subsequent three years. The laboratory was assessed each year and improvements made for the following year. This paper describes the current laboratory, and how the laboratory has been evaluated and changed to better fulfill its purpose and improve the learning experience of the students.

## Description of the Laboratory

In its current format, each laboratory section meets for one hour, once a week, in a computer classroom. A different computer simulation and exercise is performed by the students each week. Two types of computer simulations are used in the laboratory. The first type of simulation utilizes an interactive environment created with LabView® by National Instruments, a graphical software system for developing scientific and engineering applications. The user interface created with LabView® provides tools for the user to input data and receive output from the programmed application. Situations from different areas of civil engineering are simulated with LabView®, with the students observing changes in the output data depending on their input parameters.

The second type of simulation is performed with SimSite, a geoenvironmental site investigation program developed at The University of Texas at Austin described by McBrayer et al. [3] and Carter et al.[4] SimSite provides a graphical model of a real Superfund site which allows the students to perform a virtual site investigation with tools such as borings and monitoring wells. The program also tracks costs of the investigation and lab tests. Students perform a different aspect of a site investigation with each laboratory exercise based on the SimSite program.

With the exercises for both programs, students collect data from the simulated civil engineering situation, and then apply probability and statistics concepts to analyze the uncertainty in the situation. Students are assigned to groups of four for the semester. They work in pairs from their groups to perform the computer situation and collect data, then complete the analysis and the lab report as a group of four.

## Experiential Learning in the Laboratory

The laboratory exercises are designed to give students an opportunity to experience probability and statistics concepts in real-world civil engineering situations. Coleman[3] describes experiential learning as consisting of four steps. The first step is observing the effects of an action, and then the second step is understanding these effects so that they could be anticipated if the same set of circumstances occurred again. The third step is understanding the general principle that governs the particular set of circumstances. In the fourth step of experiential learning, students move beyond the particular set of circumstances in the first three steps and apply the general principle to new circumstances. When this final step has been reached, the experiential learning process has been completed and the experience should be useful in future decisions.

The laboratory exercises allow students to progress through these four steps. The first part of each laboratory is the computer simulation of a civil engineering system, and the students observe and record how the particular system performs. Questions in the laboratory exercise help guide students through the next two steps. The students are asked to find the trends in their observations, and then they are asked about the general probability concepts that are applicable to the simulation and their observations. The final part of each laboratory exercise requires the students to make a decision considering new information. An example of a laboratory exercise is shown in Figure 1.

**Cooperative Learning in the Laboratory**

The amount of learning accomplished by the students depends on the effort and thought they apply to the laboratory exercises. Coleman[3] notes that motivation is provided to students in experiential learning situations when other people are involved. Group work was therefore incorporated into the laboratory to enhance the learning experience, incorporating the features of cooperative learning as outlined by Cooper et al.[6]

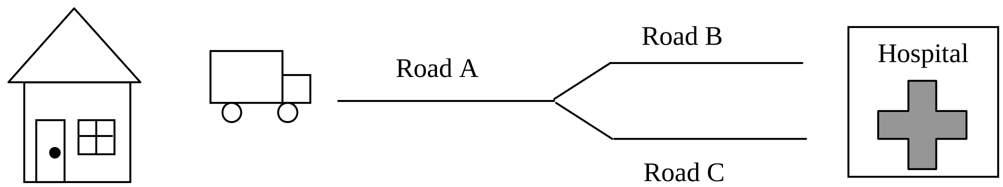
Cooper et al.[6] defines cooperative learning as “a structured, systematic instructional strategy in which small groups of students work together toward a common goal”. Cooperative learning has two key features which distinguish it from other forms of group activity: positive interdependence, where team members feel responsible for one another, and individual accountability, where students earn their own individual grades. Positive interdependence was accomplished in the laboratory by having students work in pairs to perform a computer simulation and collect data, then come together as a team to share their data, analyze it, and draw conclusions from it. The team was allowed to turn in one laboratory report for the entire group; therefore, it was in each student’s best interest to ensure that the laboratory report was done well. Although the team received one grade for the laboratory report, the laboratory was worth only 15 percent of the entire grade for the course. Individual mastery was necessary for other course components, such as exams.

Cooper et al.[6] identifies four additional features of cooperative learning. These features, and how they were applied to the laboratory, are as follows:

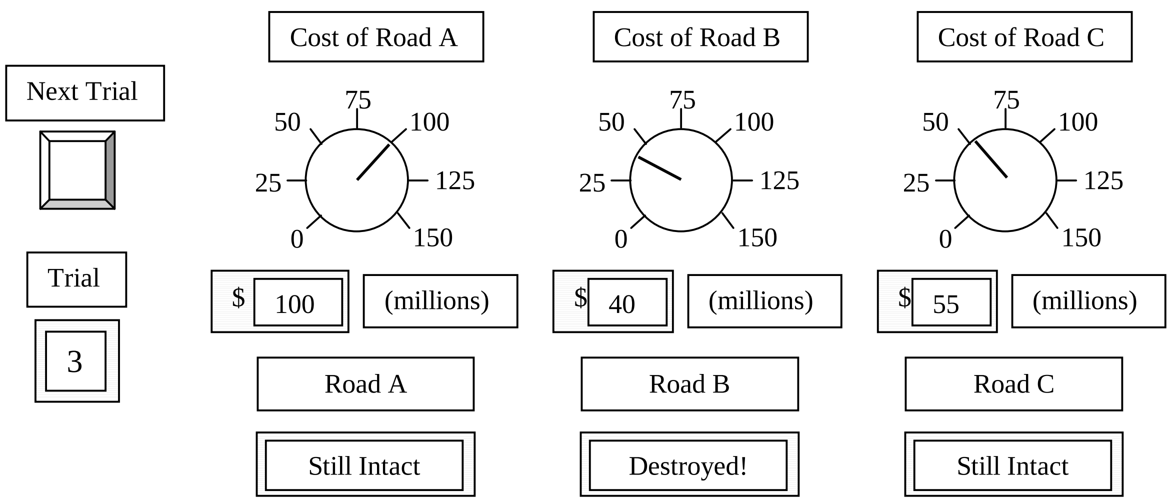
*Appropriate assignment to groups.* Assigning heterogeneous groups in terms of race, gender, prior achievement, and other appropriate characteristics has been shown to increase communication skills and improve attitudes towards the coursework and towards people from different backgrounds (Johnson and Johnson[7]). To assign groups appropriately, a survey was given to the students on the first day of class. The teaching assistant placed the students in groups of four, creating heterogeneous groups according to their university classification, their prior experience with probability and statistics, their feelings about working in groups, their work experience in civil engineering, their expected grade in the course, and their hometown.

*Teacher as coach or facilitator.* In cooperative learning, the instructor encourages the students to be interactive with each other and with the instructor. To accomplish this, the teaching assistant talked with the student groups during the laboratory, checking their work

Civil Engineering Problem: An ambulance must be able to travel between a residential area and a hospital after an earthquake. Students analyze the reliability of the roads during simulated earthquakes based on the construction cost of the roads.




Computer simulation of road performance during earthquakes, using LabView®.




Questions about simulation results, probability concepts, and design decisions.

- Identify the sample space
- Draw and label a Venn diagram
- List events that allow ambulance to get to the hospital and show them on the Venn diagram.
- What are causes of uncertainty that allow roads to survive one earthquake but not another when the construction cost is the same?
- How does increasing the construction cost of an individual road affect its reliability in an earthquake?
- Plot the frequency of failure for the road system versus the construction cost of the entire road system.
- Explain how cost affects performance of the entire road system.
- Decision: Considering the given cost of failure of the road system, what design would you as an engineer propose for the road system?

Figure 1. Illustration of the first laboratory exercise, “Defining Events Within the Context of Lifeline Design”.

and discovering where they were experiencing difficulties. When the teaching assistant explained a concept to the group and some members of the group would understand while others would not, the students were encouraged to explain the concept to their teammates instead of the TA explaining it again. The limitation of one teaching assistant in a class of approximately 30 students also encouraged the students to solve problems within their group, without relying solely on the teaching assistant.

*Explicit attention to social skills*. In order to promote cooperation among group members, a technique called group processing was utilized, where each member of the group evaluates their teammates' behavior on specified criteria to the teacher for discussion or grading. Ten percent of the students' laboratory grade was based on their teammates' evaluation of their participation in the group. Students were asked for the participation score they recommended for each teammate, and they were also asked for comments about their teammates' work in the group.

*Face-to-face problem solving*. This allows students to work together to utilize recently acquired information, developing further understanding and mastery of the information. To promote this, the laboratory exercises were scheduled to follow the introduction of the topic in lecture as closely as possible.

Consideration was also given to how the size of the groups would affect learning. Groups of four were used so that students could easily break into pairs to perform the computer simulations and collect data. When more than two students sit around a computer, the involvement of the students seems to decrease. Groups of four are generally large enough to bring diversity and different methods of thought to the group, while not so large that a student can hide and not share in the work.

**Methods of Evaluation**

Each year, the laboratory has been evaluated to determine its effectiveness as a teaching tool. An assessment of the laboratory after the first year of use was presented in Yarbrough and Gilbert[1]. This assessment was based on student questionnaires, observations of student behavior, interviews with students, and class grades. Comparisons were made between two sections of the class that participated in the laboratory and a control group that participated in a homework recitation section.

The evaluations of the three succeeding years of the laboratory consisted of instructor observations and students' comments. In the third and fourth years of the laboratory, a survey was given to students at the end of the semester which asked for their comments regarding if the laboratory helped them understand the course material better, if there were any laboratory exercises they particularly liked or disliked, if they liked working in groups, and if they had suggestions for improving the laboratory.

## Evaluation Results

Through the evaluations, the laboratory has evolved from year to year. Improvements have been made in several key areas, including how the students view the fairness of the laboratory in comparison to review time and how they view the worth of the laboratory towards their final course grade. Evaluations helped show the need for the addition of cooperative learning to the laboratory, and helped show its success once implemented. The ability of the laboratory to help students understand course material has also improved. In addition, the experiential learning accomplished by the students has been found to help them understand the broader idea of uncertainty in civil engineering and to help provide them with understanding and self-assurance that is not always measured with exams.

## Attitudes about the Laboratory

The perceived fairness of the laboratory by the students has been a major improvement in the laboratory. In the first year of the laboratory, two sections of the class participated in the laboratory while another section served as a control group, participating in a homework recitation session each week. The laboratory sessions consisted of a short period for questions about homework problems, and then students moved to a computer laboratory to perform the laboratory exercises. There were seven laboratory exercises, all using LabView® simulations. On weeks without a laboratory exercise, the full lab session was devoted to review of the homework problems.

Student interviews and surveys indicated that the control group was a distraction to the students in the laboratory, who believed there were inequalities in workload and review time between the groups (Yarbrough and Gilbert[1] and Yarbrough[2]). However, when the laboratory students did have a full hour for review, few students asked questions and class was often dismissed early.

This problem was addressed in the second year of the laboratory by eliminating the control group. However, the students still frequently complained that they needed homework review sessions every week. As in the first year of the laboratory, however, it was again observed that only a handful of students asked questions and the class was often dismissed early.

A major change was made in the third year of the laboratory to virtually eliminate this complaint. The laboratory exercises based on the SimSite program were added, which provided a laboratory exercise for every week of the course except for the weeks in which exams were held. During these weeks, the laboratory time was used for a review session. This change was successful, since only a very small handful of students in the third and fourth years remarked on their surveys that they would rather have had homework review time than the laboratory.

## Weight of Laboratory Grade

Another major improvement to the laboratory has been increasing the weight of the laboratory in the final course grade. During the first two years of the laboratory, the laboratory grade was included as a contribution to the homework grade, which was ten percent of the total grade. Because it did not count very much in their final grade, many students did not emphasize the laboratory and viewed it more as busy work than as a valuable exercise. In the third and fourth years, the laboratory grade was separated from the homework grade and counted as 15 percent of the final course grade. Putting a greater weight on the laboratory in the course grade seemed to increase the value of the laboratory as a teaching tool because students placed greater emphasis on it. As shown in Figure 2, the percentage of students who said that the laboratory did not help them with the course material or were neutral about it decreased in the third and fourth years. In addition, increasing the weight of the laboratory gave students who struggled on tests a different path to show that they understood the material and were putting effort into the class.

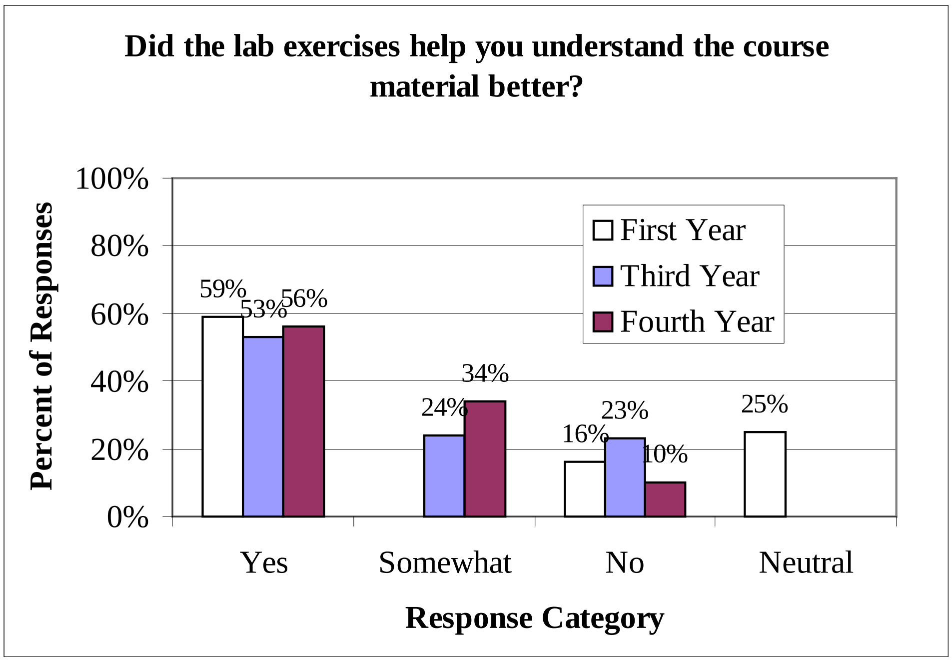



Figure 2. Summary of student responses to the question, "Did the lab exercises help you understand the course material better?"*

*First year responses were taken from Yarbrough[2], where students agreed, disagreed, or neither to the statement, "The lab helped me understand the material better". In the third and fourth years, students wrote their own answers to the question, "Did the lab exercises help you understand the course material better?" All the responses were categorized into the response categories shown.

This result is indicated on Figure 3, which shows that the percentage of students receiving a grade of D or lower has decreased significantly in the third and fouth years compared to the first and second years. From surveys completed by the students at the end of the course, the majority of students, 74 percent each year, felt that this grade scale was appropriate (see Figure 4).

**Value of Group Work**

A very important addition to the laboratory was the cooperative learning aspect that was incorporated during the third year of the laboratory. The first year laboratory evaluation results showed that students' effort affected the amount of learning that occurred in the laboratory. In the first and second years of the laboratory, students completed the laboratory reports individually. Cooperative learning was introduced in the third year of the laboratory to try to help provide motivation and encouragement for the students.

The group work was viewed very favorably by the students. The majority of students felt positively about working in groups, while only a very small number of students had negative

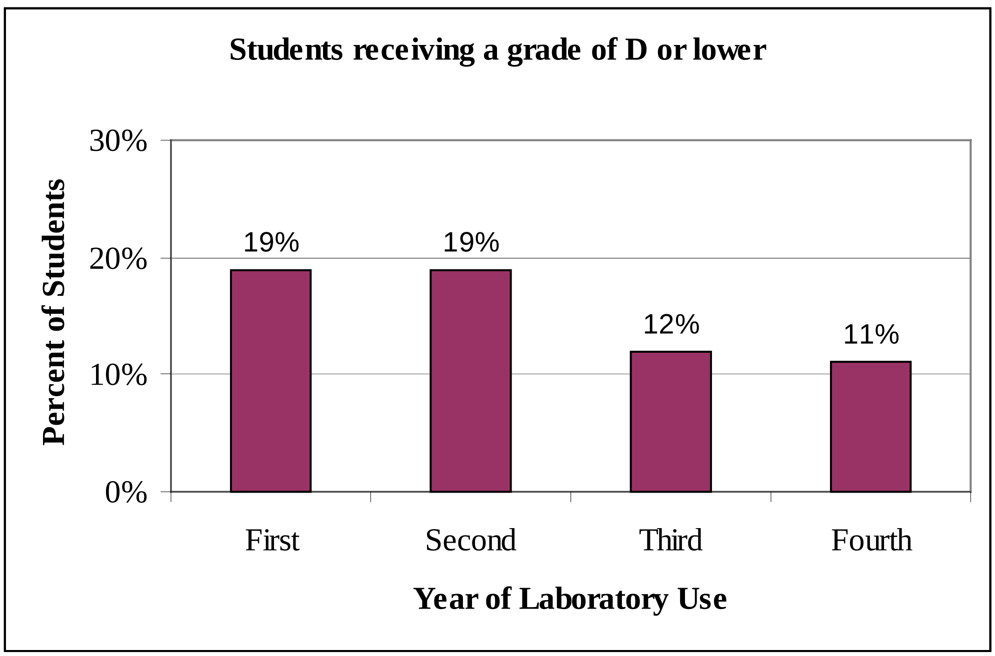



Figure 3. Percent of students receiving a grade of D or lower in each year of laboratory use.

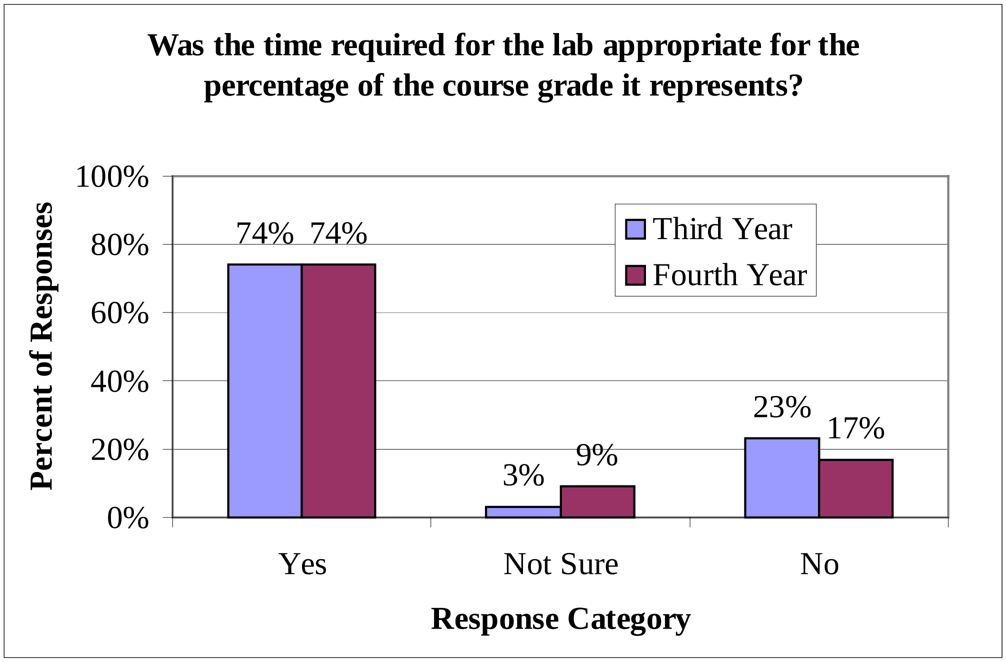



Figure 4. Summary of student responses to the question, "Was the time required for lab appropriate for the percentage of the course grade it represents?"*

*Students wrote their own answers to this question, and all the responses were categorized into the response categories shown.

responses toward it, as shown in Figure 5. Student comments about working in groups are listed in Table 1. Many students commented that working in groups helped them to meet more people in the class, and that it was helpful to see other students' perspectives when solving problems. The most common complaint from students about working in groups was meeting outside of class time with their group to complete the longer laboratory exercises. While an effort was made between the third and fourth years to decrease the time required for the exercises, these comments were still made in the fourth year. Some students thought they should be able to choose their own groups, while other students liked being assigned to groups by the teaching assistant.

The teaching assistant observed that the groups facilitated discussion among the students, particularly in the parts of the laboratory exercises that required a decision to be made. Ethical concerns were frequently discussed, especially concerning how preventing loss of human life and damage to the environment should be balanced with costs. Students were also observed to explain concepts to one another.

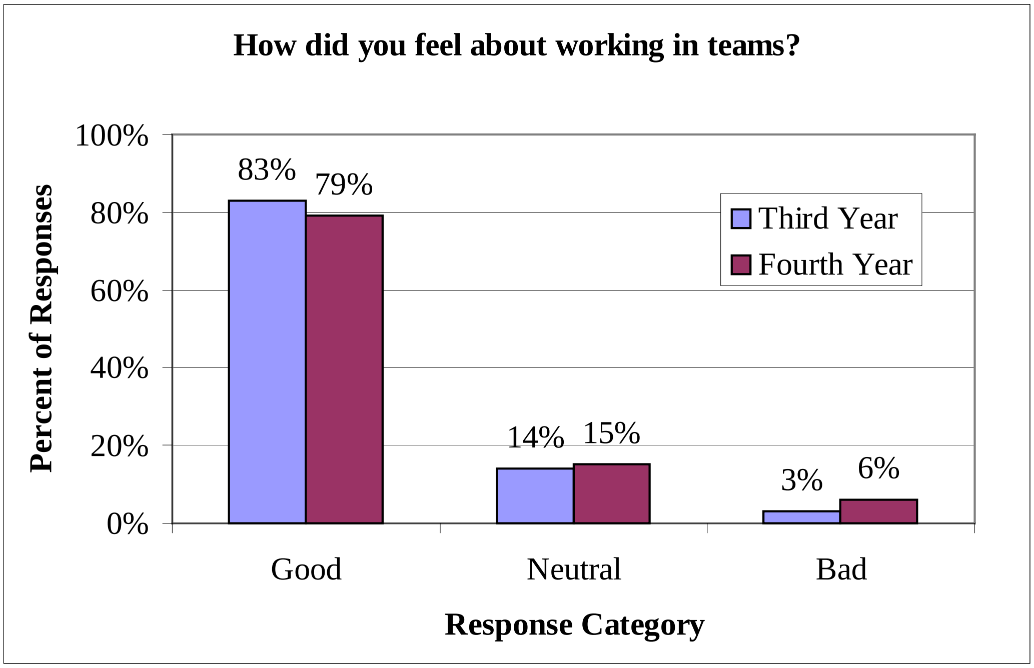



Figure 5. Summary of student responses to the question, "How did you feel about working in teams?"*

*Students wrote their own answers to this question, and all the responses were categorized into the response categories shown.

As part of the group processing technique to encourage cooperation among group members, as described earlier, each student evaluated their teammates and gave them a suggested participation score for 10 percent of their laboratory grade. Most students scored their teammates very highly, providing another indication that the group work was successful and that students found it enjoyable. When there was a problem with a teammate, however, the students were willing to give the teammate a low participation score, indicating that students were honest with their evaluations.

**Value of Experiential Learning**

An assessment of the experiential learning provided by the laboratory was conducted each year except the second year. Students were asked if the laboratory helped them to understand the course material better. Over 50 percent of the students each year responded that the laboratory did help them, as shown in Figure 2. The percentage of students responding that the laboratory did not help them dropped from approximately 20 percent in the second and third years to only 10 percent in the fourth year. In the third and fourth years, the remaining students responded that

Table 1. Sample of student responses to the question, “How did you feel about working in teams?”*

Third Year of Laboratory
- “The teams worked well. I do agree with assigning the groups randomly.”
- “Working in teams brings about a better understanding of the material, and it takes a lot of pressure off the individual.”
- “’Not so sure at first but good about it after the first few weeks.”
- “Hated the thought of it at first but I made three new friends.”
- “I like it when we do not have to meet with our members outside of class cause everyone has different schedules.”
- “I like working in teams – but I think you should pick your own – that way you don’t get stuck with people you can’t depend on.”
- “I’d rather work alone.”

Fourth Year of Laboratory
- “I liked it because getting other people’s ideas helped me understand and reason out the material much better than if I worked on my own.”
- “I felt that working in teams was very helpful. Sometimes this material isn’t easy to grasp so its good to have someone there to help you.”
- “I liked it. You got to know people in your class, and we were able to help each other out on problems we didn’t understand.”
- “I liked working in teams because it gave me the opportunity to get to know more of my classmates.”
- “The only thing I disliked was the difficulty meeting with our groups when we were unable to finish during class.”
- “Great way to work. Helps communicating skills and helps understand different ways of teamwork and sharing ideas.”
- “Awesome, that was the best way for me to learn.”
- “I liked it, although sometimes (especially at the beginning) its hard to adapt to each person’s workstyle.”
- “I would rather picked my groupmates or worked alone.”

*Comments listed in the table were selected to be representative of all the responses to the survey question. The selected comments were also among the more descriptive and informative of the student responses.

the laboratory helped them somewhat, or that some of the exercises were helpful while others were not. Students' comments indicate that the laboratory is most useful in helping them to see how the concepts learned in the course are applied to real-world civil engineering problems. A sample of students' comments is listed in Table 2.

This improvement in the fourth year of the laboratory may be due to several reasons. The first possibility is that the teaching assistant was the same in the third and fourth years, and therefore had more experience in the fourth year. An effort was made each week to help the students relate what they were doing in the laboratory to what they were doing in the lectures and homework assignments. The second possibility is the change in the laboratory exercises utilizing the SimSite program. In the third year, the SimSite exercises were completed as part of an ongoing project, with a project report due at the end of the semester. Many students complained that the project was too spread out, though, and the teaching assistant observed that nearly all of

Table 2. Sample of student responses to the question, "Did the lab exercises help you understand the course material better?"*

Third Year of Laboratory

- "Yes – I learned a lot from both listening to my partners and teaching my partners."
- "It gave me a feel of how we will use this class in the real world, but as far as helping me out for tests, I don't think the material covered was presented in a way that I could relate it to the test questions."
- "In the beginning they didn't seem to help. But towards the end when I actually understand the principles it helped show real world applications of what we were learning."
- "Not really, I learned the material on my own with homework."

Fourth Year of Laboratory

- "Yes, every topic we did during class seemed useful in real-life situations once we began the labs."
- "Yes, they kind of applied the material more realistically than homework."
- "Yes, they were very helpful…some were difficult, some were easy, but all were helpful."
- "In a way the lab exercises helped me see formulas used in class. That way homework didn't seem so foreign."
- "Yes, but only in relating it to 'Real World' problems."
- "Not really. The course material is harder most of the time."

*Comments listed in the table were selected to be representative of all the responses to the survey question. The selected comments were also among the more descriptive and informative of the student responses.

the groups left most of the work until the end of the semester rather than working consistently throughout the semester. As a result, in the fourth year the SimSite exercises were treated as individual exercises rather than as part of a project. The students were therefore required to complete the exercises and address the topics covered in them immediately, rather than waiting until the end of the semester.

Chickering[8] states that, when carried out well, "experiential learning attaches major importance to *ideas*. When ideas are used as hypotheses and tested in action, their significance and the attention given to them is greater than when they are simply memorized or left as unexamined abstractions." The laboratory tries to focus the students' attention to the idea of uncertainty in civil engineering practice. Through the experiential learning provided by the laboratory, it is hoped that the when the students become practicing engineers, they will recognize the uncertainties they encounter and be better prepared to manage it appropriately.

The idea of uncertainty is incorporated in all of the laboratory exercises, but in the last SimSite exercise during the fourth year, students were asked to address the idea specifically. They were asked to write a summary of the uncertainties they dealt with in their simulated site investigations and how those uncertainties affected their decisions about the site. Excerpts from some of the summaries are presented in Table 3. Most of the summaries contained good explanations of the uncertainties they encountered, including the sources of uncertainty, such as limited sample sizes and variability due to nature. They also explained how they used several of the probability and statistics concepts they learned in class to deal with these uncertainties. Many students also successfully related costs with the probabilities they had found in making their decisions as engineers. These summaries indicate that students have developed at least an initial understanding of uncertainty in civil engineering and how engineers can make decisions accounting for the uncertainty.

A frequent observation in experiential learning noted by Coleman[5] is that a "student does not perform well on paper and pencil test, although observation of the student's behavior indicates that he or she appears to have learned the phenomenon well." This was observed in the laboratory. In the first year, laboratory participation did not change course grades when compared to the control group. It was observed in this year, and in subsequent years, that students who struggled with homework problems and did not perform well on exams were often very interested in the laboratory exercises, understanding the concepts and their applications. Coleman[5] also stated that a benefit of experiential learning was that students develop self-assurance and a sense of mastery, and this was also observed in the laboratory. One student asked if a practicing engineer's work would be more like the laboratory or the homework problems. She enjoyed the laboratory work, but was frustrated by the homework problems and was not sure if she could actually be an engineer. The student was reassured when told that the laboratory exercises, while based on computer simulations, were indeed representations of real civil engineering problems.

Table 3. Excerpts from summaries written by students in the fourth year of the laboratory for the final SimSite laboratory exercise, explaining the uncertainties they encountered and how they affected the decision to remediate the site.

- "There were numerous sources of uncertainty in our procedure. The tests that we performed have a limited reliability. Our accuracy is limited by the number of tests that we were able to perform (which is limited by the amount of money that we are willing and able to spend), and by the locations that we happened to choose (although we use our best judgment, it is only an inference based on what we suspect the conditions below the surface might be). There are errors that we were able to quantify. We were able to obtain specific values for the mean and standard deviation of our measurements for the hydraulic gradient and hydraulic conductivity and likewise the velocity of our groundwater….Using our knowledge of statistical methods, we managed the quantitative errors in a scientific manner, and assessed the condition of the site. Our initial results indicated that we should remediate the site. However, our standard deviation [of contaminant travel time] was so high as to render our results inconclusive. Our conclusion is that we need more information (more tests) in order to determine whether the site should be remediated."
- "Some of the uncertainties we encountered were the measured values of the hydraulic gradient, hydraulic conductivity, benzene concetration, groundwater velocity, and soil types."
- "…when taking well samples, we were limited to taking a certain number of samples. This was intended to simulate the choices an actual company would have to make, in that each well would cost money and no one has the unlimited funds necessary to test to certainty."
- "Proper placement and number of testing wells were determined in order to manage uncertainties…The large confidence bounds that were found could have caused us to remediate the site when remediation was not warranted, causing us to spend a lot of money to clean up the site. Therefore, the large confidence bounds resulted in a low probability of not remediating the site when remediation was needed. Remediation should not occur until further testing could be completed."

## Conclusions

The interactive probability and statistics laboratory for undergraduate civil engineering students has evolved throughout its four years of use. Each year, the laboratory has been evaluated, and the evaluations have provided a basis for making improvements and determining the success of the learning experience provided by the laboratory. The evaluations have shown that it is important for students to feel that the laboratory constitutes an appropriate portion of the final course grade. This helps them to consider the laboratory important and encourages them to put enough effort into the laboratory exercises. The addition of cooperative learning to the laboratory has helped students by allowing them to meet and learn from their fellow classmates, which has enhanced their learning experience and made it more enjoyable. A frequent complaint about groups that still must be addressed, though, is the difficulty in meeting teammates when a laboratory exercise is not finished during the laboratory session. The laboratory helps students see how the probability and statistics concepts taught in the classroom are applied to real-world civil engineering problems. In broader terms, the students seem to have developed a sense that they will encounter uncertainty in their engineering careers, and that there are methods for dealing with uncertainty. Overall, student comments and evaluations, in addition to instructor observations of the students, have been very useful tools for assessing the efficacy of the laboratory.

The success of the laboratory also raises another issue. Although most students think the laboratory helps them, at least sometimes, to better understand the course material, their performance on exams does not seem to be affected by the laboratory. The students are able to understand concepts in the laboratory when they are able to work towards an understanding through experiential and cooperative learning. However, when given a set of information on an exam problem and asked to find a correct answer, the students frequently are not able to use these same concepts. The laboratory helps illustrate that current testing methods are not always successful in evaluating how much a student has learned, and this is an issue that should be addressed in the future.

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