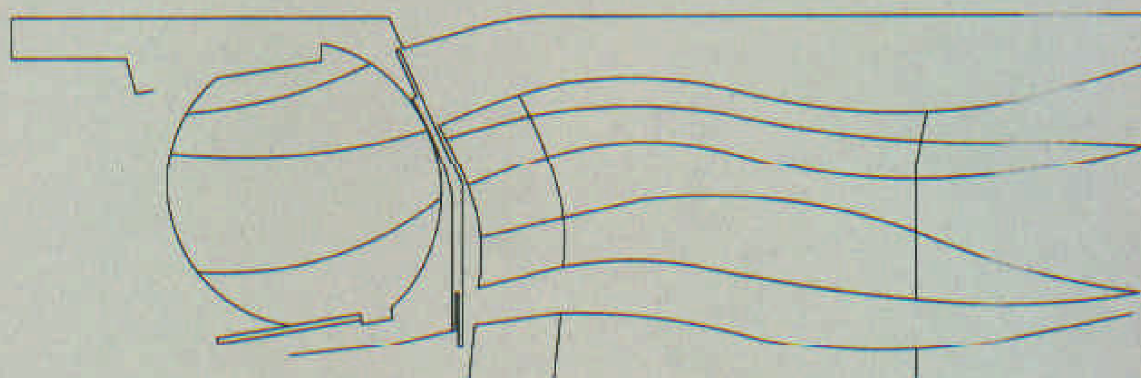
Analysis in the Service of Design
The Virtual Soil Mechanics Laboratory



By

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Foreword

Analysis is an important part of design. But to be effective, its results must be available to the designer rapidly as the design proceeds.

Professor Guido's development of the Virtual Soil Mechanics Laboratory familiarizes students with methods of soil analyses that are crucial in the design of civil engineering structures made from or in the earth. One of the examples given is that of the design of a flexible pavement utilizing an asphalt wearing surface for a given traffic loading. By reducing considerably the lengthy preparation time before students can get to the experiment, and the equally lengthy calculation for reducing data before it can be used in the design process, the virtual lab shows students how analysis and design can form an effective, tight feedback loop. It also initiates students to modern methods of computer-aided engineering design which are now becoming the norm in industry.

As an industrial reviewer of the virtual lab writes:

> "I applaud you for the concept of taking soil mechanics laboratory tests and making them meaningful by requiring the students to develop a design based on the results of their tests. That knowledge will serve them well in their future careers. They will remember these tests and their applications to design are better than if they had just done testing out of context."

And another adds:

> "This experience will be valuable for the students in their working career, because they understand that the engineer's final product is an economical, buildable design."

As a consequence, the department of Civil Engineering is now considering a similar approach for such courses as Environmental System Engineering, Hydraulic Engineering, and Structural Engineering I. In many ways, Professor Guido's work has set standards, and provides a model which can be applied to other disciplines.

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Jean Le Mée
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Session 3226

The Virtual Soil Mechanics Laboratory

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Abstract
The Virtual Soil Mechanics Laboratory is used in conjunction with the introductory undergraduate course in Soil Mechanics, which is required of all students majoring in Civil Engineering at the Cooper Union.

Integrating the laboratory portion of the introductory Soil Mechanics course with the world wide web has many significant benefits. At the forefront is the ability to improve the students' perception of the material at hand. An on-line laboratory provides students with the capability to perform experimental calculations directly from their home computers using regular browsers. Furthermore, the availability of the Virtual Soil Mechanics Laboratory on the world wide web allows students from all over the world access to Cooper Union's Virtual Soil Mechanics Laboratory, its manual and procedures.

I. Introduction

Civil Engineering is the oldest form of engineering, dating back to ancient Egypt and the building of the great pyramids. Civil Engineering is comprised of Environmental Engineering, Geotechnical Engineering, Hydraulic Engineering, Structural Engineering, Transportation Engineering and many others, such as Geoenvironmental Engineering. The fundamental course upon which the Geotechnical Engineering field is founded is Soil Mechanics, which is the name given to the scientific approach to understanding soil action.

Soil Mechanics may be defined as the study of the engineering behavior of soils, with reference to the design of civil engineering structures made from or in the earth. Its introduction into the United States is generally accredited to Dr. Karl Terzaghi and is considered to have occurred in 1925.

At the Cooper Union for the Advancement of Science and Art – Albert Nerken School of Engineering, Soil Mechanics is a required course for all students majoring in Civil Engineering. It is offered in the spring semester of junior year and is a 4.5 credit course, comprised of three hours of lecture and three hours of laboratory per week. The laboratory has always been an integral part of the course, where the students perform experiments determining the indexing and strength properties of soil. A total of eleven experiments are performed:

Experiment #1 – Sample Preparation
Experiment #2 – Specific Gravity Determination
Experiment #3 – Grain Size Distribution Analysis
Experiment #4 – Liquid and Plastic Limits of Soil
Experiment #5 – Compaction

Experiment #6 – Constant Head Permeability Test
Experiment #7 – Variable Head Permeability Test
Experiment #8 – Direct Shear Test on Cohesionless Soil
Experiment #9 – Consolidation
Experiment #10 – Unconfined Compression Test
Experiment #11 – Triaxial Compression Test on Cohesionless Soil

The first five experiments are performed on one soil, usually a glacial till, with the students working in groups of three to four. The soil is analyzed for its suitability as a subgrade soil in a flexible pavement. From this analysis each group of students must design a flexible pavement utilizing an asphalt wearing surface, base course and sub-base course for a given traffic loading. The inclusion of geotextiles and/or geogrids is a requirement of the design. The remaining six experiments are performed as an entire class with individual laboratory reports required for each experiment. In total, the laboratory accounts for one-third of the grade for each student.

Prior to the spring of 1998 the only means of preparation for the Soil Mechanics Laboratory was a laboratory manual developed in-house. This manual was distributed to each student at the start of the semester and contained the laboratory procedures and data sheets necessary for experiments 1 to 5. Experiments 6 to 11 had data sheets but no formal laboratory procedure written down. The data for all eleven experiments was processed by using a DOS-based "C" program which one would hardly describe as "user-friendly".

In the 1996-1997 academic year a project was funded at the Cooper Union by the NSF/Gateway Coalition for the development of a Virtual Soil Mechanics Laboratory. This funding was continued in the 1997-98 and 1998-99 academic years, and was the impetus for the development of additional formal laboratory procedures for experiments 6 to 11, where none had previously existed.

II. The Virtual Soil Mechanics Laboratory

The Virtual Soil Mechanics Laboratory is a fully functional website that has been used since the Spring of 1998 for instruction with the undergraduate Soil Mechanics course at the Cooper Union. The website address is http://www.cooper.edu/vsoil. It is accessible from any browser both inside and outside the Cooper Union.

Educators are constantly seeking new and improved methods of preparing and presenting their coursework to students; methods which distill the key information and reduce the potential for confusion; or which allow for independent study. The use of the world wide web has increasingly become significant in this effort, offering a unique and always-visible approach to providing the coursework for any class, from a simple training course to a full-scale degree program. However, while the web has been available for a number of years, it has only been in the last couple of years that major advancements in computers and web programming have enabled this medium to become a robustly-equipped teaching tool.

The marriage of course material with the web can highly impact the educational experience students receive. Using the Soil Mechanics course, the objective of the Gateway-funded project entitled Virtual Soils Mechanics Laboratory was to create an interactive environment that was both stimulating and educational, using the latest in web-based technology.

Traditionally, the laboratory information was dispensed through a paper-based manual containing only text. The students were required to prepare for each experiment prior to the scheduled laboratory session by reading the procedures associated with the respective experiment. Ideally, it would be most beneficial for the students to witness a live demonstration of each experiment before conducting it themselves. Due to the limited number of hours allocated per session and the number of students in each class, this becomes an impossible task to accomplish. Yet it is important, because it provides students with the knowledge to safely perform the experiments with understanding and efficiency. The visual incorporation of text and images on the web can allow for this.

Upon completion of each experiment, the data obtained was then processed. Prior to the development of the website, our students were familiarized with the steps involved in processing the data. Due to the complex and repetitive nature of the associated calculations, a computer program had been written to reduce the processing time and effort. It was an archaic (by today's standards) DOS-based "C" program. The Virtual Soil Mechanics Laboratory provides the necessary references as part of the design, and allows for instantaneous answers in the lab, in many cases during the experiment. Thus, should an error be detected through a flaw in the results, the students often have time to address this issue during the same lab period, saving much time and effort later.

The characteristics of the course make it a prime candidate from which to create interactive educational web content. The use of the web allows for the complex nature of the information associated with the laboratory experiments to be presented and manipulated in numerous ways unavailable in the traditional practice. The static text manual can be replaced with interactive multimedia elements using hypertext links, pictures, videos, and animation. The students will view the enriched experimental procedures on line prior to actually performing the experiments in the laboratory, and are therefore being much more informed on – and aware of – what is to be done in the laboratory and what results to expect. With web-based demonstrations, students can obtain the needed experimental skills without setting foot into the laboratory prior to the experiments.

The DOS-based software package used in the calculations can be converted into a graphical interface (GUI) common to the Windows and web environments. This allows the students to visually digest and better understand the procedures of the calculations as they are being performed.

The web also provides the students with the opportunity to study the experiments at their own pace and from virtually any computer, within or outside of Cooper Union. They are provided with a flexible and relaxed interactive learning experience.

The Virtual Soil Mechanics Laboratory has transferred all of the reference material and computational capability to the web, while also including significant improvements in the presentation and clarity of the material. By including photographs of the laboratory equipment used for each experiment with each procedure, students are able to see what will be required, and they become familiar with what each piece looks like prior to entering the laboratory. Video clips of the instructor's description of the procedures (for the more involved experiments) allow students to see the actual setup of the experiments in the lab by students. The human brain remembers information according to how it is recorded, and visual impact is much more desirable, because it may be recalled as the actual steps taken, rather than as future steps to take.

Also, a Virtual Tour of the physical laboratory has been incorporated, which shows the placement of major equipment and supplies. Thus, the traditional need to familiarize the class with the laboratory environment prior to the start of experimentation has been reduced significantly, since the class may now tour the lab and view the equipment at their leisure prior to the class period. This advanced preparation also allows most basic questions about the lab to be answered ahead of time, and gives the students opportunity to prepare pointed questions for the instructor in advance, to be answered more quickly and prior to – rather than during – the experiment.

III. Creation of the Web Page

In designing the Virtual Soil Mechanics Laboratory, many issues were considered, including those mentioned above, as well as: ease of use/user interface, potential internet connection speeds (from off-campus sites), color scheme, interpretability and compatibility with other programs/browsers, and the ability to save data for future reference. These issues reflect important concerns in the web page design. While, for example, the pages are primarily accessed from the Cooper Union Computer Center or from the laboratory, part of the purpose of this project was to allow access from other facilities and locations. A major concern in this regard is the speed of the remote user's interface, especially if they are accessing the pages from home. As such, we decided that the pages must not have large-sized files, to reduce download times. Compatibility with other programs and browsers was also key, as there are several competing browser technologies currently in use. The browser with the features most useful for this project, however, was determined to be Netscape Navigator 4.02, and all the pages were primarily written for this platform.

The documentation for experiments 1 to 11 was prepared as an on-line interactive manual. The general format consists of the objectives, references, apparatus, procedures, and calculations related to each particular experiment. They were prepared in a graphical user-friendly environment. The use of hyperlinked pictures and video clips were incorporated into the text, allowing students to familiarize themselves with the apparatus they would be using and the procedures they would be performing, prior to entering the laboratory.

The procedure for creating these pages and applets was as follows:

1. The original text of the laboratory procedure was obtained. Since experiments 6 through 11 were not part of the original paper-based manual, these procedures were taken from the instructor's notes.

2. The information on references used to create the procedures was verified and updated, if necessary.

3. The materials and equipment to be used in the lab were itemized and verified, and photographs of the same were taken using a Kodak DCS-120 digital camera.

4. Video clips of different parts of the experiments were shot using an 8mm Sony camcorder.

5. Using Microsoft FrontPage 98, the text of the procedure was entered from the notes, and links

were created from the equipment lists to the images of the materials and equipment used. Any calculations associated with the experiments were itemized here as well.

6. In order for a computer to recognize any multimedia file, the file must be of a digital type. Using Media-100 hardware and software, the analog videos were converted to digital format. Once on the computer and in digital form, the videos were exported to Quicktime format.

7. Audio wave files were recorded using an ordinary in-line computer microphone and the Windows Sound Recorder software. Smooth integration of the sound tracks into the video tracks were done using the Quicktime 4.0 Pro utility. The combined video and audio movie clips were finally compressed and streamed for fluid internet playback.

8. The integration of the videos into the appropriate sections of the on-line experimental procedures was achieved using html code and Java Scripting. An animated gif button was used to link the existing web page with the video clips.

9. The data sheets for the experiments were coded using JavaScript and were placed in the html coding of the applicable page. These data sheets are self-calculating and contain *save* and *export* functions. The *save* function enables the students to save and retrieve their data and results, and the *export* function allows the students to transfer data and results from the web page to a spreadsheet.

10. The pages were then tested for compatibility and correct operation on an IBM Thinkpad 770 and on Pentium 133-based personal computers using Netscape Navigator, versions 3.0 and 4.01, and Microsoft Internet Explorer, versions 3.0 and 4.0. Any issues that arose during this testing were then posted on the website, and were checked over the internet via an ISP account for functionality. The pages have been thoroughly checked for accuracy, and have been "field-tested" in the laboratory during the actual experiments, yielding qualitative and quantitative data about the effects of using this method.

In addition to the basic issues of how to program the features, the user interface and site color plan were a major issue in the design of web pages. Both the colors and the layout of web pages influence the users' experience with the page. A site may be fully comprehensive, but may hinder the user so greatly that it provides little of the desired information. It is the primary function of the Virtual Soil pages to provide information effectively and efficiently to the user, so the pages must be both technically convenient and enjoyable to look at while functionally complete. Several different layouts and color schemes were suggested for the pages, to improve readability and ease of navigation.

Light text on black background was selected to lessen the strain on the readers' eyes. Dark text on a light background, when viewed on a computer screen, may appear to be more intense, and can cause excessive stress for the reader. The darker background has a relaxing effect on the eyes, while not causing drowsiness, and the new styling of the text (using a Helvetica instead of a Courier font) allows for a better style of text to read, thus enhancing the transfer of data to the user. In addition, a splash page was included. It is essentially an index, and is the first page visitors see when accessing the site. The splash page uses an elevator theme, suggesting that the site will raise the user's experience in Soil Mechanics. The splash page also offers a clean and clear map to the pages within, containing all the choices within the limits of the first page, and connecting the user to the desired choices with minimal effort.

Following the splash page is a page containing a Photovista Panoramic view of the square within The Cooper Union Campus. This page may be obtained from either direct addressing or from the splash page. Here, users may obtain a better feel for what the site is intended to do, and may receive background on the Soil Mechanics class. Here also the user is introduced to the navigation bar, which allows access to any other major index page from any page in the site, without the need to hit the back button or to retrace one's steps through a myriad of menus and sub-links. With one click, the user may go directly to the main lab manual index, or the main data sheet index, back to the introduction pages, to the virtual tour of the soil mechanics laboratory, or to the links page.

A virtual tour of the Soil Mechanics laboratory is the third page of the website. Users can tour the Cooper Union Soil Mechanics Laboratory from the comfort of any computer with access to the web. This allows a familiarization previously unavailable to the user, since no photos of the laboratory were included in the paper-based manual, and access to the lab is generally not permitted prior to the class sessions. Users can locate supplies in the room, view key pieces of equipment, and just look around at the facility to become familiar with it, thereby reducing, if not eliminating, the need for a potentially lengthy introductory session by the instructor. The lab manual and data sheets follow the virtual tour.

IV. Evaluation Plan

As part of the evaluation plan, two practicing engineers were asked by the instructor of the course to evaluate the Virtual Soil Mechanics Laboratory website. Both have done extensive commercial soil mechanics laboratory work. These gentlemen are both managers of Soil Mechanics Laboratories, one at the Port Authority of New York and New Jersey, and the other at Mueser Rutledge Consulting Engineers, a consulting firm specializing in foundation engineering. Their comments can be found below.

> Overall, we found the Virtual Soils Laboratory to be an upgrade from the traditional methods of teaching laboratory soils testing, which relies principally on textbooks and written notes. We cite the following reasons.
>
> 1. The Virtual Soil Mechanics Laboratory is an interactive medium with a principal advantage in allowing the student to blend visual images of the actual test apparatus and equipment with the written test procedures prior to embarking on the performance of the test in the laboratory.
>
> 2. The Virtual Laboratory is an integrated platform allowing students to review test procedures, apparatus and equipment, reduce test data and visualize and interpret test results in a single setting. The computerized format enables quick and easy reference between the lab manual, test data sheets and test results, eliminating the need to shuffle between textbook, class notes and test data sheets. The integrated structure saves the student time and we believe makes learning laboratory soils testing less tedious and more enjoyable.
>
> 3. The Virtual Tour of the Soils Laboratory allows the students to enter and view the lab on his own terms and at his own pace, allowing him to explore the lab and its equipment, something he might not do in the actual physical condition due to time constraints or other limitations. The Virtual Lab is always open and readily accessible.
>
> 4. The Virtual Laboratory, with its built in graphical capabilities and ability to export test data to other software packages, allows quick and easy visualization and interpretation of the data.
>
> 5. Civil engineering students choosing career paths other than geotechnical engineering may be required to specify or interpret soils testing later in their careers. Exposure to the Virtual Laboratory will provide them with an easily accessible and efficient means for recalling test objectives and procedures.

The Virtual Soil Mechanics Laboratory website has been evaluated by the students twice: once in the Spring of 1998 and again in the Spring of 1999. In Spring 1998, one-half of the Soil Mechanics class was to prepare for the Soil Mechanics Laboratory in the conventional way (using a paper-based laboratory manual). The other half of the class would use the Virtual Soil Mechanics Laboratory website for its preparation. No interaction between the two groups was allowed. The Cooper Union Gateway evaluator and the course instructor developed two survey forms that were filled out by the students in the course. See Tables 1 and 2 for the surveys developed. One form was completed by only those students using the website for lab preparation. The intent of this survey was to develop a preliminary evaluation of the benefits – if any – of the Virtual Soil Mechanics Laboratory website. The other form was completed by the entire class. The intent of this survey was to evaluate the students' competencies obtained in Soil Mechanics. In the spring of 1998, 21 students registered for Soil Mechanics: 12 in Section A, and 9 in Section B. Section A was the group of students arbitrarily chosen to use the website. The result of the surveys and their evaluations by the Gateway Evaluator may be found below and in Table 3. The following are the Gateway evaluator's comments:

> We have strong, consistent evidence to suggest that your Virtual Lab is a good, efficient learning tool. Students exposed to it (group A) scored higher in all competencies proposed, and particularly in those competencies which reflect the goals you prioritized in you course goals for this phase of the course. Students in group A have a self-perception that they have developed the competencies we proposed for assessment (overall, and each of them) in a higher degree than students in group B (0.624 units higher, or 12.48% higher). Overall, students in group A scored 3.856 (maximum is 5); and students in group B scored 3.232. These scores mean that students in both groups (but particularly students in group A) have reasonably high self-perception of their skill development throughout the phase of the course being assessed.
>
> The significant percentage difference between groups regarding USE OF COMPUTER TOOLS (25.82% higher in group A than in B) could be expected: one of the groups (A) heavily used computers -the Virtual Lab website- whereas the other group (B) did not. Leaving this competency aside, the two competencies in which inter-group differences are broadest are VISUAL COMMUNICATION SKILLS and UNDERSTANDING OF THE EXPERIMENT PROCESS AS A WHOLE (in both cases, students in group A scored 17.5% higher than students in group B). This result confirms that two of the main goals of the Virtual Lab as you designed it are being accomplished, as perceived by students.
>
> I also think it is very revealing that the next two competencies -as ordered by percentage differences between the two groups- are TEAMWORK (10.82% higher in group A than in B), and CREATIVE PROBLEM-SOLVING (10% higher in group A than in B). PROJECT MANAGEMENT/LEADERSHIP and SYSTEMS THINKING register small percentage differences between groups. In the case of the first one, Project Management/Leadership (3.32% higher in group A), we have both groups with high self-perceptions of accomplishment (over 4 points in a maximum of 5), a very positive result that indicates that all of your students feel prepared, particularly after working on the 5 experiments, to set goals, prioritize tasks, and apply corrective actions based upon feedback from others, as the competency was defined.
>
> The interesting thing here is to compare results for this competency with results for TEAMWORK, a competency in which your students in group A feel clearly more prepared than students in group B after working on the experiments. A straight conclusion to be drawn from this is that your Virtual Lab incited student teams, and every student in each team, to contribute a fair share to the completion of the project. However, we should also consider the actual arrangements of the teams in this particular course to establish more precisely whether the difference is due to the Lab tasks or to the teams' composition. In any case, both Teamwork and Project Management/Leadership are the two competencies registering highest scores in both groups, what makes our concerns about these skills less urgent perhaps.

An analysis of qualitative responses from students exposed to the Virtual Lab can now give us a closer, richer picture of their opinions and suggestions.

Your Virtual Lab is highly regarded as being very effective for accomplishing the goals of the course . Most of the 12 students exposed to it give it a score between 4 and 5 (5 being the maximum). They also think that it is a useful learning tool, however improvable (they particularly feel they should be able to save the calculations).

In general, it was felt that those students using the website were better prepared for the Soil Mechanics laboratory, and had a better level of understanding in the course than those who did not use the website. However, several glitches were encountered in the self-calculating data sheets. These included faulty operation of the *compute* and *save* functions as well as the inability to export from the website to a spreadsheet. Overall, the first year use of the Virtual Soils Laboratory proved to be a success and deemed the project a great tool for providing instructions to the students.

In the Spring of 1999, all the students taking Soil Mechanics (20) were to prepare for the Soil Mechanics Laboratory using the Virtual Soil Mechanics Laboratory website. The same two surveys used in the Spring of 1998 were used again in the Spring of 1999, but this time all students completed both forms. The result of the surveys and their evaluation by the Gateway evaluator can be found below:

I have analyzed the data on question 1. The results will give you a quantitative picture of what students think of the lab's effectiveness. Overall the lab works very well. There are some problems that could be overcome with a bit of work. The students' comments to questions 2a and 2b (which I have not transcribed) are consistent with results to question 1. (See Table 4.)

The vast majority of students think that the Virtual Soils Lab is a useful tool. ***Overall, 77% of the responses given by the students who used it were 4 or 5 -on a 1 to 5 scale.*** This is a great result, and in my view, the minimum acceptable in a school committed to excellence as Cooper Union is. ***Reversely, 23% of the responses registered a score lower than four***. I would like to focus on these. The question is, once we have reached a high level of effectiveness with the Virtual Lab, how can we improve on the aspects that concern students? Figs. 1 and 2 show % of responses that were lower than 4 or 5 on the 1 to 5 scale. The figures do not show success directly, but rather improvable areas. **How can we lower the % of responses registering scores lower than 4 on a 1 to 5 scale?** Are these figures due to the Lab design, to its performance features, or to organizational aspects and dynamics of the course? These are considerations to be kept in mind for next year.

The "Effectiveness Rate" that I have used as indicator for analyzing results to question 1 is 23 for overall results. It means that 23% of the responses registered a score lower than 4. It can be read as an indication of problems experienced by students in using the Virtual Lab.

An assessment of the students' competencies for 1999 and their comparison to 1998 can be found in Table 5 and Fig. 3. The mean score of the seven competencies surveyed decreased only 0.256

from 3.856 to 3.6 from Spring 1998 to Spring 1999. This is essentially a status quo condition.

As part of the continuing evaluation process for the Soil Mechanics course, the instructor invited a prominent practitioner in the geotechnical engineering field - a partner at Mueser Rutledge Consulting Engineers, to help evaluate the oral presentations made by the class on their flexible pavement design. This was done both in the Spring of 1998 and the Spring of 1999. The Gateway evaluator and the instructor devised an assessment sheet for the oral presentations (see Table 6). The invited guest was very impressed with the caliber of these presentations, and his comments can be found below:

Spring 1998:

> I was very pleased to participate in evaluating the presentations of your laboratory students. During the course of Monday afternoon's program, I listened to presentations by seven groups of three students each. Their names are on the attached sheet. The problem which each group had been given was to evaluate soil conditions and to design a flexible pavement for a particular site. Each group described the problem, described the laboratory tests which they performed, and then described the design process which they went through to determine the pavement thickness, evaluate costs and develop an economical design. I was very impressed with the technical content of the presentations, the comprehensive summaries of data, the design process which each group was able to describe, the interesting and clear use of visual aids and the excellent verbal presentation. Each of the 21 participating students spoke clearly, concisely and with a confidence that illustrated their underlying knowledge of the material being presented.
>
> I applaud you for the concept of taking soil mechanics laboratory tests and making them meaningful by requiring the students to develop a design based on the results of their tests. In so doing, each of these students has developed an understanding of basic concepts of soil behavior, moisture- density relationships and the implications of that information on pavement design. That knowledge will serve them well in their future careers. They will remember these tests and their applications to design are better than if they had just done testing out of context.
>
> I encourage you to continue this concept in future years and would be happy to participate in a similar session again.

Spring 1999:

> On Monday, May 3, I attended the project presentations by your students in partial completion of the requirements of the referenced course. Six teams, varying from 3 to 4 students, made presentations. Group identifications and team member names are on the attached sheet.
>
> Each team described a sample of soil which they were given at the start of the course. They tested the soil in the school's laboratory to determine subgrade properties. They performed Atterberg limits, specific gravities, gradation with sieve and hydrometer, proctor compaction tests and CBR tests. From those data,

they designed a pavement section, selected geogrid reinforcement, and prepared comparative cost estimates for a section of highway.

I was impressed by the thoroughness of the work performed by the teams. Each team was able to present soil data and describe its significance, and then use that data to develop plausible pavement designs. They used computer-generated graphics to present their projects to the audience, and in every case, did a credible job of explaining the project and documenting their conclusions. This course has provided your students with an appreciation for the engineering process from data gathering, through testing design and presentation. This experience will be valuable for the students in their working careers, because they understand that the engineer's final product is an economical, buildable design.

I encourage you to continue this concept in future years and would be happy to participate in a similar session again.

V. Conclusions

It is the opinion of the Department of Civil Engineering at the Cooper Union that the Virtual Soil Mechanics Laboratory website is an unequivocal success. It will become a permanent part of the Soil Mechanics course and the only means of preparation for the lab and data evaluation. Other courses with labs are also considering the development of virtual laboratory websites. These courses are: Environmental Systems Engineering, Hydraulic Engineering, and Structural Engineering I.

VI. Acknowledgments

The author would like to thank the NSF/Gateway Coalition for the funding provided for this project, without which it would have been very difficult to have started; and Mr. Gerardo del Cerro, the Gateway Evaluator at the Cooper Union, for his help in developing and assessing the surveys given to the students. In addition, the author would like to thank two graduate students: Messrs. Roni Benjamini and Frank Krupicka, and two undergraduate students: Messrs. Eran Dekel and Aleksandr Krutovskiy, who worked very diligently on this project from start to finish.

Table 1. Virtual Lab Assessment**.**

1. How effective is the Virtual Lab for accomplishing the goals of the course? Please circle in each cell; rate from 1 (not effective) to 5 (very effective).

	OBJECTIVE	REFERENCES* How many did you use? Were they useful?	APPARATUS	PROCEDURE	CALCULATIONS
EXP #1 Preparation of Samples for Exp. 2 to 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
EXP #2 Specific Gravity	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
EXP #3 Grain Size Distribution	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
EXP #4 Consistency Limits	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
EXP #5 Compaction	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
EXP #6 Constant Head Permeability	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
EXP #7 Variable Head Permeability	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
EXP #8 Consolidation	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
EXP #9 Direct Shear of Cohesionless Soil	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
EXP #10 Unconfined Compression	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
EXP #11 Triaxal Compression of Cohesionless Soil	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5

2.A Do you think the Virtual Lab is a useful **learning** tool? How? Please explain.
2.B Do you have any suggestion to improve the design of the Virtual Lab? (Specify Exp. # if necessary)
OBJECTIVE
REFERENCES
APPARATUS
PROCEDURE
CALCULATIONS

Table 2. Assessment of Competencies Obtained.

Throughout this phase of the course, the team developed the following knowledge, skills, and abilities:

	N/A	**Not at All**	**To a Limited extent**	**To a Moderate Extent**	**To a Great Extent**	**To a Very Great Extent**
TEAMWORK **Every member of the team contributes a fair share to the completion of the project.**	N/A	1	2	3	4	5
PROJECT MANAGEMENT/LEADERSHIP **Every member of the team contributes to set goals, prioritize tasks, and every one applies corrective actions based upon feedback from others.**	N/A	1	2	3	4	5
DEMONSTRATES AN ABILITY TO USE COMPUTER TOOLS in the service of the goals of the project.	N/A	1	2	3	4	5
VISUAL COMMUNICATION SKILLS **Understands and applies modes of visual communication to which the team is exposed throughout the development of the project.**	N/A	1	2	3	4	5
CREATIVE PROBLEM-SOLVING **Develops many potential solutions to problems and suggests new approaches and challenges the way things are usually done.**	N/A	1	2	3	4	5
SYSTEMS THINKING **Integrates and uses knowledge from various courses and understands how events interrelate.**	N/A	1	2	3	4	5
DEMONSTRATES AN UNDERSTANDING OF THE EXPERIMENT PROCESS AS A WHOLE through the development of experimental skills and an awareness of results beforehand.	N/A	1	2	3	4	5

Table 3. COMPARING GROUPS A & B, Spring 1998

Means for each competency in each group. Absolute and % differences between groups between brackets.

COMPETENCIES	GROUP A	GROUP B
Teamwork	4.416 (+0.541/ 10.82%)	3.875
Project management/leadership	4.166 (+0.166/ 3.32%)	4
Ability to use computer tools	4.416 (+1.291/ 25.82%)	3.125
Visual communication skills	4 (+0.875/ 17.5%)	3.125
Creative Problem-Solving	3 (+0.500/ 10%)	2.5
Systems Thinking	3.25 (+0.125/ 2.5%)	3.125
Understanding of the experiment process	3.75 (+0.875/ 17.5%)	2.875
TOTALS MEANS	26.998 3.856 (+0.624/ 12.48%)	22.625 3.232

Table 4. VIRTUAL LAB EFFECTIVENESS TABLE 1999 (The table includes % of responses <4 on a 1 to 5 Scale)

	OBJECTIVE	**REFERENCES**	**APPARATUS**	**PROCEDURE**	**CALCULATIONS**	**TOTALS**
EXP #1 Preparation of Samples for Exp. 2 to 5	23	23	23	29	29	**25**
EXP #2 Specific Gravity	23	17	23	29	29	**24**
EXP #3 Grain Size Distribution	17	23	17	23	35	**23**
EXP #4 Consistency Limits	17	11	23	11	29	**19**
EXP #5 Compaction	11	29	23	17	35	**23**
EXP #6 Constant Head Permeability	5.5	11	23	29	35	**21**
EXP #7 Variable Head Permeability	11	17	11	23	23	**17**
EXP #8 Consolidation	29	35	29	29	52	**35**
EXP #9 Direct Shear of Cohesionless Soil	11	23	17	17	41	**22**
EXP #10 Unconfined Compression	17	17	11	17	29	**19**
EXP #11 Triaxial Compression of Cohesionless Soil						
TOTALS	**17**	**21**	**21**	**23**	**34**	**23**

Table 5. Assessment of Competencies Obtained – Spring 1998 and Spring 1999
N=19

	Spring 99 (entire class)	Spring 98 (group A only)
TEAMWORK	3.6	4.416
PROJECT MANAGEMENT/LEADERSHIP	3.5	4.166
USE OF TECHNOLOGY	4	4.416
VISUAL COMMUNICATION SKILLS	3.7	4
CREATIVE PROBLEM SOLVING	3.4	3
SYSTEMS THINKING	3.5	3.25
UNDERSTANDING OF EXPERIMENT PROCESS	3.6	3.75
MEAN	3.6	3.856

Table 6. **ASSESSMENT OF ORAL PRESENTATIONS.**

Group............... Members...
....
....
....
....

Please rate from 1 (lowest) to 5 (highest).

Organization Skills:
1. Did the presentation have a sense of objective to it?
2. Was the presentation well organized?
3. Did the speaker(s) show interest in the subject matter?
4. Did s/he (they) understand the subject matter?
5. Were they able to create visuals for the presentation?
6. Were they able to use technology and graphics to support ideas?

Communication Skills:
7. Did they articulate ideas in a clear and concise fashion?
8. Did they explain concepts effectively?
9. Were they able to synthesize the material effectively?
10. Rate the following:
    .eye contact
    .speed of speech
    .enunciation of words
    .gestures used

Teamwork:
11. Did the group have a unified sense of purpose to it?
12. Was the group well organized?
13. Did the group appear to function as a unit?
14. How would you rate the overall impression of the group?

To the interviewer:
15. Were you ***interested*** in the material presented?
16. Were you ***convinced*** by the facts and arguments presented?

Additional comments on the presentation:

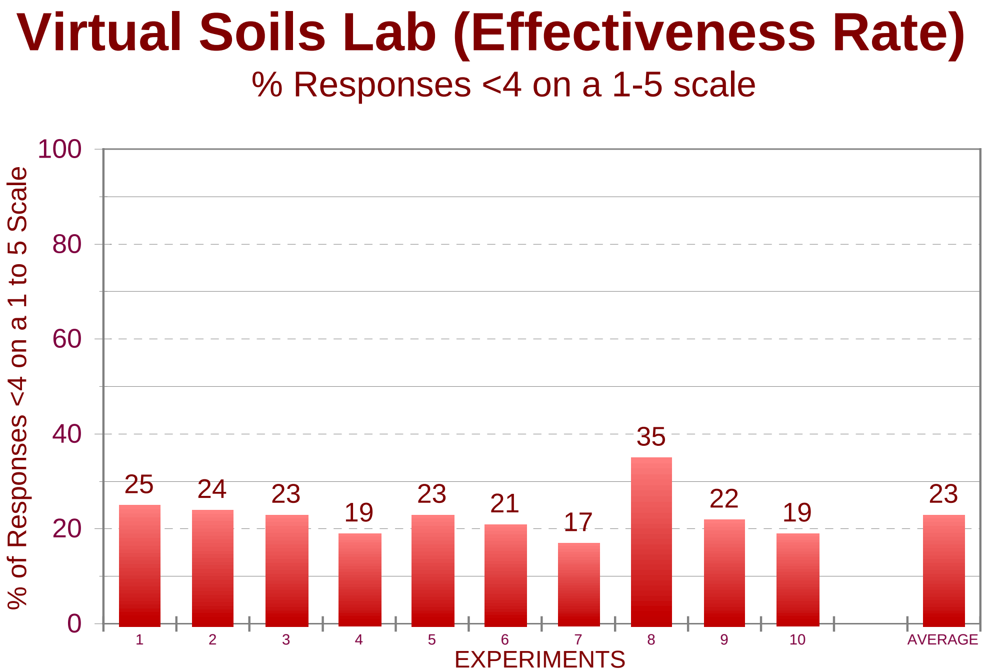

Virtual Soils Lab (Effectiveness Rate)
% Responses <4 on a 1-5 scale
% of Responses <4 on a 1 to 5 Scale
100
80
60
40
20
0
25
24
23
19
23
21
17
35
22
19
23
1
2
3
4
5
6
7
8
9
10
AVERAGE
EXPERIMENTS

Fig. 1

Fig. 2

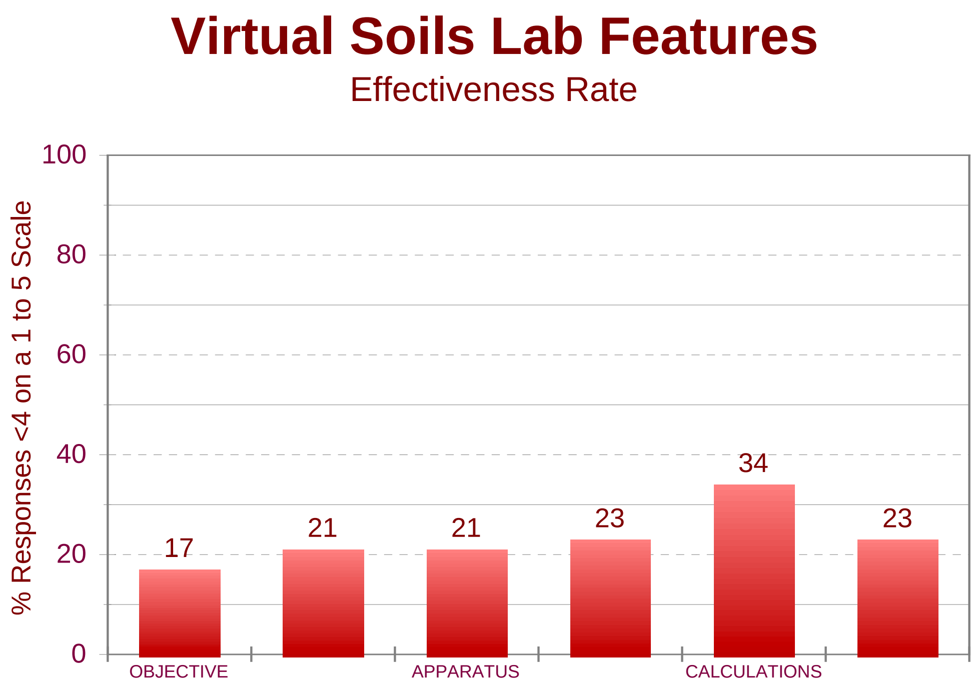
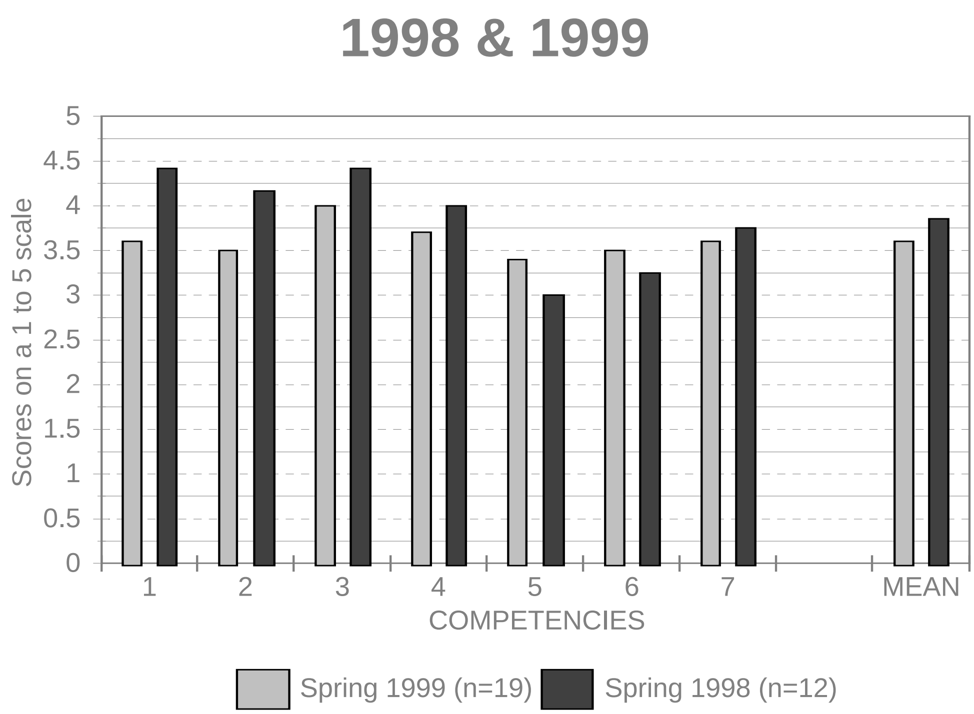

Virtual Soils Lab Features
Effectiveness Rate
% Responses <4 on a 1 to 5 Scale
100
80
60
40
20
0
17
21
21
23
34
23
OBJECTIVE
APPARATUS
CALCULATIONS

Fig. 3. Assessment of Competencies



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