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Effective integration of lecture and laboratory components in a civil engineering materials course to enhance student learning

Yusuf A. Mehta† & Leslie Myers McCarthy‡

Rowan University, Glassboro, New Jersey, United States of America†
Villanova University, Villanova, Pennsylvania, United States of America‡

ABSTRACT: At Rowan University, civil engineering (CE) materials laboratory is taught in the junior year as a required course for all CE students. This is a two-credit course involving a seventy-five minute class and two-hour forty-minute laboratory every week. The typical enrolment is around twenty students and there are no teaching assistants allowed. The limited laboratory space and equipment does not provide sufficient hands-on experience to all the students. Several universities have a situation similar to that of Rowan University, and this makes teaching core courses like civil engineering materials very challenging. The course was modified so that it addressed the concepts required to conduct laboratory experiments and its practical applications. The objectives of the laboratory experiments were well defined, however, the process was left to the innovative ideas of the students. The students had to determine the best way to achieve the objectives of the laboratory, building upon the information learnt not only in this class but also in statics, structural analysis and mechanics of material. This article, presents the course outline with a week-by-week breakdown of activities, with objectives for each of the four experiments and typical examination questions, and the unique pedagogical technique to teach civil engineering materials.

Keywords: Innovative, civil engineering materials

INTRODUCTION

Civil engineering material course at Rowan University is a required two-credit junior-level course that is offered in the fall semester. The course covers civil engineering materials, like wood, aggregates, cement concrete and asphalt concrete. The class of 20 to 25 students is divided into four groups. There are two time slots allocated for this course in a week, one hour-fifteen minute for lecture and two hour-forty minutes for the laboratory.

The civil engineering material laboratory at Rowan University houses equipment for specimen preparation and testing of various civil engineering materials, soils, aggregates, asphalt, cement, asphalt concrete and cement concrete. The space and equipment are adequate to safely and comfortably conduct laboratory experiments for only one group out of the four, a situation that is common for teaching institutions that do not allow teaching assistants and multiple sections in a week. This led to the following problems: 1) the students were not able to correlate the lecture courses with the laboratory; and 2) it was difficult for students to understand the significance of laboratory and its application to civil engineering industry as a whole.

The authors modified the teaching style and the structure of the course so that the students are not only actively engaged in the laboratory during the class time but also plan the laboratory ahead of time and understand the appropriate implications in the civil engineering industry. The methodology optimises the resources available and provides an opportunity for students to actively participate in the laboratories.

The authors tried this technique in the past four years, and it has proved to be successful. In this article, in addition to the detailed pedagogical techniques used and ways of assessing their course performance, the student evaluations and student comments are presented. In the following sections each of the courses will be presented in detail.

Civil Engineering Material Behavior Translated into Human Response

The mechanical behavior of civil engineering materials is best understood if it can be given a form of *human* emotions and behavior. For example, if a repeated load is applied to a material, say cement concrete, it will be difficult to withstand the same load as the number of repetitions increase. This concept of fatigue can be translated very easily to human behavior. If a student is asked to carry a 20 pound load up and down three floors 20-times, the same load will seem much heavier the twentieth time as compared to the first time. The authors have brought across the above concept through laboratory experiments.

Using Laboratory Experiments

The laboratory provides an opportunity for students to feel and *play* with the material. The laboratory was designed in such a way that experiments could be used as a tool to enhance student understanding.

As an example, the instructor used the experimental procedure of measuring the bending strength of wood to explain healing behavior. The students applied load on wood at different rates. They observed that wood strength was greater when it was loaded at a slower rate. This phenomenon was easy to understand when relating it to the physical response of humans. The faster a person runs, the more tired he/she becomes as compared to when he or she is running slow because the faster person does not get as much of chance to recuperate in the process as a slower person.

After the students had seen that behavior and related it to what they experience almost on a daily basis, a simple question was posed to them *So-what? How does this phenomenon affect civil engineering?* The students determined that the wood should be selected depending on anticipated loading rates. Thus, it was easier for students to understand the significance of this behavior in selection of wood for a given application.

The main point of this argument is that civil engineering materials can become mundane and would completely lose its importance if the class is focused just on facts and details. Instead of just focusing on the different properties of wood and their strengths, the students were required to be able to take the knowledge about the types of wood to the next level, which is the process of selection based on specific applications. Such a level of critical thinking allowed the students to make the connections between the properties of materials and their behavior and to determine their impact on civil engineering applications. With the objective of making students think beyond just the properties, but translating that information into civil engineering applications, the instructor developed this unique pedagogical and evaluation technique.

WHY IS THIS TECHNIQUE INNOVATIVE?

The instructor has observed that in other schools, the laboratory component is merely an *add-on* to the lectures. Such a pedagogical technique underutilises the impact a laboratory can have on student learning. The instructor in this course used the laboratory as the focal point of the course and innovatively designed the lectures emphasising the concepts behind the experiments in the laboratories. An extensive review of the education literature focused primarily on different unique laboratory experiments offered in the course, but none focused on the pedagogical technique that effectively integrates the traditional lecture and laboratory to maximise student learning [1-5].

Laboratory Set-up

It was overwhelming when the author taught the class for the first time using the same course outline and syllabus as the ones in schools with multiple sections and teaching assistants. Even though the laboratory procedure and testing standards were emphasised, there was a need for a link between lectures and laboratories. This was mainly because many of the students did not have an opportunity to actively participate in the laboratory.

In the following year, the authors did two modifications; the first modification was to change the focus of the class to the material covered in the laboratory. The information taught in the lectures classes emphasised the theory behind developing these laboratory procedures, its application in construction materials industry and influence on performance. The second modification was to split the laboratory into multiple sections, so that every student in a group had a chance to actively participate in the laboratory.

Each group provided steps to be taken in the laboratory for approval from the instructor before proceeding. The students were not only required to justify the process but explain the concepts involved in developing them. The authors have successfully applied this methodology of open-ended laboratory modules in another class [6][7].

However, the syllabus covered was much less because more time was now devoted to ensuring that each group actively participated in the laboratory. The lecture classes revolved around the laboratory allowing the authors to cover the material in depth. This effort was complemented by evaluating the students on laboratory participation and reports. In addition, the examinations included questions on concepts on specifications and their significance. The detail of the course and each laboratory module is explained in the following sections.

Course Outline

The course (Table 1) included four laboratories, wood or timber, aggregates, cement concrete and asphalt concrete. When there were no laboratories, a lecture class was conducted for the entire time slot of 160 minutes. The following sections explain the course on a topic basis. The textbook used in the class is titled, *Material for Civil and Construction Engineers* by Mamlouk and Zaniewski (1999). This textbook was easy to teach and complemented the teaching style. It was also well received by the students. The laboratory procedure at the end of the textbook was very helpful in teaching the laboratory.

Table 1: Course outline.

Week	Day	Session	Class Topic
1	1[1]	Class (160 minutes)	Mechanical Properties-Variability
	2[2]	Class	Mechanical Properties-Variability
2	1[1]	Class (160 minutes)	Timber/Wood
	2[2]	Class	Timber/Wood
3	1[1]	Lab 1 (G: I and II)	Timber/Wood
	2[2]	Class	Aggregate
4	1[1]	Lab 1 (G: III and IV)	Timber/Wood
	2[2]	Class	Aggregate
5	1[1]	Class (160 minutes)	Aggregates and Review of Examination I
	2[2]	Examination I Topic covered: Timber and aggregates	
6	1[1]	Lab 2 (G: I, II, III and IV)	Aggregate
	2[2]	Class	Cement
7	1[1]	Class (160 minutes)	Cement
	2[2]	Class	PCC
8	1[1]	Lab 3 (G: III and IV)	PCC
	2[2]	Class	PCC
9	1[1]	Lab 3 (G: I and II)	PCC
	2[2]	Class	PCC
10	1[1]	Class (160 minutes)	Asphalt and Review of Examination II
	2[2]	Examination II Topic covered: Portland Cement Concrete	
11	1[1]	Class (160 minutes)	Asphalt
	2[2]	Class	Asphalt
12	1[1]	Lab 4 (G: I and II)	Asphalt Concrete
	2[2]	Class	Asphalt Concrete
13	1[1]	Lab 4 (G: III and IV)	Asphalt Concrete
	2[2]	Class	Asphalt Concrete
14	1[1]	Presentations (G: I, II, III, IV)	
	2[2]	Review for final examination	
Final Week		Final Examination: 2-hour Comprehensive	

[1]Two hours-forty minute (160 min) time slot; [2]One hour-fifteen minute (75 min) time slot

Mechanical Properties and Variability

In the first week of the course, the author explained and reviewed various mechanical properties, responses, modes and behavior of civil engineering materials. In addition, the various sources of variability were explained and its influence on mechanical properties and performance was emphasised. This was followed by the timber or wood module.

Timber/Wood Module

Timber was covered in this course beginning from second week (Table 1). The objectives of the timber laboratory were:

1. To determine the compressive strength, flexural strength and flexural stiffness of various replicates of pine and oak.
2. To compare the mechanical properties and comment on the sources of variability and its influence on mechanical properties and performance.

The lectures were based on the above objectives of the laboratory. The class covered the basics of timber, its chemical composition, the various mechanical properties and its influence on performance. The two groups conducted the laboratory within one allotted time slot of 160 minutes. The other two groups during that time were assigned a series of problems based on the syllabus-covered to-date.

Aggregates Module

The aggregates topic was started at the end of the third week. The objectives of the aggregates laboratory were to determine:

1. The rodded unit weight of coarse aggregates (two replicates).
2. The dry and saturated surface dry bulk specific gravity of coarse aggregates (two replicates).
3. The gradation of sand (two replicates).

4. Based on the data collected, the students had to determine the variability of the measured parameters and the influence of the measured parameters on the performance.

The lecture classes included sources of aggregates, physical and mechanical properties, gradation and its influence on aggregate structure and performance in asphalt and cement concrete. Various test procedures required to measure the aggregate properties and concepts involved in designing these experiments.

All groups could finish the laboratory within one period of 160 minutes. The laboratory was divided into two 80-minute slots; two groups conducted the laboratory in each 80-minute time slot. The students in the laboratory were always actively involved because at a given time they were assigned different experiments. The other two groups that were not conducting the laboratory solved review problems in class.

The first examination included topics of timber and aggregates, the questions included concepts behind the testing procedures; a typical question: *Based on your experience, what steps or measures would you take in the laboratory to ensure accurate and precise measurements of flexural modulus of timber?* The first examination was typically a wake-up call for many students; they realised that the focus of the course was the laboratory. The sincerity and diligence of students in the laboratory improved considerably after the first examination.

Cement and Portland Cement Concrete (PCC) Module

The topic of cement and PCC was started at the end of sixth week (Table 1). The class focused on chemical, physical and mechanical properties of cement and cement paste. The Portland cement concrete topic focused on the mixture design, the trends between different parameters in the design. The objectives of the laboratory were:

1. To conduct a cement concrete mixture design using local aggregates and Type I cement for a 3000 psi concrete.
2. Redesign and prepare mixtures using water reducers.
3. Determine 7, 14 and 28-day strength of both the mixtures and a 14-day flexural strength of beams.
4. Comment on the slump, unit weight and the air content of both the mixtures.
5. Compare the compressive strengths, flexural strength of both the mixtures.
6. Compare compressive strength from non-destructive (rebound hammer) testing and destructive (cylinder) testing.

The second examination covered aggregates, cement and Portland Cement Concrete. The laboratory procedures and concepts of measuring techniques and its application in civil engineering industry were tested in the examination.

Asphalt and Asphalt Concrete Module

The topic of asphalt and asphalt concrete was covered at the beginning of tenth week and continued until the second-to-last week of classes (Table 1). The topic covered in this class was physical, chemical and mechanical properties of asphalt, asphalt emulsion and cutbacks, asphalt and asphalt concrete mixture design, Superpave versus Marshall mixture design and the influence of these properties on asphalt concrete and pavement performance. The laboratory included the following:

1. To evaluate properties of asphalt cement using Penetration test.
2. Develop a Superpave asphalt concrete mixture design for a given traffic and environmental conditions, given the aggregate sources and type of binder. The laboratory set-up in the above two modules was similar to the Wood/Timber module.

PAPER, PRESENTATION AND FINAL EXAMINATION

Each group was required to write a paper and make a 20-minute presentation on a civil engineering material not covered in the class. The guidelines for the paper were similar to that of the laboratory report. The students learned about non-traditional civil engineering materials that are not typically covered in classes, some of these include, but are not limited to, steel, epoxy bars, bamboos, polymers and recycled materials.

The presentations were done in the week before the final week of class. The last class was a review before the final examination. The final examination was a comprehensive examination with emphasis on asphalt, aggregates and asphalt concrete.

Grading

Each laboratory report was 10% (for a total of 40%), all homework together was weighed 10%, the first and second examination together was 15%, the paper and presentation were weighed 15% and the final examination was weighed 20%. If the student missed a laboratory and only participated in report writing, the student was awarded only 75% of the report grade.

STUDENT EVALUATIONS

The authors did not have the resources to conduct a study to compare the impact between the control group and the group exposed to the proposed technique to particularly assess the technique. The authors mention about the incremental changes made between the first and the second year of teaching the course, but these changes were minor to make a significant impact on the evaluations. The authors made a significant effort to review the literature to obtain evaluations from traditional CE materials courses that could serve as a *control* group but could not find the data [1-5]. This comment is added to the article.

The instructor evaluation from five courses and 77 students (Table 2) was very encouraging and positive using the technique. The laboratory evaluation clearly showed that 93% of the students in civil engineering felt that the laboratory complemented well with the courses. The response to questions 2 and 5 (in bold) clearly showed that a significant percentage of students (92 %) were actively engaged in teaching and learning, and found the class stimulating.

Questions 7, 8 and 9, address the impact of the pedagogical technique proposed in this study. The response to questions 7 and 8 clearly show that 74 out of 77 perceive that the laboratories and lectures complement well. The response to question 9 indicates that 72 out of 77 believed that the laboratory reports prepared them to be practicing civil engineers. These responses clearly show that the pedagogical technique had a significant impact on student learning. As mentioned earlier, no data from the control group was available for comparison.

The comments (Table 3) clearly showed that the students perceived the class positively. Even though the lecture class included primarily the concepts of the laboratory, none of the students felt that the syllabus covered was insufficient. Since all the students actively participated in the laboratory, they could relate to the course material easily. The most critical comments were that the workload was very extensive and not representative of a two-credit course.

The authors believe that the assigned workload is essential only for this group of students to understand the subject and prepare them for future classes, not only in civil engineering materials, but also in presentation and report writing. The authors have discussed the issue of increasing the credit load with the Department. The Department is currently reviewing the authors' request.

Table 2: Student evaluations on instructor and laboratory.

		Student Scores (77 students)				
	Question	1 (poor)	2	3	4	5 (excellent)
	Instructor					
1	Was the professor enthusiastic about the subject?				7	70
2	Did the professor stimulate thinking?			5	17	55
4	Did the professor require a high level of student performance?			2	3	72
5	Did the professor encourage questions and comments during the class?			1	10	66
6	Did the professor actively involve students in teaching and learning?			6	17	54
	Laboratory					
7	Do you think the material covered in the lecture and the laboratory was sufficient to perform and understand the laboratories that were conducted?			3	33	41
8	Do you think that the experiments in this laboratory helped your understanding of the material covered in the lecture portion of the course?			3	36	38
9	Do you think that the laboratory reports you prepared were adequate to explain the results of your experiment to practicing civil engineers?			5	23	49

Applicability to other Engineering Courses

The proposed technique is effective in courses, which require problems solving to enhance the understanding of the theory, such as Fluid Mechanics, Geotechnical Engineering, Environmental Engineering, Pavement Design (3), and Structural Analysis. On the other hand, the material covered in Civil Engineering Materials course covers physical, mechanical behaviour of aggregates, asphalt, cement concrete and aggregates.

The information requires a more conceptual understanding of the materials and, hence, may not be appropriate to use this technique.

Table 3: Student comments in Civil Engineering Materials Laboratory.

No	Comments
1	Really enjoyed the class.
2	I learned a lot and understood more material with him as the instructor than I probably would have if another professor taught the class.
3	In think Dr Mehta's teaching style was extremely effective.
4	He was very thorough and demanded much from the students. He graded very strictly regarding the laboratory reports. The tests were very exhaustive but fairly graded.
5	Dr Mehta did an excellent job & tests were challenging yet fair. I look forward to having him in other classes.
6	I think Dr Mehta was an excellent teacher but this course is only a two-credit class and he needs to calm down on the level of work.
7	This is only a 2-credit course so the workload doesn't have to be so heavy.
8	He is a very good teacher. Very hard but very good.
9	Good instructor but tough. I have 6 other classes not just this one. Too intensive, requires too much of students.
10	Dr Mehta is a really great teacher. His expectations are very high. What's hard is the amount of work he requires. Although the assignments help w/understanding. I feel too stressed trying to complete the necessary work.
11	Class is very hard, but you learn a lot.
12	Great job. Learned a lot.
13	Dr Mehta is a really great teacher. His expectations are very high. What's hard is the amount of work he requires. Although the assignments help w/understanding. I feel too stressed trying to complete the necessary work.

Long Term Evaluation

The long term evaluation, though anecdotal, was that civil engineering academic staff teaching laboratory in other courses have commented that student reports were very organised and thorough. In addition, they also observed that this class laid a good foundation for classes like geotechnical and structural design. The author also taught the same group of students in the advanced class of Pavement Materials Design the following year. The author observed that they had a significant retention of the material and understood pavement material behaviour reasonably well.

Even though the long term evaluation is based on anecdotal evidence, it was invaluable because it came from faculty who were teaching at the Department before one of the authors taught this course. Academics clearly saw improvement in student performance in their courses, especially in report writing. The detailed report guidelines used in the course were later applied throughout the curriculum in various courses, such as Fluid Mechanics, Environmental Engineering, Geotechnical Engineering and Senior Design. The reinforcement of the guidelines in different courses was critical in teaching students how to write good quality technical reports. These guidelines also served as an excellent template for student research project and design reports.

CHALLENGES

Scheduling Concerns for Civil Engineering Materials Laboratory

The authors found that this technique created a few unexpected problems, which were especially evident in scheduling. Initially, the groups that were not conducting the laboratory were underutilising precious class time. After the first two laboratories, the authors decided to provide a review tutorial session. In these sessions, higher-level thinking and design problems were assigned. The students could work on those individually or as a group, but had to finish it in class and submit it to the instructor. This appeared to work well because it gave an opportunity for the instructor to encourage students to think on practical (design) problems in construction materials design industry, beyond the topics covered in lecture classes.

Increase in Class Sizes

The authors found that this technique created a few unexpected problems, which were especially due to increase in class-size in the last couple of years. When the course was designed, there were 10-14 students; it was easier for the authors to follow-up on the effort of students in class problems, where the most learning is happening. With the increase in class size to 28-30, it has become harder to pay close attention to all the students within the allotted time as they solve the in-class problems. However, the technique has still been effective. The author has supplemented the course with tutorial sessions beyond the class time to supplement the in-class problems. It has been very hard because at Rowan University no teaching assistants are assigned for the classes. It is unclear at this time at what critical class size this technique may become ineffective.

CONCLUSIONS

The authors strongly believe that the new technique is beneficial for both the instructor and students. The methodology has been very effective; the information is more organised and flows better. The information covered was extensive and very relevant to civil engineering applications. This can be attributed to the fact that the rationale behind developing standardised laboratory procedure has broad ranging applications to the civil engineering industry as a whole.

This technique could be used in primarily teaching institutions that have limited space and equipment resources and that do not allow multiple sections of laboratory in a week. The authors strongly believe that teaching is a learning process for the academic staff. The authors are continuously evolving and improvising the technique to ensure that students stay current with the latest developments and have a fruitful learning environment.

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BIOGRAPHIES

Dr Yusuf A. Mehta is an Associate Professor at the Department of Civil and Environmental Engineering at Rowan University, Glassboro, New Jersey, USA. Dr Mehta has extensive experience in teaching pavement materials and pavement systems, and has published several technical and educational papers in leading professional organisations.

Dr Leslie Myers McCarthy is an Assistant Professor at the Department of Civil and Environmental Engineering at Villanova University, Villanova, Pennsylvania, USA. Dr McCarthy has experience in teaching pavements and transportation engineering. She has published several technical papers in leading professional organisations.