The Evolution of the Breadth and Depth in Civil Engineering Laboratory Classes

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Abstract

Engineering programs use multiple methods to teach their students. One of the more popular approaches is to include laboratory experiences on specific engineering topics. Providing students with hands-on laboratories gives the students sensory learning experiences they can use to see, touch, smell, and hear phenomena they learn in classes. Sometimes the laboratories are connected to a specific course and tethered together. The content is then presented in parallel. Other times the classes and laboratory are independent, may be in different semesters, and might cover a variety of topics.

The objective of this study was twofold: First, to study the evolution in laboratory experiences at the Virginia Military Institute since its inception as an accredited engineering program in the 1930s. As previously reported, the curriculum has undergone numerous changes, many cyclical, in the past eighty years. While the number of credits has been studied and remained consistent, the content of the laboratory credits has not been investigated. Second, many universities use different methods to implement laboratory experiences. This project investigated the nine accredited civil engineering and civil engineering technology programs in the Virginia Region as defined by the American Society of Civil Engineers (ASCE) student conference. The number of classes, the credit hours, and the course content were recorded and compared among the universities. The results reveal that laboratories are still an important part of all civil engineering curriculum and all universities exceed the recommendations by ASCE and ABET, but the methods used to implement laboratories vary significantly.

Keywords

Engineering Programs, Curriculum, Laboratories, ABET, Body of Knowledge

Introduction/Background

The Virginia Military Institute (VMI) is a public, state-supported undergraduate-only college that currently has three engineering departments. The Civil and Environmental Engineering Department (CEE) has approximately 200 total students and has been continuously ABET accredited since 1936. The CEE curriculum, as published in the yearly course catalogues, was studied every ten years starting in 1936 for this paper. This interval was selected because it reveals macro changes in the curriculum and has been used successfully in the past **[1]**.

Students at VMI are called cadets, are taught in a military-like environment, and are required to take Reserve Officer Training (ROTC) courses and Physical Education (PE) courses every semester. These courses are typically considered hands-on courses, but they were not included in

the total number of laboratory courses for this study. Since most other colleges including all of the civil engineering programs near VMI do not require ROTC and PE courses, only engineering and science laboratory courses were considered in this study **[2]**.

Engineering instructors at VMI currently use various types of delivery methods for the engineering curriculum. Varying the delivery method is generally considered a good teaching practice because it appeals to different learning styles. The curriculum at VMI has always included laboratory experiences either as part of a specific course or as a separate stand-alone course. Traditional laboratory experiences at VMI require cadets to perform hands-on experiments. Hands-on has been defined as "any educational experience that actively involves people in manipulating objects to gain knowledge or understanding." **[3]** In recent years, most of the laboratories at VMI take place in the afternoon while the more traditional three-credit courses take place in the morning. Cadets appreciate this daily schedule because it offers a break in the day. The inclusion of laboratory experiences is also attractive to the instructors because it provides an opportunity to deliver topics in a way that cadets are likely to remember. Lastly, the benefit of long-term retention is one of the biggest appeals to laboratory experiences.

Another important reason to use laboratories is to meet ABET criteria. ABET accreditation of civil engineering programs includes the minimum criteria for laboratory offerings. In the Criteria for Accredited Engineering Programs, General Criterion 3 – Student Outcomes, students must have the "ability to develop and conduct appropriate experimentation, analyze and interpret data." Further, in General Criterion 5 – Curriculum, programs are expected to teach "mathematics and basic sciences with experimental experience appropriate to the program." Neither of these requirements give minimum credit hour requirements, however, in the Civil Engineering Program Criteria (CEPC), Section 1- Curriculum, students are expected to "conduct experiments in at least two technical areas of civil engineering and analyze and interpret the resulting data." This requires laboratories in at least two areas, but it does not preclude it from being one laboratory that covers two topics. **[4]**

Another standard used by the civil engineering community to design program content is the Civil Engineering Body of Knowledge (CEBOK). In the most recent edition, the "Experimental Methods and Data Analysis" outcome requires students to "Conduct experiments in at least two specialty areas of civil engineering." Taking courses in Mathematics and Natural Sciences is required in the CEBOK, but there is no reference to require laboratories on these topics. Similar the ABET CEPC, the focus is on offering coursework in two areas of civil engineering. **[5]**

Civil Engineering programs are given significant flexibility in how to meet the laboratory criteria requirements. The VMI CE laboratory curriculum has been under review the past year and part of this process has been to determine if the right number of topics and credit hours are included in the program. For comparison purposes, both historic data on the VMI program and current data on similar programs in the region are part of this review. This paper discusses some of the results and the implications for other programs considering how to make changes to their laboratories. In particular, two research questions were created for this program:

1) How have the laboratory course offerings changed over time in the VMI civil engineering program?

2) Do ABET accredited programs in the same region as VMI offer similar laboratory courses in their civil engineering curriculum?

Procedures

The research in this study focused on two comparisons among laboratory offerings in civil engineering programs. First, a comparison of historical trends in laboratory offerings was investigated at the VMI since it became accredited in 1936. Second, the current laboratory offerings in the ABET accredited civil engineering and civil engineering technology programs in Virginia and West Virginia were compared. These programs were selected because they were direct competitors with VMI for students and have historically attended similar functions sponsored by the American Society of Civil Engineers (ASCE).

Data collection from the programs followed the same process as a previous study that measured macro trends in course offerings in the VMI civil engineering program over ten decades. **[1]** For the first part of the study, data was gathered from published VMI course catalogues starting in 1936 and continuing every ten years until 2016. The goal was to identify overall trends in course offerings. The assumption is most long-term programmatic changes occur with time and are not implemented quickly. Sampling data every ten years should produce large long-term changes even though small changes may be missed. For the second part of the study, data was gathered from the current published course catalogues in Fall 2021 from the nine universities offering degrees focused on civil engineering in Virginia and West Virginia.

Data was recorded on any required course that included a laboratory component in the program curriculum. First, the number of credit hours that corresponded to the laboratory was recorded. All universities in the study used semester credit hours. When the laboratory was part of the course, a breakdown of laboratory credits and classroom credits were recorded based on the information in the course catalogue description. Next, the number of physical hours in each laboratory was recorded. Credit hours do not translate to the same number of physical hours in the laboratory setting. The results revealed most schools do not clearly list this data in the course catalogue, so the focus on the physical hour data was only on the laboratories at VMI. ROTC and physical education laboratories were not included in the study. While all other laboratories were investigated, only science and engineering laboratories existed in the programs studied. Table 1 lists the categories of laboratories identified within this study.

Table 1 – Laboratory categories recorded

Science Laboratories	Engineering Laboratories
Physics Chemistry Other Science	Intro to engineering Seminar Steel Environmental Water Resources/Fluid Mechanics Materials Geotechnical Structures Surveying Drawing Circuits Programming Transportation

Results

The first comparison revealed the number of laboratory credit hours in the civil engineering program at VMI since 1936. As shown in Figure 1, the range was 10 credits in 2006 and 2016 to 23 credits in 1956. In 1936 the program started with 12.5 credits before dropping to 11 in 1946 and then increasing to the highest credit values in 1956 and 1966. Between 1976 and 1996 the number of laboratory credit hours remained very close to the overall average of 14.3 credits. The laboratory credits at VMI have trended down for the past 60 years.

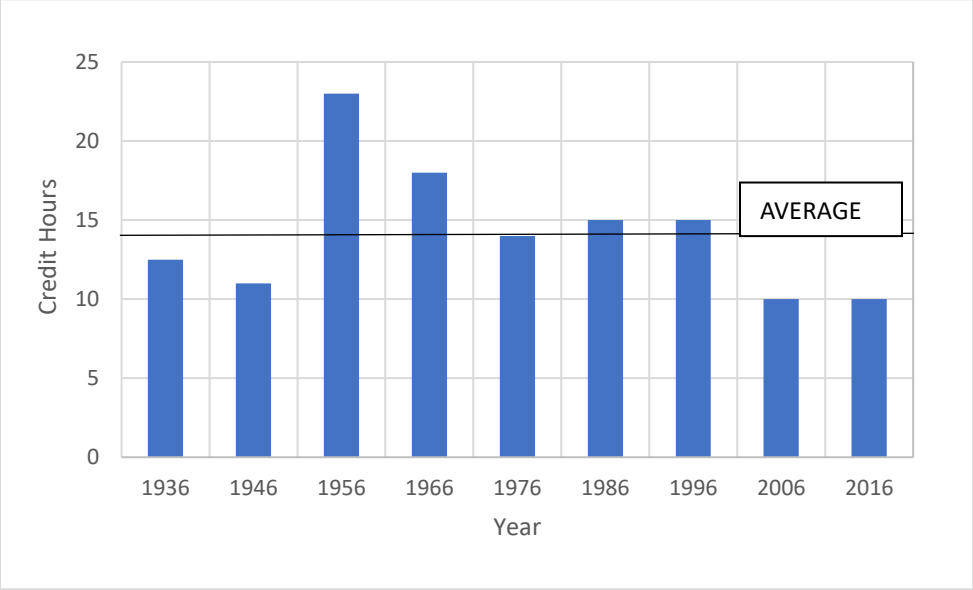

Figure 1 – The number of laboratory credit hours required in the VMI Civil Engineering Program

The number of physical hours in the laboratory at VMI each year are presented in Figure 2. The initial number of physical laboratory hours was 42 in 1936 and has dropped to 25 in 2016, the lowest number of any year measured. The numbers have varied throughout, but were generally higher until 1956 before dropping below the average (36.4 physical hours) in every year from 1966 to 2016 except in 1996.

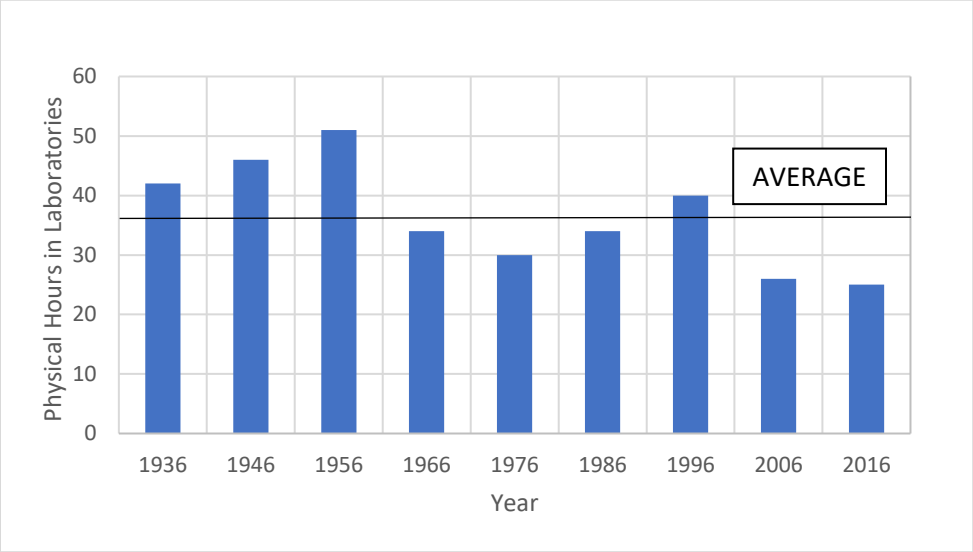

Figure 2 – The number of physical hours in laboratory required in the VMI Civil Engineering Program

Figure 3 shows the variation in number of topics covered in the laboratories at VMI over time. In 1936 and 1976, seven topics were covered, the lowest amount at any point in the program. The highest number covered was in 1996 with twelve and the average has been nine. Six of the nine years surveyed were between eight and ten topics. The topics that were included in every year include physics, chemistry, and surveying. The topics covered in only one or two of the years studied include other science (Biology, Geology, etc.), general engineering laboratories, steel design, and structures.

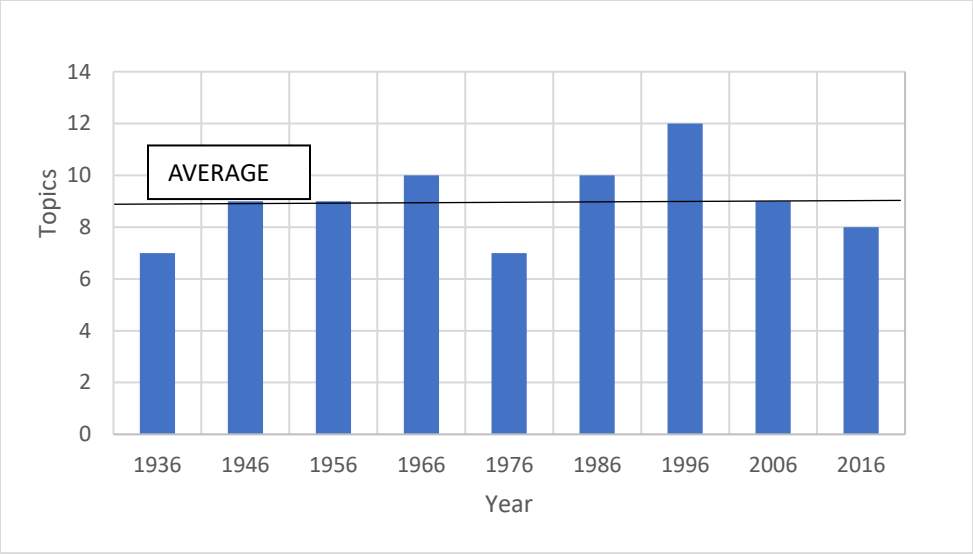

Figure 3 – The number of topics covered in the required laboratories in the VMI Civil Engineering Program

Nine additional ABET-EAC and ABET-ETAC accredited civil engineering programs were identified in Virginia and West Virginia and their program content was reviewed. The average number of laboratory credit hours varied from 4 to 10.5 (Figure 4). The average was 6.7, but three schools had 4 credit hours and three schools had 9 or more credit hours. The range is broad and only one school had a number (6) close to the average. The school with the maximum number of credit hours, U5, and one of the schools with the minimum number of credit hours, U8, are both technology programs (ABET-ETAC). All other programs are ABET-EAC accredited.

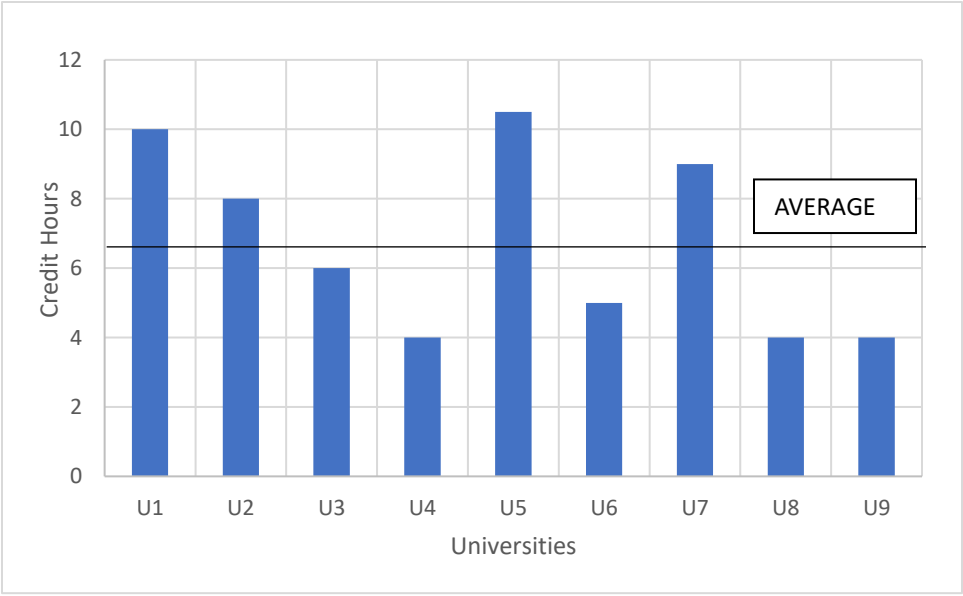

Figure 4 – The number of laboratory credit hours required in Accredited Programs in the Virginias

Figure 5 shows the number of topics covered in the civil engineering programs in the Virginias. The range is 3 to 7 topics and the average is 5.1. Similar to the credit our comparison, the two technology programs cover the extreme number of topics, 3 and 7, respectively. The number of topics varies, but 4 is the most common number. The only topic covered in all 9 programs is physics. Chemistry and water resources/fluids are in 6 programs and geotechnical laboratories are in 5 programs. Topics that are not included in any laboratory include seminar, professional issues/topics, steel design, structures, mechanics, and circuits.

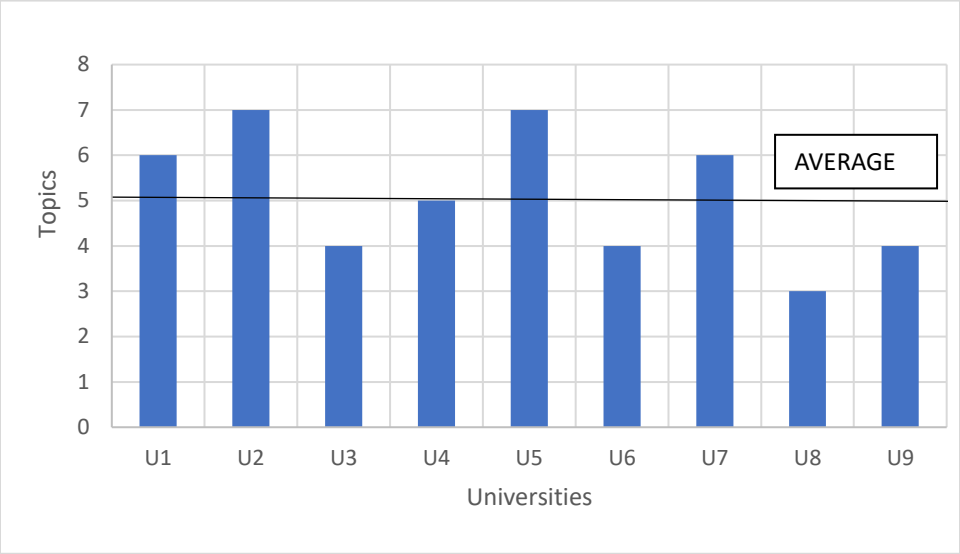

Figure 5 – The number of topics covered in the required in Accredited Programs in the Virginias

Conclusion

Both the ABET CPEC and the ASCE BOK require that civil engineering students conduct experiments in two areas **[4, 5]**. As shown in Figures 3 and 5, all colleges and universities investigated currently require laboratory experiments in more than two areas, with a current average of 5.1 topics for the nine colleges and universities investigated. VMI also currently requires cadets to perform laboratory experiments in 8 topics. Only one university investigated, U8, approached the minimum number of 2 topics by requiring laboratory experiments in 3 areas. It can be concluded that most colleges and universities recognize that laboratory experiments are valuable since all colleges and universities continue to offer more laboratory experiences than the minimum required by ABET CPEC and the ASCE BOK. Since laboratories typically cost more to initially build compared to traditional classrooms and require additional yearly funding, the fact that most colleges and universities continue to recognize the benefits of laboratory experiments is helpful for funding justification.

Although the number of laboratory topics required by most colleges and universities investigated has typically remained above the minimum required for accreditation, the total number of laboratory credit hours has dropped below the average recently at VMI. As shown in Figure 2,

VMI required 25 physical hours of laboratory time in 2016, down from an initial value of 42 hours in 1936 and below the overall average of 36.4 hours. This reduction is due partly to the increase in requirements from ABET and ASCE. As additional requirements have been added to the curriculum, some laboratory hours, by necessity, have been dropped. Looking to the future, as additional requirements are proposed, it will be important to consider adding them into the curriculum within a laboratory experience.

Figure 1 shows that VMI has averaged 14.1 required laboratory credit hours since 1936. The number of required laboratory credit hours has dropped to 10 in 2006 and 2016. Currently, as shown in Figure 4, the nine colleges and universities investigated require an average of 6.7 laboratory credit hours. This is less than half the long-term average of VMI, but close to the current number of credits at VMI required in 2006 and 2016. Three of the nine colleges and universities required as low as four credit hours. This indicates that, although all nine colleges and universities easily meet the minimum requirement for the number of laboratory topics, the number of credits required to meet this requirement varies significantly.

During the COVID-19 disruption, many colleges and universities were forced to either significantly modify laboratory experiments, cancel experiments altogether, find clever ways to have students perform experiments at home, or transition to fully virtual laboratories. Virtual laboratories can allow students to learn and gain knowledge as well as prepare for real-life experiments. **[6]** Although some have encouraged colleges and universities to transition to fully virtual laboratories, the results of this research indicate that colleges and universities still see the benefits of actual hand-on experiments and have not removed these from the curriculum.

Considering the traditional hands-on nature of VMI, it is understandable that VMI requires more laboratory experiences than its peer institutions in civil engineering in Virginia and West Virginia. However, it is useful to realize that, although all colleges and universities investigated use different curriculum models to meet ABET accreditation requirements, all require students to take more than the minimum number of topics. Also, many require that a significant amount of time in the curriculum be dedicated to laboratory experiences. Hands-on learning is still considered valuable in this digital age.

References

[1] C. Newhouse and M. Swenty, "The Dynamics of Civil Engineering Program Content," in *ASEE-SE Proceedings*, 2021.

[2] Virginia Military Institute, "Civil and Environmental Engineering," VMI, [Online]. Available: https://www.vmi.edu/academics/departments/civil-and-environmental-engineering/. [Accessed 10 11 2021].

[3] D. L. Haury and P. Rillero, Perspectives on Hands-On Science Teaching, Columbus: ERIC Clearinghouse for Science, Mathematics, and Environmental Engineering, 1994.

[4] ABET, "Criteria for Accrediting Engineering Programs," 30 11 2019. [Online]. Available: https://www.abet.org/wp-content/uploads/2020/09/EAC-Criteria-2020-2021.pdf. [Accessed 10 11 2021].

[5] Civil Engineering Body of Knowledge 3 Task Committee, ASCE, Civil Engineering Body of Knowledge: Preparing the Future Civil Engineer, Reston: ASCE, 2019.

[6] M. Budhu, "A Civil Engineering Materials Courseware with a Virtual Laboratory," in *American Society of Engineering Education Annual Conference*, Montreal, Canada, 2002.

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