Rationale and Design Approach for Full-scale Experiential Learning Opportunities in Structural Engineering

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Professor Hanson brings four years of military and industry experience to the classroom. Upon completing his Ph.D. in structural engineering at Cornell University, he taught for two years at Bucknell University. He is a registered Professional Engineer.

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Introduction

Civil engineers are responsible for the design, construction, maintenance, and renovation of the aging infrastructure of the United States and a well-prepared workforce is crucial to its continued operation and improvements. Developing well-prepared leaders and innovators is highly influenced by the learning process, but engaging students in the learning process can be challenging under certain circumstances. Buildings and bridges are some of the largest man-made structures in the world and the concepts related to their design and construction can be very difficult for students to visualize and understand. Although a number of small-scale projects exist that successfully engage students in the learning process, full-scale testing can be a powerful form of experiential learning in structural engineering courses. Most curricula focus on the proverbial "nuts and bolts" of structural engineering by teaching students to calculate forces and displacements along with member capacities. However, students regularly struggle to grasp structural behavior whether that is simply sketching a deflected shape or describing failure mechanisms. Rather than passively experiencing structural element or system behavior through pictures, videos, simulations, and small-scale projects, full-scale testing provides students with a first-hand, lasting understanding of fundamental behavior. Additionally, students also gain invaluable perspectives often difficult to glean from traditional classroom instruction such as constructability and tolerance issues. Full-scale testing is essential for student understanding of structural engineering concepts and there is a significant need for well-organized experiential learning opportunities with appropriate scales that successfully illustrate structural behavior.

This paper provides the rationale and design approach for full-scale experiential learning opportunities in structural engineering at Saint Louis University (SLU) and Rose-Hulman Institute of Technology (Rose-Hulman). SLU is a large, private, four-year, highly residential university with doctoral programs and high research activity (R2); Rose-Hulman is a small, private, four-year, highly residential university without doctoral programs, classified as special focus four-year: engineering schools. Neither institution had a structural engineering laboratory prior to this implementation, but both focus heavily on the undergraduate learning experience. The rational of the project is based on faculty's observations related to student understanding of structural behavior in four courses: structural analysis, reinforced concrete design, steel design, and foundation design courses. The design approach of the experiential learning modules highlights several factors including desired structural behavior, scale, testing capabilities, and implementation feasibility. Some supporting data regarding student perceptions of difficult topics is provided to reinforce faculty observations. The paper also provides brief descriptions of the thirteen experiential learning modules developed for the four courses to improve student understanding of structural behavior and concludes with a brief discussion of project assessment efforts.

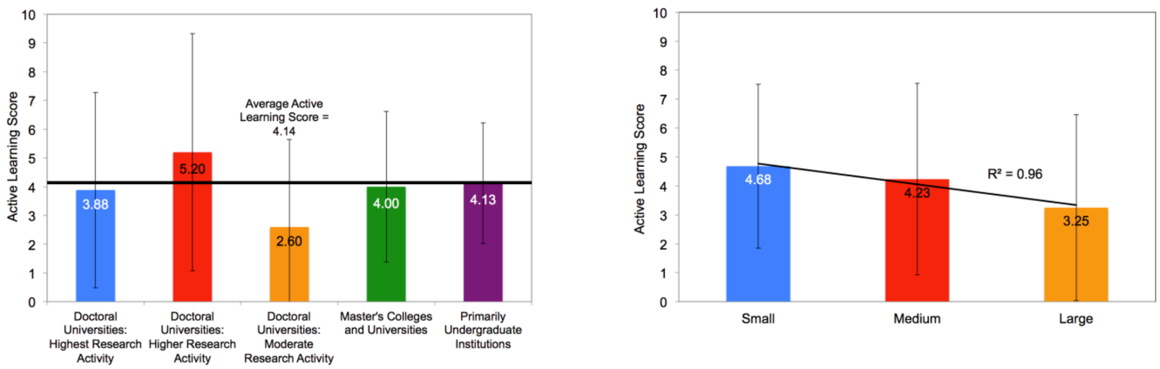
Background and Supporting Literature

Engaged Student Learning

Engaged student learning typically takes the form of active learning, but this approach can be difficult to maintain in engineering design courses. Introductory courses in engineering regularly include group projects that require students to "design" and build various items. However, as students progress through engineering curricula, engineering systems and their behavior increase in complexity making it difficult to design and actually build something, which diminishes excitement and engagement.

Traditional design courses present material deductively where instructors begin with theory and derive equations, eventually explaining the application of said theory with an example. The laboratories sometimes associated with such courses generally involve problem sessions rather than actual laboratory experiments or projects. An alternative approach is an inductive method, presenting existing data, a case study, or a quick problem to solve that could potentially summarize a general theory. Prince and Felder [1] summarize a number of these inductive methods available for use by instructors, including inquiry learning, problem-based learning, project-based learning, case-based teaching, discovery learning, and just-in-time teaching, all of which are considered to be active learning techniques and learner-centered [2]. Active learning is defined as an instructional method that *engages students* in the learning process, using meaningful learning activities that require a deeper thought process [3], in which students take ownership of their learning experience [4]. The primary objectives of active learning are to promote student activity and to engage them in the learning process [5], with the most extreme version being project-based or experiential learning. Project-based learning provides an open-ended project with a variety of problems to solve over the course of an extended period of time. The primary advantage of project-based learning is the opportunity for students to experience the activity. However, to classify as experiential learning, students must also have an opportunity to reflect and apply what they learn.

A survey [6] was sent to approximately 240 civil engineering programs to determine the extent of active learning use in upper-level courses and to assess the structural engineering testing facilities across the country. Sixty-four diverse programs responded to the survey (26.6% response rate) representing a fairly consistent breakdown of Basic Carnegie Classifications of all civil engineering programs. One part of the survey asked "What describes the format of the following courses in your department?" which included Civil Engineering Materials, Structural Analysis, Reinforced Concrete Design, Steel Design, and Foundation Design. A score was assigned to each response to determine an "Active Learning Score." The available responses were Traditional lecture (0 points), Traditional lecture plus traditional lab (1 point), Traditional lecture plus project-based lab (2 points), Interactive lecture (1 point), Interactive lecture plus traditional lab (2 points), and Interactive lecture plus project-based lab (3 points). "Traditional lecture" was defined as chalkboard or whiteboard style presentation; "traditional lab" was defined as guided activities; "interactive lecture" was defined as active learning or problem-based instructional approach; and "project-based lab" was defined as open-ended type of activities or projects. The active learning scores for the five courses were averaged to obtain the average active learning score for each institution. Fig. 1 (a) shows the average active learning scores broken down by Basic Carnegie Classification and Fig. 1 (b) shows the average active learning scores with respect to class size, where small is 0-25 students, medium is 26-50 students, and large is greater than 50 students. While active learning varies widely with respect to program type, the majority of programs indicated that active learning techniques were used in at least some of their courses and the level of implementation appears to be most dependent on class size.



(a) (b)

Fig. 1—(a) Active learning score vs. Carnegie Classification and (b) active learning score vs. class size.

SLU and Rose-Hulman faculty note that students struggle to retain fundamental engineering knowledge and skills when they do not observe the physical mechanisms of member and system behavior. This results in students playing "catch-up" and/or faculty having to review prerequisite material. As requirements for future engineers continue to increase [7, 8], losing either basic analytical skills or time to cover the increasing breadth of essential content poses a significant problem, which is not exclusive to SLU and Rose-Hulman. A well-orchestrated course includes a variety of active learning techniques that keep students engaged and excited about the course content. Several active learning techniques can be easily implemented by instructors with sufficient pedagogical understanding and minimal resources. However, the more advanced forms of active learning, such as experiential learning, are much more difficult to implement and require more experience and access to the necessary resources. A number of projects exist for structural engineering students and although each project has its merit, more full-scale opportunities would better illustrate structural behavior.

Supporting Student Data

Over the course of two years students at each university were asked to take a course content survey to evaluate their perception of the topics most difficult to understand in structural analysis, reinforced concrete, steel design, and soil mechanics and foundation design. The survey used a standard five-point Likert scale where 1 = Very difficult, 2 = Difficult, 3 = Neutral, 4 = Easy, and 5 = Very easy. The results include the mode, average, and standard deviations based on the numerical values associated with each response. Tables 1-4 show the results for each respective course and those highlighted in grey indicate an average response less than or equal to 3.0 at one or both universities. Note that not all topics listed in the tables are taught at both universities. Topics not taught at a specific university are denoted by a dash.

Over the course of two years, 94 students at the two schools participated in the structural analysis course content survey, the results of which are shown in Table 1. Eleven topics had an average response less than or equal to 3.0. Furthermore, Topics 14, 16, 19, and 25 had modes of 2, indicating that a significant number of students selected “Difficult” on the survey. The results of the survey were fairly consistent across universities and not surprising. However, topics 2, 3, and 4 had higher scores than expected; students tend to struggle with those concepts, which is discussed in more detail hereafter.

Table 1—Students’ perception of the most difficult topics in structural analysis

#	Topic	SLU			Rose-Hulman			Total		
		Mode	Avg.	SD	Mode	Avg.	SD	Mode	Avg.	SD
1	Types of loads (e.g. live, dead, rain, snow, wind, earthquake, etc.)	4.00	3.91	0.81	4.00	3.43	0.92	4.00	3.64	0.90
2	Load paths	4.00	3.52	0.98	3.00	3.21	0.69	3.00	3.35	0.83
3	Structural idealization	3.00	3.25	0.79	3.00	3.25	0.70	3.00	3.25	0.73
4	Predicting results	3.00	3.19	0.75	4.00	3.11	0.99	3.00	3.14	0.89
5	Statically determinate structures	4.00	3.77	1.07	3.00	3.70	0.78	4.00	3.73	0.91
6	Trusses (method of joints)	5.00	4.09	0.97	4.00	3.96	0.88	4.00	4.02	0.91
7	Trusses (method of sections)	4.00	3.86	0.94	4.00	3.82	1.02	4.00	3.84	0.98
8	Internal forces (calculating forces and moments at a section cut)	4.00	3.82	1.01	4.00	3.59	0.89	4.00	3.69	0.94
9	Internal forces (axial force equations/diagrams)	3.00 & 4.00	3.59	1.01	4.00	3.36	1.03	4.00	3.46	1.01
10	Internal forces (shear and moment equations)	4.00	3.41	1.05	4.00	3.57	1.00	4.00	3.50	1.02
11	Internal forces (shear and moment diagrams)	4.00	3.55	1.06	4.00	3.57	1.00	4.00	3.56	1.01
12	Deflections (virtual work for trusses)	3.00	3.32	0.99	3.00	2.79	0.92	3.00	3.02	0.98
13	Deflections (virtual work for beams)	3.00	3.43	0.98	3.00	2.79	0.92	3.00	3.06	0.99
14	Deflections (virtual work for frames)	2.00 & 3.00	3.05	1.09	3.00	2.63	0.84	3.00	2.82	0.97
15	Deflections (conjugate beam method)	3.00	2.91	0.97	-	-	-	-	-	-
16	Deflections (moment-area method)	2.00	2.80	0.77	-	-	-	-	-	-
17	Deflections (double integration method)	-	-	-	4.00	3.19	0.83	-	-	-
18	Indeterminate beams (force method)	3.00	2.68	0.84	-	-	-	-	-	-
19	Indeterminate frames (force method)	2.00	2.55	0.86	-	-	-	-	-	-
20	Indeterminate composite structures (method of compatibility)	4.00	2.50	0.86	-	-	-	-	-	-
21	Influence lines (determinate structures)	4.00	3.27	0.94	-	-	-	-	-	-
22	Influence lines (indeterminate structures)	4.00	3.18	1.14	-	-	-	-	-	-
23	Approximate analysis (indeterminate trusses)	3.00	2.91	1.02	3.00	2.79	0.69	3.00	2.84	0.84
24	Approximate analysis (indeterminate beams)	3.00	3.00	1.07	3.00	2.69	0.68	3.00	2.83	0.88
25	Approximate analysis (braced frames)	2.00	2.73	1.03	3.00	2.61	0.57	3.00	2.66	0.80
26	Approximate analysis (unbraced frames)	3.00	3.00	1.07	3.00	2.58	0.58	3.00	2.77	0.86
27	Matrix analysis (trusses)	3.00	3.41	1.05	-	-	-	-	-	-
28	Matrix analysis (beams)	3.00 & 4.00	3.41	1.05	-	-	-	-	-	-
29	Matrix analysis (frames)	3.00	3.27	1.08	-	-	-	-	-	-

Over the course of two years, 90 students at the two schools participated in the reinforced concrete course content survey, the results of which are shown in Table 2. Four topics had an average response less than or equal to 3.0. Only Topics 17 and 18 had modes of 2, indicating that a significant number of students selected "Difficult" on the survey. It is not surprising to see Topics 17 and 18 with the lowest values, which is consistent with faculty's observations. However, it is worth noting that Topic 3 and 4 had two of the lower averages among the remaining topics. Surprisingly, the students rated Topic 8 higher than expected; they tend to regularly struggle with this topic. Overall, the results were fairly consistent across universities.

Table 2—Students' perception of the most difficult topics in reinforced concrete

		SLU			Rose-Hulman			Total		
#	Topic	Mode	Avg.	SD	Mode	Avg.	SD	Mode	Avg.	SD
1	Concrete Material Properties	4.00	3.58	0.94	4.00	3.81	0.65	4.00	3.72	0.78
2	Uncracked Elastic Section (gross transformed section properties)	3.00	3.31	0.92	4.00	3.43	0.86	4.00	3.38	0.88
3	Cracked Elastic Section (cracked transformed section properties)	3.00	3.11	0.85	4.00	3.15	0.82	4.00	3.13	0.83
4	Deflections (effective moment of inertia)	3.00	3.19	0.89	3.00	3.35	0.72	3.00	3.28	0.80
5	Equivalent Rectangular Stress Block (a, β_1)	3.00	3.61	0.93	4.00	3.57	0.80	4.00	3.58	0.85
6	Tension controlled flexural failure	3.00 & 4.00	3.39	0.80	4.00	3.46	0.79	4.00	3.43	0.79
7	Transition flexural failure	3.00	3.31	0.80	4.00	3.23	0.81	3.00 & 4.00	3.27	0.80
8	Compression controlled flexural failure	3.00	3.28	0.78	4.00	3.40	0.82	3.00	3.35	0.80
9	Strength reduction factors for flexural failures	4.00	3.61	0.96	4.00	3.40	0.79	4.00	3.48	0.87
10	Beam design (b&h known)	4.00	3.25	0.97	4.00	3.69	0.95	4.00	3.51	0.97
11	Beam design (b&h unknown)	3.00	2.61	1.05	4.00	3.20	1.02	3.00 & 4.00	2.97	1.06
12	Flexural strength of beams with compression steel that yields	4.00	3.42	0.91	4.00	3.26	0.81	4.00	3.33	0.85
13	Flexural strength of beams with compression steel that **does not** yield	4.00	3.34	1.06	4.00	3.12	0.80	4.00	3.21	0.91
14	Flexural strength of "T-beams"	3.00	2.94	0.86	4.00	2.91	0.94	3.00 & 4.00	2.92	0.90
15	One-way slab design/continuous beams	3.00	3.06	1.00	3.00	3.36	0.81	3.00	3.29	0.86
16	Analysis of beams in shear	3.00 4.00	3.00	0.99	4.00	3.41	0.84	4.00	3.24	0.92
17	Shear design of beams (uniform stirrup spacing)	2.00 3.00	2.94	0.97	4.00	3.43	0.88	4.00	3.24	0.94
18	Shear design of beams (variable stirrup spacing)	2.00	2.64	1.05	4.00	3.33	0.87	2.00 & 3.00	3.06	1.00
19	Column interaction diagram	3.00	3.08	1.08	2.00 & 4.00	3.11	0.95	4.00	3.10	1.00
20	Column design	4.00	3.08	1.11	4.00	3.34	0.90	4.00	3.24	0.99

Over the course of two years, 90 students at the two schools participated in the steel design course content survey, the results of which are shown in Table 3. Twelve topics had an average response less than or equal to 3.0. Topics 12, 22, and 23 had modes of 2 indicating that a significant number of students selected "Difficult" on the survey. Topics 22 and 23 are two of the more difficult topics in the course, so that is not surprising. Flexural failure modes consistently had some of the lower averages among the other highlighted topics, which is also not surprising. In this particular course, the averages at Rose-Hulman were consistently higher than the averages at SLU. At this time, there is no definitive reason why that occurred.

Table 3—Students' perception of the most difficult topics in steel design

#	Topic	SLU			Rose-Hulman			Total		
		Mode	Avg.	SD	Mode	Avg.	SD	Mode	Avg.	SD
1	Steel material properties	4.00	3.64	0.83	4.00	4.00	0.64	4.00	3.86	0.74
2	Tension members (yielding of the gross section)	4.00	3.31	0.89	4.00	3.89	0.69	4.00	3.66	0.82
3	Tension members (rupture of the net section)	4.00	3.14	0.80	4.00	3.79	0.74	4.00	3.53	0.83
4	Connections (block shear)	3.00	3.06	0.73	3.00 & 4.00	3.33	0.87	3.00	3.22	0.82
5	Connections (bolt shear)	3.00	2.97	0.77	-	-	-	-	-	-
6	Connections (bolt bearing and tearout)	3.00	3.00	0.83	-	-	-	-	-	-
7	Welds	2.00	3.06	1.04	-	-	-	-	-	-
8	Compression members/columns	3.00	2.86	0.81	4.00	3.60	0.72	3.00	3.31	0.84
9	Effective length factors (K)	4.00	3.22	1.05	4.00	3.85	0.66	4.00	3.60	0.88
10	Flexural strength of compact beams (yielding)	3.00	3.00	0.93	4.00	3.67	0.75	3.00	3.40	0.88
11	Flexural strength of compact beams (lateral-torsional buckling)	3.00	2.86	0.93	3.00	3.39	0.86	3.00	3.18	0.92
12	Flexural strength of beams with compact webs (flange local buckling)	2.00	3.00	0.93	3.00	3.37	0.78	3.00	3.22	0.86
13	Moment gradient calculation (C_b)	3.00	3.31	0.89	4.00	3.56	0.80	4.00	3.45	0.84
14	Flexural strength of beams with non-compact webs (yielding)	3.00	2.94	0.87	3.00	3.27	0.78	3.00	3.14	0.83
15	Flexural strength of beams with non-compact webs (lateral-torsional buckling)	3.00	2.89	0.75	3.00	3.24	0.74	3.00	3.09	0.76
16	Flexural strength of beams with non-compact webs (flange local buckling)	3.00	2.89	0.78	3.00	3.31	0.76	3.00	3.14	0.79
17	Flexural strength of beams with slender webs (yielding)	3.00	2.89	0.78	3.00	3.30	0.78	3.00	3.12	0.80
18	Flexural strength of beams with slender webs (lateral-torsional buckling)	3.00	2.81	0.82	3.00	3.23	0.79	3.00	3.05	0.82
19	Flexural strength of beams with slender webs (flange local buckling)	3.00	2.78	0.76	3.00	3.29	0.80	3.00	3.07	0.82
20	Beam design (Z tables)	4.00	3.33	1.12	4.00	3.65	0.74	4.00	3.52	0.93
21	Beam design (moment vs. unbraced length charts)	4.00	3.31	1.09	4.00	3.56	0.79	4.00	3.46	0.93
22	Beam-columns	2.00	2.64	1.02	3.00	3.26	0.68	3.00	3.01	0.88
23	Second order effects (B_1, B_2)	2.00	2.40	0.91	3.00	3.20	0.75	3.00	2.85	0.91

Over the course of two years, 109 students at the two schools participated in the soil mechanics and foundation design course content survey, the results of which are shown in Table 4. Eleven topics had an average response less than or equal to 3.0. Topic 10 was the only topic with a mode of 2, indicating that a significant number of students selected "Difficult" on the survey. Topics 12, 13, 15, 24, and 25 had some of the lower averages, which was not surprising.

Overall, the results were fairly consistent across universities. Topics 17-25 are taught in a separate courses at Rose-Hulman that is not consistently taught at SLU, so those topics were not included at SLU.

Table 4—Students' perception of the most difficult topics in soil mechanics and foundation design.

#	Topic	SLU			Rose-Hulman			Total		
		Mode	Avg.	SD	Mode	Avg.	SD	Mode	Avg.	SD
1	Engineering geology	4.00	3.92	0.89	3.00	3.52	0.74	3.00	3.62	0.79
2	Subsurface sample and characterization methods	4.00	3.77	0.91	3.00	3.48	0.68	4.00	3.55	0.75
3	Soil phase relationships	4.00	3.89	0.80	3.00 & 4.00	3.47	0.77	4.00	3.58	0.79
4	Soil plasticity and clay mineralogy	4.00	3.58	0.95	3.00	3.32	0.69	3.00	3.38	0.76
5	1-D and 2-D groundwater flow	3.00	3.33	0.96	3.00	3.16	0.79	3.00	3.21	0.84
6	Earthwork engineering and compaction	4.00	3.48	0.94	3.00	3.41	0.75	3.00	3.43	0.79
7	Total and effective stresses	4.00	3.48	0.98	4.00	3.65	0.84	4.00	3.61	0.87
8	Mohr's circle and states of stress	3.00	3.30	1.17	3.00	2.89	1.04	3.00	3.00	1.08
9	Induced stresses and superposition	3.00	2.93	0.92	3.00	3.12	0.71	3.00	3.07	0.77
10	Consolidation settlement of shallow foundations	2.00	2.96	0.98	3.00	3.11	0.77	3.00	3.07	0.82
11	Consolidation time rate	3.00	2.96	0.90	3.00	3.26	0.76	3.00	3.19	0.80
12	Shear strength of soils	3.00	2.70	0.72	3.00	3.33	0.78	3.00	3.17	0.81
13	Bearing capacity analysis of shallow foundations	3.00	2.85	0.86	3.00	3.34	0.79	3.00	3.22	0.83
14	Elastic settlement of shallow foundations	-	-	-	3.00	3.13	0.74	-	-	-
15	Lateral earth pressures	3.00	2.89	0.88	3.00	3.26	0.74	3.00	3.18	0.78
16	Retaining wall types and uses	3.00	3.00	0.79	3.00	3.07	0.87	3.00	3.05	0.84
17	Shallow foundation design charts	-	-	-	3.00	3.15	0.81	-	-	-
18	Structural design of shallow foundations	-	-	-	3.00	3.25	0.77	-	-	-
19	Deep foundation load test interpretation and use	-	-	-	3.00	3.13	0.89	-	-	-
20	Deep foundation axial load transfer	-	-	-	3.00	3.09	0.82	-	-	-
21	Static analysis of deep foundations	-	-	-	3.00	3.14	0.89	-	-	-
22	Dynamic analysis of deep foundations	-	-	-	3.00	2.95	0.91	-	-	-
23	Lateral capacity of deep foundations	-	-	-	3.00	2.98	0.86	-	-	-
24	Structural design of deep foundations	-	-	-	3.00	2.89	0.84	-	-	-
25	Downdrag of deep foundations	-	-	-	3.00	2.76	0.89	-	-	-

Benefit of Full-scale Tests

Pictures, videos, simulations and small-scale projects are valuable to student learning, because the qualitative observations provide a portrait of the overall construction process and behavior. However, like research, there is added value to constructing and testing a full-scale specimen for better understanding. First, pictures and videos of the construction process show students how things are constructed and videos and simulations show their behavior, but first-hand experience invaluably reinforces what is taught and even what is not taught in class. For example, 94% of the programs that responded to the aforementioned survey include either a traditional or project-based lab for the Civil Engineering Materials course. Mixing and testing concrete in a lab setting is invaluable for student understanding. Unfortunately, only 30%, 45%, 41%, and 25% of programs include lab sections with Structural Analysis, Reinforced Concrete Design, Steel Design, and Foundation Design, respectively. Incorporating large to full-scale tests in these classes provides the opportunity to reinforce what students learn and illustrate details of analysis and design that may often be lost in a traditional lecture-based course.

Second, dimensional differences in larger specimens have minimal effects on their overall behavior, but the same differences can have a major effect on the behavior of very small-scale specimens. For example, a reinforced concrete beam design calls for a 20 ft long, 12 in. wide by 24 in. deep beam with four No. 9 rebar and 4,000 psi concrete. If the rebar are placed 3 in. from the bottom of the beam, the maximum load the beam can support at mid-span is 72,200 lbs, but if the rebar is accidentally placed 3.125 in. from the bottom of the beam during construction that load reduces to 71,700 lbs, a 0.7% decrease. On the contrary, a student's project design calls for a 40 in. long, 2 in. wide by 4 in. deep small-scale beam with one ¼ in. diameter piece of deformed wire (used to represent rebar) and 4,000 psi concrete. If the wire is placed 0.5 in. from the bottom of the beam, the maximum load the beam can support is 965 lbs, but if the wire is accidentally placed 0.625 in. from the bottom during construction, that load reduces to 929 lbs, a 3.7% decrease. This effect is further magnified by other fabrication issues associated with very small-scale specimens. Furthermore, the size of the coarse aggregate in a regular concrete mix is roughly 0.5-0.75 in., which poses a problem when making very small-scale specimens. When smaller size rocks are used in the mixes, the concrete behaves more like a grout or mortar. Very small-scale projects have their merit, but students sometimes find their fabrication tedious and difficult to construct.

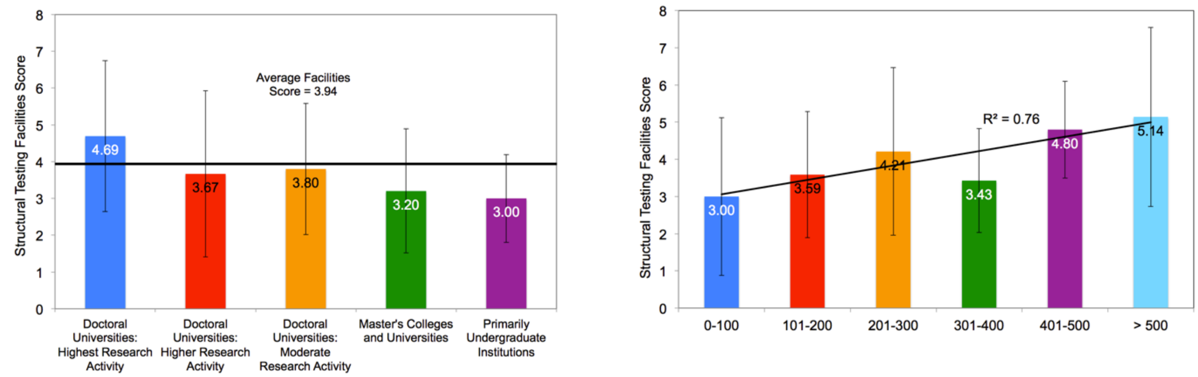
Overview of Structural Engineering Laboratories

The aforementioned survey [6] results showed that a number of programs include active learning techniques to some extent in their courses, more often in smaller classes. Additionally, the course content survey identified several topics that students at SLU and Rose-Hulman self-reportedly find more difficult. Furthermore, there is justification for the benefits of conducting full-scale tests. The unfortunate circumstance that prohibits smaller programs who often have smaller class sizes from conducting such tests is many times a lack of testing facilities, but various solutions exist to overcome that barrier. There are roughly 240 ABET accredited civil engineering programs listed in the Carnegie Classification of Institutions of Higher Education [9] and about half of those programs are estimated to have fully equipped structural engineering laboratories, which are needed to conduct full-scale experimental tests. A fully equipped structural engineering laboratory includes a "reaction floor" and overhead bridge crane, and in some cases a "reaction wall." Reaction floors provide an extremely rigid floor to which various test frames can be anchored allowing tests of full-scale beams (up to 100 ft long) and even small full-scale bridges. Some labs use various frame configurations anchored to the reaction floor to provide lateral load testing capabilities, but the more complete laboratories use a reaction wall. Reaction walls allow tests of full-scale structures and/or components subjected to lateral loads. While the combination of the reaction floor and reaction wall allow for these specific tests, the whole system allows for almost unlimited testing configurations. Fig. 2 (a) shows an example of a structural engineering laboratory. Unfortunately, labs like this require high levels of research activity to justify their expense and are rarely used for undergraduate education. An alternative to the larger structural engineering laboratories is the use of self-contained frames similar to the one shown in Fig. 2 (b). These steel frames vary in size and shape and allow researchers to conduct smaller experiments. Although the self-contained frames are an economical solution for smaller programs, they are limited in size and usually limited to specific configurations. Such self-contained frames are more often used for undergraduate education.

(a) (b)

Fig. 2—(a) Structural engineering laboratory (Georgia Tech) and (b) a self-contained frame at Rose-Hulman.

The survey [6] mentioned earlier was used to determine the extent of active learning implementation in upper-level courses and to assess the structural engineering testing facilities across the country. The results included responses from 64 diverse programs. One part of the survey included three questions regarding the structural engineering testing facilities at each institution and a score was assigned to the response of each respective question to determine a "Structural Engineering Testing Facilities Score." The purpose of the score is to compare the testing capabilities of each program. The first question asked, "Which of the following best describes your structural engineering testing facilities?" Potential responses included High bay (2 points), traditional laboratory (low ceiling) (1 point), or none (0 points). The second question asked, "Which of the following best describes your vertical load testing capabilities?" Potential responses included large reaction floor (3 points), medium reaction floor (2 points), small reaction floor (1 point), self-contained steel load frame (1 point), other self-contained system (1 point), or no vertical load testing capabilities (0 points). The third question asked, "Which of the following best describes your lateral load testing capabilities?" Potential responses included double reaction wall (3 points), single reaction wall (2 points), steel frame attached to a reaction floor (1 point), concrete blocks attached to a reaction floor (1 point), or no lateral load testing capabilities (0 points). Fig. 3 (a) shows the average facilities scores broken down by Basic Carnegie Classification and Fig. 3 (b) shows the average facilities scores with respect to program size (number of undergraduate students). On average, the programs at doctoral universities have better testing capabilities and further comparisons revealed a general trend with respect to overall program size. It appears that average facilities scores increase with increases in program size. In most cases, program size also relates to class size with the exception of programs offering multiple sections of the same course. This poses a significant problem for smaller programs such as SLU and Rose-Hulman. The desire to implement experiential learning strategies exists, but such programs may be limited because of the testing infrastructure.



(a) (b)

Fig. 3—(a) Structural testing facilities score versus Carnegie Classification and (b) structural testing facilities score versus program size.

Modular Strong-block Testing System

Fully equipped structural engineering laboratories can be very expensive to construct. Such a cost is almost insurmountable for smaller programs and it is difficult to complete projects related to structural engineering without adequate testing capabilities. The Modular Strong-block Testing System [10] is one potential economical solution for full-scale testing capabilities at smaller programs. It is a modular system, comprised of 12 individual, 1 yd^3 reinforced concrete "strong blocks," each of which weighs approximately 4,500 lbs. Each block is an identical 36 in. cube, with interlocking shear keys along with eight internal anchorage points coupled with six longitudinal and four lateral steel post-tensioning ducts. Six post-tensioning ducts run in the direction of the long dimension of the test setup, while four additional post-tensioning ducts run in the direction of the short dimension of the test setup. One-inch diameter steel DYWIDAG bars run throughout the system within each post-tensioning duct, each of which can be stressed up to 90,000 lbs, generating up to 540,000 lbs of compression on the system. When the system is assembled, it acts like a "slice" of a reaction floor and provides full-scale testing capabilities. Fig. 4 shows a vertical load test on a beam and a lateral load test on a frame conducted using the Modular Strong-block Testing System.

(a) (b)

Fig. 4—The Modular Strong-block Testing System setup for (a) a beam test and (b) a frame test.

Project Justification

There is a need for better learning experiences in structural engineering related courses for civil engineering students and smaller programs have a strong desire to implement such experiences. Unfortunately, smaller programs lack the facilities to implement those experiences. This project includes two such programs that are implementing several experiential learning modules in their structural engineering related courses by using the Modular Strong-block Testing System. Nearly all of the students in both programs that have the opportunity to experience these activities are junior level students required to take each course. The following sections highlight additional rationale for experiential learning modules in each course based on faculty observations followed by brief overviews of those modules.

Structural Analysis

The content of structural analysis courses varies widely among universities and may include topics ranging from load paths all the way to matrix analysis. However, most courses include a core list of topics such as loads and load paths, determinate structures, truss analysis, shear and moment diagrams, deflections, indeterminate structures, and approximate methods of analysis. The prerequisite material for structural analysis courses mainly includes statics and mechanics of solids. Among the topics that students learn and those that students self-reported to be more difficult, the authors have noted particular student struggles with analysis skills that require deeper understanding and judgement. Some of the particular topics are: 1) the difference between theoretical assumptions and actual connection behavior, 2) load paths and load combinations, 3) visualizing the deflected shapes of beams and calculating non-standard deflections, and 4) approximate analysis of braced and unbraced rigid frames and visualizing their behavior.

First, the difference between theoretical assumptions and actual connection behavior is difficult to grasp mainly because students have essentially seen three connection types up to this point: a pin, a roller, and a rigid connection. Students learn that a pin transfers forces in the X and Y directions and is free to rotate, a roller only transfers forces in a single direction depending on its orientation and is free to rotate, and a rigid support transfers forces in the X and Y directions along with moment about the Z-axis. The structural analysis course introduces students to the fact that while calculations have exact mathematical answers the analysis methods are based on assumptions and are only approximations; structures rarely have pin or roller connections that are frictionless or rigid connections that are completely rigid. Those differences can be difficult for students to grasp.

Second, load paths and load combinations are relatively new topics for students in a structural analysis course. The problems in statics and mechanics of solids are relatively simple structures with given loads. Students may have to determine the resultant force generated by a distributed load or solve a structure with multiple parts and transfer loads across internal pins, but there is little if any discussion of load paths and no discussion of different load types and combinations. Most structural analysis courses cover how load pressure applied to a floor or roof diaphragm distributes to the supporting members and how the load in the supporting members transfers through beams and girders to the supporting columns. The students learn to identify if the floor has one-way or two-way slab behavior based on the aspect ratios to idealize the distributed load on the supporting members, and to calculate the force being transferred from one beam to another. Identifying the sequence of load path through a system of beams and girders cannot be expressed with rules or formulas, so students struggle more with this part. Furthermore, the different load types (e.g. live, dead, snow, rain, wind, earthquake, etc.) and corresponding load combinations most always confuse students, especially when the types of loadings take various forms (e.g. concentrated, distributed, pressure, and moment) and especially when those loadings have different signs.

Third, visualizing the deflected shapes of beams and calculating non-standard deflections seems to plague students in structural analysis. Students want an equation they can plug values into and get an answer. While such equations do exist for simply supported beams, cantilever beams, and other basic configurations, students should still understand the methods used to determine those equations and be able to sketch the deflected shape of a beam without making detailed calculations. While much attention is given to the reasonability of answers, students sometimes lose sight of how reasonable those answers may be. Students will sometimes get an answer that is off by magnitudes or specify a direction that contradicts the applied loading and not notice that something is wrong.

Fourth, conducting an approximate analysis of braced and rigid frames and visualizing their behavior is particularly difficult for students. Each type of frame requires different assumptions, and the assumptions even change depending on the type of loading. If the students are told to use a particular analysis method, they tend to do well. The struggle comes when they are given a problem and just told to analyze it; they must select the best set of assumptions to perform the approximate analysis. Additionally, students also have difficulty drawing the deflected shapes and determining the reactions of both determinate and indeterminate frames. Such tasks generally require students to use virtual work and the force method and some of their mistakes are similar to the mistakes made with beams: answers that are off by magnitudes or the calculated directions contradict the applied loadings.

The structural analysis courses includes four experiential learning modules based on the instructors' observations and supported by self-reported student survey data. Those four modules focus on connections, load paths, deflections of beams, and deflections of frames. Listed below are brief descriptions of each module and Fig. 5 shows representative samples of the recent implementation of the modules. Table 5 shows how each module maps to the course content topics initially displayed in Table 1. A full description of the design, fabrication, and implementation of the modules is presented by Derks et al. [11].

<u>Module 1—Connections</u>: Module 1 focuses on connections and features a "science center style exhibit" structure made from EXTREN® structural members including an 8 in. wide channel for the base, an 8 in. wide flange beam for the column, and a 6 in. wide flange beam for the cantilever beam. The structure is bolted together using EXTREN® angles. The purpose of the module is for students to physically feel and see the differences in connection behaviors.

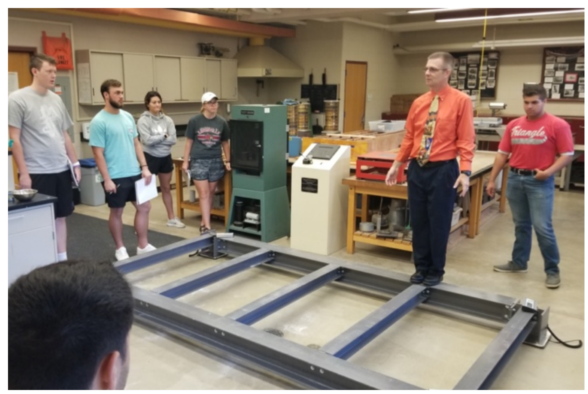
<u>Module 2—Load Paths</u>: Module 2 focuses on load paths and includes an interactive floor system constructed from 10 ft long girders attached to very short columns with 5 ft long beams spanning

between the two girders every 2.5 ft. The four columns sit atop postage scales to show the forces in each column depending on where and what type of loading is applied. The purpose of the module is for students to observe load paths and the application of different types of loads.

<u>Module 3—Deflections of Beams</u>: Module 3 simply features 8 in. wide EXTREN® channels cut to length. The long beam is 12 ft 4 in. long to create a 12 ft center-to-center span and the short beams are 6 ft 4 in. long to create a 6 ft center-to-center span. Additionally, the long beams can be supported at mid-span to create a continuous beam with two 6 ft center-to-center spans. Postage scales are placed at each support to show the reaction forces. The purpose of the module is for students to observe the behavior of beams and compare the effects of different support configurations.

<u>Module 4—Deflections of Frames</u>: Module 4 focuses on the behavior of rigid frames. The frame is made from three 4 in. wide flange EXTREN® structural members. The frame is 6 ft tall and 6 ft wide consisting of two columns and a single beam. The connections between the beam and columns are made from steel plate to create a rigid connection and the columns have pin and roller supports at the bases. The frame can be loaded both vertically and horizontally using the Modular Strong-block Testing System. The purpose of the module is to help students understand frame behavior and the effect different supports have on that behavior.


(a)


(b)


(c)


(d)

Fig. 5—(a) Connections module; (b) load paths module; (c) deflections of beams module; and (d) deflections of frames module.

Table 5— Alignment of Structural Analysis modules with topics.

	Topic	Module 1	Module 2	Module 3	Module 4
1	Types of loads (e.g. live, dead, rain, snow, wind, earthquake, etc.)				
2	Load paths		X		
3	Structural idealization	X			
4	Predicting results	X	X	X	X
5	Statically determinate structures		X		
6	Trusses (method of joints)				
7	Trusses (method of sections)				
8	Internal forces (calculating forces and moments at a section cut)				
9	Internal forces (axial force equations/diagrams)				
10	Internal forces (shear and moment equations)			X	X
11	Internal forces (shear and moment diagrams)			X	X
12	Deflections (virtual work for trusses)				
13	Deflections (virtual work for beams)			X	
14	Deflections (virtual work for frames)				X
15	Deflections (conjugate beam method)				
16	Deflections (moment-area method)				
17	Deflections (double integration method)				
18	Indeterminate beams (force method)			X	
19	Indeterminate frames (force method)				X
20	Indeterminate composite structures (method of compatibility)				
21	Influence lines (determinate structures)				
22	Influence lines (indeterminate structures)				
23	Approximate analysis (indeterminate trusses)				
24	Approximate analysis (indeterminate beams)				
25	Approximate analysis (braced frames)				
26	Approximate analysis (unbraced frames)				X
27	Matrix analysis (trusses)				
28	Matrix analysis (beams)				
29	Matrix analysis (frames)				

Reinforced Concrete

Reinforced concrete includes a core set of topics taught among most universities typically including serviceability, analysis of rectangular and non-rectangular beams, design of rectangular beams, analysis and design for shear, and analysis and design of columns. The prerequisite material for reinforced concrete courses mainly includes statics, mechanics of solids, civil engineering materials, and structural analysis. Students who struggle with fundamental concepts in any of these prerequisite areas tend to struggle with many, if not all, course topics typically associated with reinforced concrete design. These struggles can be lumped into three main categories: insufficient prerequisite knowledge, misunderstanding of a specific course concept or topic, and difficulty aggregating and synthesizing multiple course concepts or topics.

Among the topics that students learn and those that students self-reported to be more difficult, the authors have noted particular student struggles with topics related to behavior. Some of the particular topics are: 1) service loads and deflections, 2) flexural failure modes and ductility, 3) differences in moment curvature and load-deflection relationships, and 4) shear design.

First, students have a difficult time understanding when to use unfactored service loads versus factored loads and how to estimate deflections. Deflections are a serviceability limit state and are dependent on several factors including uncracked section properties, cracked section properties, crack distributions, and load duration. Therefore, students must understand how to calculate transformed section properties, how to calculate an effective moment of inertia to account for crack distributions, and how load duration effects the long-term deflections. In many cases, students will incorrectly calculate transformed section properties or incorrectly use the effective moment of inertia.

Second, the type of failure mode and ductility are difficult for students to understand mainly because this is the first time they have seen inelastic behavior. Students are able to correctly analyze a singly reinforced rectangular beam by following a well-defined process using the equivalent rectangular stress block, but they struggle with in-depth questions related to the physical behavior of a beam. For example: What effect does concrete strength have on the strength and ductility of a beam? What effect does adding more tensile reinforcement have on the strength and ductility of a beam? What are the physical differences in behavior of a tension-controlled beam and compression-controlled beam?

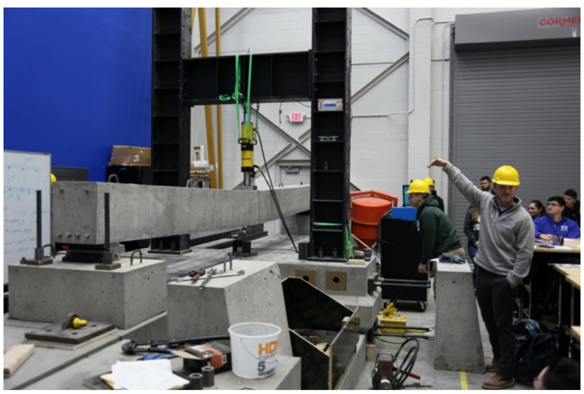
Third, differences in moment-curvature and load-deflection relationships between beams are also difficult for students to understand. The concept of moment-curvature is difficult to explain as it is, which makes it that much more difficult for students to understand. The instructor can show students how to calculate curvature and sketch deflected shapes of beams, but similar to failure modes and ductility, students are able to make the calculations, but they struggle with in-depth questions related to the physical behavior of a beam.

Fourth, many instructors would agree that analysis and design for shear is one of the most difficult topics in reinforced concrete to teach. Specifically, determining an appropriate spacing of stirrups when designing a beam for shear is arguably the most difficult topic for students to understand in a reinforced concrete course. Students consistently struggle to understand the failure mechanisms associated with shear and how to appropriately space stirrups.

The reinforced concrete course includes four experiential learning modules based on the instructors' observations and supported by self-reported student survey data. Those four modules focus on service loads and deflections, flexural failure modes and ductility, moment-curvature and load-deflection relationships, and shear design and failure. Listed below are brief descriptions of each module and Fig. 6 shows the recent implementation of modules 1-3, which use the same test specimens. Table 6 shows how each module maps to the course content topics initially displayed in Table 2. Although Modules 1, 2, and 3 align with topics not listed as difficult by students, the authors feel these topics are of the most important within the course for students to fully understand and that a better understanding of these topics may indirectly improve student understanding of other topics like beam design and "T-beams." A full description of the design, fabrication, and implementation is planned for a future publication.

Module 1 - Service Loads and Deflections; Module 2 - Flexural Failure Modes and Ductility; and Module 3 – Moment-curvature and Load-deflection Relationships: Modules 1, 2, and 3 are all related and use the same two test specimens. The two reinforced concrete beams are 12 in. wide, 14 in. deep, and 19 ft long with a target concrete compressive strength of 4,000 to 5,000 psi. Each beam has a center-to-center span of 18 ft. One beam contains four No. 7 bars and is designed to have a very ductile failure. The beam will hold approximately 35,000 lbs applied at mid-span and will visibly deflect before complete failure. The other beam contains eight No. 8 bars and is designed to have a very brittle failure. The beam will hold approximately 60,000 lbs applied at mid-span and will deflect very little before complete failure. The purpose of the three modules is to show the complete behavior of reinforced concrete beams and allow students to compare and contrast two different designs.

Module 4 - Shear Design and Failure: Module 4 includes two reinforced concrete beams for shear that are also 12 in. wide and 14 in. deep, but have a length of 10 ft with a target concrete compressive strength of 4,000 to 5,000 psi. Each beam has a center-to-center span of 9 ft. One beam contains No. 3 stirrups at the correct spacing, while the other beam has intentional design errors. The purpose of this module is to show the difference in failures and allow students to compare the results and discuss the failure mechanisms.



(a)

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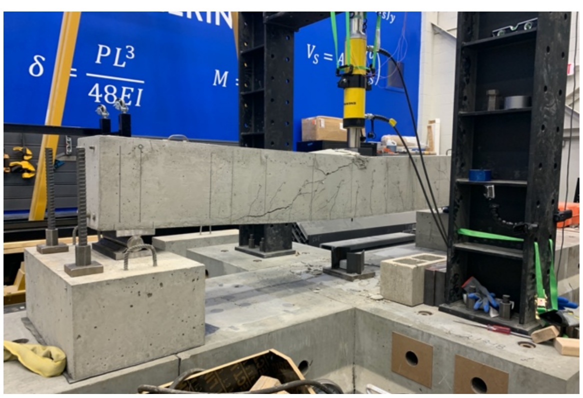

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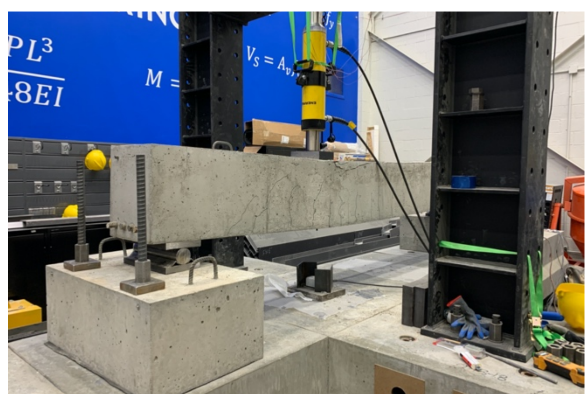


(d)

Fig. 6—(a) Tension-controlled reinforced concrete beam test; (b) compression-controlled reinforced concrete test; (c) reinforced concrete beam with stirrups spaced incorrectly; and (d) reinforced concrete beam with stirrups spaced correctly.

Table 6—Alignment of Reinforced Concrete modules with topics.

	Topic	Module 1	Module 2	Module 3	Module 4
1	Concrete Material Properties				
2	Uncracked Elastic Section (gross transformed section properties)	X			
3	Cracked Elastic Section (cracked transformed section properties)	X			
4	Deflections (effective moment of inertia)	X			
5	Equivalent Rectangular Stress Block (a, β_1)		X		
6	Tension controlled flexural failure		X	X	
7	Transition flexural failure				
8	Compression controlled flexural failure		X	X	
9	Strength reduction factors for flexural failures				
10	Beam design (b&h known)				
11	Beam design (b&h unknown)				
12	Flexural strength of beams with compression steel that yields				
13	Flexural strength of beams with compression steel that **does not** yield				
14	Flexural strength of "T-beams"				
15	One-way slab design/continuous beams				
16	Analysis of beams in shear				X
17	Shear design of beams (uniform stirrup spacing)				X
18	Shear design of beams (variable stirrup spacing)				
19	Column interaction diagram				
20	Column design				

Steel Design

Like reinforced concrete, steel design consists of a core set of topics taught among most universities typically including tension members and connections, compression members, flexural members, and beam-columns. Introducing structural steel design concepts to students presents its fair share of challenges. The proper analysis and design of structural steel elements requires a sound understanding of their failure modes and structural behavior when subjected to loads. That sound understanding builds upon prerequisite material from statics, mechanics of solids, civil engineering materials, and structural analysis. Among the topics that students learn and those that students self-reported to be more difficult, the topics noted by instructors that students tend to struggle with the most are 1) failure modes of tension members, 2) buckling modes of columns, and 3) flexural failure modes.

First, students consistently have difficulty visualizing and accurately predicting the potential failure modes of a tension member: yielding of the gross section, rupture of the net section, and block shear. Rupture of the net section and block shear are particularly difficult to visualize along with the effects of shear lag and member shape. Also difficult for students to understand is the effect of bolted connection lengths and bolt patterns on failure mode.

Second, the buckling modes of steel columns vary with shape and type of bracing. It is quite difficult for students to visualize the buckling mechanisms about the strong and weak axis and even more difficult for students to determine about which axis a column will buckle first based on effective lengths. Equally challenging is explaining the effect of the support conditions on the extent of column buckling.

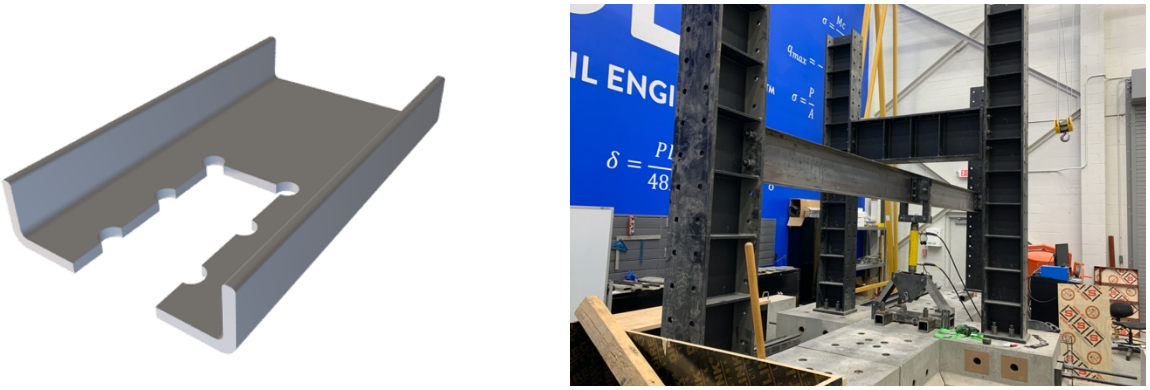
Third, flexural failure modes of steel beams are complex and fall into three categories for compact shapes: yielding of the cross section, inelastic lateral torsional buckling, and elastic lateral torsional buckling, which is dependent on the unbraced length of the compression flange. Other forms of failure for non-compact sections include local buckling of the flange or web. Lateral torsional buckling is by far the failure mode that most students struggle to explain. Why and how does it occur? Identifying the relationship between the unbraced length and beam span and how the unbraced length affects the flexural capacity are particularly difficult for students to understand.

The steel design course includes three experiential learning modules based on the instructors' observations and supported by self-reported student survey data. Those three modules focus on tension connection failures, column buckling, and flexural failure modes. Listed below are brief descriptions of each module and Fig. 7 shows a schematic of a tension connection failure model and a lateral torsional buckling beam test setup. Table 7 shows how each module maps to the course content topics initially displayed in Table 3. A full description of the design, fabrication, and implementation is planned for a future publication.

<u>Module 1 - Tension Connection Failure</u>: Module 1 includes a set of tension connections cut from fiberglass structural shapes to more easily use in class. The tension connections consist of a plate, angle, channel, and W-shape including rupture of the net section, effects of shear lag, and block shear. The purpose is for students to better visualize the types of failure mechanisms associated with various connection configurations.

<u>Module 2 - Column Buckling</u>: Module 2 consists of W3x2.9 "junior beam" used for the columns. The columns are designed to buckle about their weak axis and depending on bracing mechanism, their strong axes. The purpose of the module is for students to predict and see the differences in column buckling modes and the effect of lateral bracing.

<u>Module 3 - Flexural Failure Modes</u>: Module 3 includes two wide-flange beams. The first is approximately 18 ft long and has no lateral bracing resulting in an elastic lateral torsional buckling failure. The second beam is approximately 12 ft long and is braced at mid-span resulting in an inelastic lateral torsional buckling failure. The purpose of the module is for students to compare the different failure types based on unbrace length and understand the difference between elastic lateral torsional buckling and inelastic lateral torsional buckling.



(a) (b)

Fig. 7—(a) Block shear connection failure and (b) lateral torsional buckling test setup.

Table 7—Alignment of Steel Design modules with topics.

	Topic	Module 1	Module 2	Module 3
1	Steel material properties			
2	Tension members (yielding of the gross section)			
3	Tension members (rupture of the net section)	X		
4	Connections (block shear)	X		
5	Connections (bolt shear)			
6	Connections (bolt bearing and tearout)			
7	Welds			
8	Compression members/columns		X	
9	Effective length factors (K)		X	
10	Flexural strength of compact beams (yielding)			
11	Flexural strength of compact beams (lateral-torsional buckling)			X
12	Flexural strength of beams with compact webs (flange local buckling)			
13	Moment gradient calculation (C_b)			
14	Flexural strength of beams with non-compact webs (yielding)			
15	Flexural strength of beams with non-compact webs (lateral-torsional buckling)			
16	Flexural strength of beams with non-compact webs (flange local buckling)			
17	Flexural strength of beams with slender webs (yielding)			
18	Flexural strength of beams with slender webs (lateral-torsional buckling)			
19	Flexural strength of beams with slender webs (flange local buckling)			
20	Beam design (Z tables)			
21	Beam design (moment vs. unbraced length charts)			
22	Beam-columns			
23	Second order effects (B_1, B_2)			

Geotechnical Engineering: Soil Mechanics and Foundations

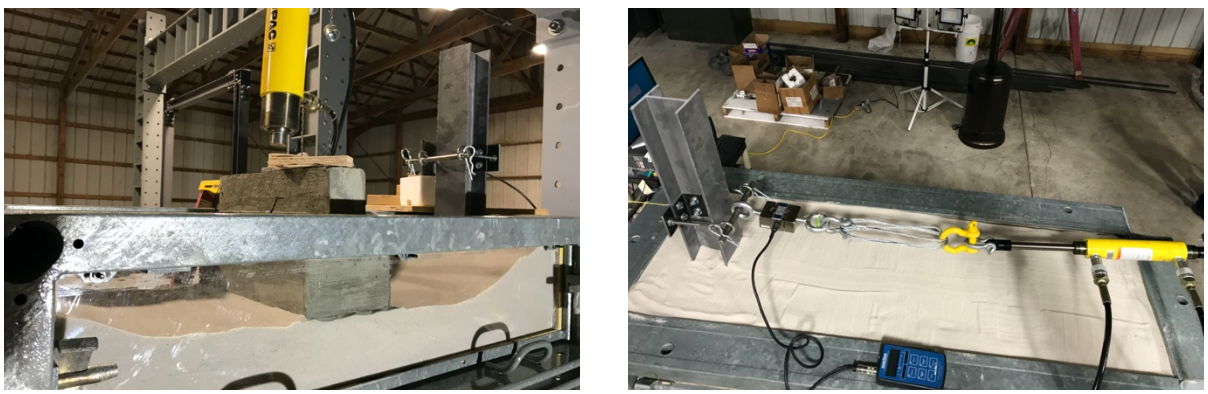
The geotechnical engineering discipline incorporates fundamental concepts in soil mechanics and foundations, which include a variety of topics that are particularly difficult for students to understand and master. What happens below ground is difficult to visualize and the mechanisms are typically sketched in two dimensions. Soil mechanics is a core course within most civil engineering programs and typically includes topics such as soil composition, compaction, groundwater, consolidation, and shear strength. Some applications to slope stability and foundations are also included towards the end of the course. Foundation design is generally an upper-level elective and varies widely among programs including topics ranging from bearing capacity and settlement of shallow foundations, axial and lateral capacity of deep foundations (driven, drilled), retaining walls, structural design of foundations and walls, and sometimes ground modification. Students taking the first geotechnical course generally arrive with no knowledge of soil mechanics. The pre-requisite courses typically include mechanics of solids and civil engineering materials; in some cases, fluid mechanics. Pre-requisites for the foundation design course typically include soil mechanics and reinforced concrete design. Among the topics that students learn and those that students self-reported to be more difficult, the topics authors noted that students tend to struggle with the most are 1) the difference in strength and service limit states in shallow foundation design, 2) soil-structure interaction associated with lateral behavior of deep foundations, and 3) the influence of near-surface soil on lateral behavior of deep foundations.

First, students struggle understanding deformation and stability conditions when soils are loaded. That is why a significant portion of the soil mechanics course is dedicated to consolidation and strength, respectively. These struggles lead to a misunderstanding of the relationship between the geotechnical strength limit state (bearing capacity) and the service limit state (settlement) in shallow foundation design. The topics are typically taught separately and involve two distinct theories from mechanics, including shear strength and stress-strain relationships. Many students fail to understand that a shallow foundation must be sized appropriately to meet both limit states. This is particularly evident when the service limit state controls and the students calculate a relatively high factor of safety for bearing capacity and then think that they have an inefficient design.

Second, students have difficulty understanding soil-structure interaction associated with lateral behavior of deep foundations. Because the stress-strain response of the foundation is linear within the typical loading range and the soil stress-strain response is non-linear, it is difficult for students to assess the influence of each component (soil and structure) on the lateral behavior.

Third, many students fail to realize the large influence that the near-surface soil has on lateral behavior of deep foundations. Axial design of deep foundations must account for soil strength along the length of the foundation, and students assume that the same must be true for lateral analysis. However, the near-surface soils have much more influence on lateral behavior because of the low confining stress, a concept covered in soil mechanics.

Module 1 - Shallow Foundation Failure Modes and Module 2 - Lateral Capacity: Both Foundation Design modules use the same testing system. The project team has designed a 6 ft by 4 ft by 1.5 ft box using prefabricated concrete forms that is filled with a fine sand and used for both modules. The plywood on one side of the box was replaced with plexiglass so students can see the shear failure within the soil. Module 1 uses a small 4 in. by 18 in. concrete footing (i.e. foundation), placed on top of the sand. The footing is loaded vertically until a definitive soil failure occurs. Module 2 uses an EXTREN® wide flange beam as a vertical pile. The pile is fixed to the bottom of the test box and loaded from the side until a lateral failure of the soil occurs. Load and deformation are monitored for both modules to make a comparison to theoretical predictions made by the students. Fig. 8 shows the shallow foundation test and lateral load test on an FRP pile. Table 8 shows how each module maps to the course content topics initially displayed in Table 4. A full description of the design, fabrication, and implementation is planned for a future publication.



(a) (b)

Fig. 8—(a) Shallow foundation test and (b) a lateral load test on an FRP pile.

Table 8—Alignment of Soil Mechanics and Foundations modules with topics.

#	Topic	Module 1	Module 2
1	Engineering geology		
2	Subsurface sample and characterization methods		
3	Soil phase relationships		
4	Soil plasticity and clay mineralogy		
5	1-D and 2-D groundwater flow		
6	Earthwork engineering and compaction		
7	Total and effective stresses		
8	Mohr's circle and states of stress		
9	Induced stresses and superposition		
10	Consolidation settlement of shallow foundations		
11	Consolidation time rate		
12	Shear strength of soils	X	
13	Bearing capacity analysis of shallow foundations	X	
14	Elastic settlement of shallow foundations		
15	Lateral earth pressures		
16	Retaining wall types and uses		
17	Shallow foundation design charts		
18	Structural design of shallow foundations		
19	Deep foundation load test interpretation and use		
20	Deep foundation axial load transfer		
21	Static analysis of deep foundations		
22	Dynamic analysis of deep foundations		
23	Lateral capacity of deep foundations		X
24	Structural design of deep foundations		X
25	Downdrag of deep foundations		

Project Assessment

The project features both qualitative and quantitative forms of assessment during each year of the project. Years 1 and 2 were used to collect control data and the subsequent years of the project will be used to collect data on the students who experience the interventions. First, during years 1 and 2, students from both universities were asked to take the Student Response to Instructional Practices (StRIP) survey [12]. The StRIP survey includes several questions related to instructional practices. Additionally, a section was added devoted to the most difficult topic for students to understand for each respective course. The control group data related to student perceptions of the most difficult topics in each course were shown in Tables 1 through 4. Open-ended questions related to the experiential learning modules were added for the intervention groups' surveys. Second, exam questions were written for each respective course for use throughout the project. Like the StRIP survey, students from both universities during years 1 and 2 served as the control groups for the study by taking exams with specific exam questions included. The exams are graded at both universities using the same grading rubrics.

Moving Forward

The project is currently in its third year and interventions are in progress. The project team is planning eight additional publications. Four of those publications will feature the design and implementation of the experiential learning modules in each of the aforementioned courses, while the other four publications will feature the effects of implementation on student learning based on the assessment data.

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