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Board 40: Using "Anchored Instruction" to Teach Fundamental Bridge Engineering Principles: A Case Study.

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Ben Dymond obtained his B.S. and M.S. degrees in Civil Engineering at Virginia Tech before obtaining his Ph.D. in Civil Engineering at the University of Minnesota Twin Cities. Ben is currently an associate professor of structural engineering at Northern Arizona University.

Davis Ray

My name is Davis Ray. I am 21 years old, and a life-long resident of Arizona. I am a first year Mechanical Engineering graduate student at Northern Arizona University. My primary research project is sponsored by the Federal Highway Administration, and focuses on improving engineering education methods. I am also contributing to a research project sponsored by the US Department of Energy, in which I am assisting with the solid mechanics modeling of moisture swing polymers for use in low-energy carbon capture. For my senior capstone, I led the development of a theoretical offshore wind farm for the 2022 Collegiate Wind Competition, and helped our team earn second place at the competition. This experience led me to become the current president of NAU's Energy Club, where I now manage two interdisciplinary engineering teams who are working to complete the Collegiate Wind Competition and Hydropower Collegiate Competition. I am also the president of NAU Skate Club, which I founded this semester in order to provide enriching opportunities for community members, and share the benefits of skateboarding with others. I enjoy holding leadership roles, and apply myself entirely to the projects I am involved in.

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John Tingerthal joined the Construction Management faculty at Northern Arizona University in 2007 and was appointed as a Distinguished Teaching Fellow in 2015. His engineering career spans a variety of design and forensic engineering experiences. He spent eight years practicing structural engineering in Chicago. This work culminated with design work on the Minneapolis Public Library and the Overture Center for the Arts in Madison, Wisconsin. He was also involved with forensic investigations in Iowa and Wisconsin and participated in structural coordination efforts at Ground Zero in September of 2001. He is currently the Associate Chair of Civil Engineering, Construction Management and Environmental Engineering at NAU and holds professional engineering licenses in the states of Arizona and Illinois.

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Using “anchored instruction” to teach fundamental bridge engineering principles, a case study.

Abstract

The objective of this paper is to present a case study on developing and implementing evidence-based interventions into a traditional civil engineering course of study to better teach fundamental engineering principles in the context of engineering practice. Entry-level engineers often struggle applying fundamental engineering principles acquired in their formal education to the engineering applications encountered when entering the workforce. The purpose of the interventions presented in this paper is to improve students’ ability to transfer this fundamental knowledge. These interventions are based on “anchoring” the content; that is, deeply contextualizing fundamental engineering principles to one or two case studies (related to bridge engineering) throughout students’ four-year course of study. Anchored learning is based on the construct of situated cognition that also forms the basis for what is widely called experiential learning. Anchored learning is founded on the notion that knowledge can be recalled when people are explicitly asked to use it as a “tool” for solving a problem.

To illustrate the methodology, a local truss bridge is described in detail and then used to teach several key topics in structural engineering, including determinacy in students’ statics class, normal stress in their subsequent mechanics of materials class, and the method of virtual work in their structural analysis class. Repeatedly investigating the same structure, in varying contexts and across the curriculum, increases the relevance of the underlying theories, as well as reduces student’s “cognitive load” associated with learning a new concept while internally relating the analytical model to an actual structure. A key feature of this project is that the anchored learning methodology can be implemented within an already crowded engineering program of study with minimal change to the curriculum, learning outcomes, and learning objectives. This aspect is essential for the anchored instruction to be adopted.

Quantitative and qualitative data were collected and used to assess the effectiveness of teaching fundamental engineering concepts with anchored instruction. A quantitative survey was deployed at the beginning and end of each anchored course to measure students’ attitude toward a career in bridge engineering. Qualitative data were collected from a free response question on the survey and from interviews with student focus groups and instructors involved with courses containing anchors. Results indicated that students found bridges more interesting, had a better understanding of what a bridge engineer does, were more likely to pursue a career in bridge engineering, and could become a successful bridge engineer after being exposed to the anchored learning material. Instructors involved with deploying the anchor modules noted that implementation of four to five modules was not difficult. Both the students and instructors involved in this study noted that field trips to a local structure and inclusion of real-life bridges in the coursework are highly influential; feedback suggested that significant effort should be spent introducing the anchor case studies, with adequate detail and information, to make them more memorable and important.

Introduction and Objective

Traditionally, undergraduate engineering students view their coursework simply as a means toward graduation and obtaining a degree. After graduation, the students enter the workforce and learn what it "really takes" to be a professional engineer, but they do not necessarily view the knowledge acquired in college as foundational principles. Thus, they often struggle transferring and applying fundamental engineering principles to the engineering applications encountered in the workforce. According to Bransford et al. [1], 'it is left to the student to transfer theoretical knowledge to the solving of problems.' Furthermore, according to the Federal Highway Administration (FHWA) [2], "most undergraduate structural engineering curricula do not fully prepare students for professional practice in bridge engineering. Bridge design firms are challenged to educate new engineers on topics that are beyond what is considered normal 'on-the-job-training.' …there is a need for college-level courses that better prepare students for their transition into bridge design practice." There is a lack of college-level courses that prepare students for their transition into engineering design practice [3].

In response to this need, the objective of this study was to develop an approach to teach fundamental engineering principles using a concept called "anchored" instruction; the goal of this methodology was to both broaden the pool of students interested in bridge engineering and more effectively prepare those students for a career in bridge engineering. However, due to the focus on bridge engineering, this study does not address the effectiveness of anchored instruction for students not interested in bridge engineering. The instructional anchors were evidence-based learning tools that were implemented in several consecutive classes within an existing undergraduate civil engineering curriculum such that fundamental knowledge and principles were more likely to be transferred from the theoretical context of the classroom to the applied context of practice. A key feature of this methodology is that the anchored learning approach was implemented within an already crowded engineering program of study with minimal change to the curriculum, learning outcomes, and learning objectives.

Background

Knowledge Transfer

Knowledge transfer, in the context of engineering education, is a students' ability to use understood information to solve new problems across time and contexts. For a student to demonstrate proficiency in transferring knowledge, given a problem within a new context, they must be able to interpret what is being asked, recall a previous experience in which pertinent information was used to solve a similar type of problem, identify how the information from the previous situation can be correctly applied to the new problem, and retrieve the results successfully. With the goal of creating professionals who can use scientific knowledge to solve new problems, it is paramount for educators to foster students' ability to transfer knowledge, as opposed to memorizing technical information. Students who exhibit an ability to transfer knowledge are better equipped to make meaningful contributions to their respective industry [4].

Anchored Learning

Anchored learning is based on the construct of situated cognition, which also forms the basis for what is widely called experiential learning. Anchored learning is founded on the notion that knowledge can be recalled when people are explicitly asked to use it as a tool for solving a problem [5]. Bransford et al. [1] discuss the advantages of anchored learning as a pedagogical framework for classroom instruction. At the root of their efforts was the acknowledgement that traditional education practices leave much to be desired in terms of student output. Bransford et al. stated that "the basic problem is that traditional instruction often fails to produce the kinds of transfer to new problem-solving situations that most educators would like to see" [1]. The authors recognized that one of the primary reasons students are unable to transfer their knowledge into new problem-solving situations is because they perceive new information as the end goal, as opposed to a tool that can be used to solve other problems. As an example, the authors mention how astronomers in the early 1600's frequently dealt with tedious computations involving big numbers. When the mathematical concept of logarithms was invented, they recognized the concept as a tool that could be used to make the problems they were solving much more manageable. On the other hand, when students in the modern era are introduced to logarithms, they tend to think of them as a problem instead of a tool. They cannot appreciate them the way the 17^{th} century astronomers did because they do not have the context that highlights their relevance.

Bransford et al. [1] described their vision of anchored learning:

> *"At the heart of the model is an emphasis on the importance of creating an anchor or focus that generates interest and enables students to identify and define problems and to pay attention to their own perception and comprehension of these problems."*

When describing the varieties of anchors, Bransford et al. paid particular attention to video-based content, which provides students with heightened auditory and visual signals to process as opposed to other mediums. The music, scenes of towns, gestures, and dialogue presented in videos allow students to direct their interest down multiple avenues and identify problems that satisfy their curiosity. In this way, they come up with the information they want to gain on their own and process that information as the means for solving their problem. To put this theory to the test, the researchers designed a study that measured students' ability to recall and spontaneously use information that they had just recently acquired. Two test groups were formed, comprised of 5^{th} and 6^{th} graders who were at least one year behind their peers in math achievements. The first group was introduced to the concept of "planning a trip" by viewing the first ten minutes of *Indiana Jones: Raiders of the Lost Ark,* where Indiana is shown retrieving an idol from ancient ruins in the South American jungle. The class started by discussing the various food and items that Indiana would want to bring on his trip to the jungle and were then provided with reading materials on relevant food and items. The second group was first asked to consider what would be needed on a trip to the jungle and were told to read the same selected materials. Half of the students in both groups were selected to complete a specific task. The first task was to simply recall as many topics as they could remember from the articles they just read. The second task, completed by the remaining half of the students, was to develop a list of information that would be relevant for planning a trip to the Western Puebloan caves in the United States. The results from these tests proved that the students who were introduced to the topic in the anchored context of *Indiana Jones* performed significantly better on both tasks and gave much more specific information.

Jones [6] investigated the impacts of an anchored career-focused curriculum on high school students who were at risk of dropping out. The anchored curriculum focused on improving career development skills in 42 students. A control group of 32 students followed a traditional curriculum. The anchored curriculum included five lessons that scaffolded on one another, requiring students to use the information developed in previous lessons to complete subsequent lessons. Jones deployed 27 videos to anchor the lesson plans, which were shown to the students throughout the curriculum. The videos included personal experiences from employers regarding the hiring of potential candidates, which helped connect the content in the videos to real life. The effectiveness of the career-focused curriculum was evaluated using a career awareness pre- and post-test alongside a career awareness survey, which students from both groups completed. The career awareness pre- and post-test was the same 17-question multiple choice test, which directly assessed students' knowledge. The career awareness survey was a 10-question survey that asked students to self-assess their knowledge on several of the topics taught in the anchored curriculum. Student and teacher interviews were also conducted at the end of the study to share their experiences with the program. Jones [6] concluded that the career-focused curriculum "was successful in increasing the understanding of transition concepts for the career preparation of high school students at the risk of dropping out of school."

The Cognition and Technology Group at Vanderbilt (CTGV) discussed two educational programs they developed and introduced to students in fifth and sixth grade [7, 8]. The authors stated that one of the core problems they set out to solve in their research project was that of "inert knowledge." Inert knowledge refers to information that has been absorbed by students, but never gets used because the students do not know why or when it is useful. To illustrate this concept, CTGV described a case study in which an educational psychology teacher gave students a long article and only ten minutes to learn as much information about the article as possible. This example demonstrates how students often fail to recall information when it would be useful.

> *"Almost without exception, the students began with the first sentence of the article and read as far as they could until the time was up. Later, when discussing their strategies, the students acknowledged that they knew better than to simply begin reading. They all had classes that taught them to skim for main ideas, consult section headings, and so forth, but they did not spontaneously use this knowledge when it would have helped.* [7]*"*

CGTV [7] delivered anchored instruction in the form of investigation-based problem-solving environments that were guided by richly contextualized videos. The videos had many avenues worth investigating, which provoked meaningful discussion and questions from the students. The authors report that the students' questions were sparked by genuine interest and directed towards a familiar phenomenon they had all observed in the video. In this type of classroom environment, students were directing the conversation to satisfy their interests, while anchoring their newly gained information in a rich context that illustrated the importance of their investigation.

CGTV [8] readdressed key aspects of their original work and provide updated information on how their views on anchored instruction had changed three years later. The authors also provided valuable information on the types of assessment strategies that the team has considered throughout the project. They make it clear that their goal for the anchored curriculum is not to improve students' scores on standardized tests but rather to improve students' holistic approach to problem solving. This refers to the way students identify a problem, generate subgoals that are necessary for solving the problem, and then actually solve it. To help measure the effects of anchored learning on students, the researchers designed several studies that assessed their ability to solve complex problems. In these studies, the control students were taught the same information as those in the experimental group, but without the context provided by the anchor. Instead of experiencing the content in a video format, the control group learned the same principles through one- and two-step word problems that involved the same mathematical calculations. Both groups of students were required to solve the same complex problems. The results indicated that the students who had been taught the information in the context of the anchor demonstrated a stronger ability to transfer knowledge and apply it to the problems.

Bottge et al. [9] determined the effects of anchor interventions on student performance in specific mathematics topics. Additionally, they observed inclusive classrooms that involved students with and without disabilities in math. The results from their study helped determine how anchored learning affects students in both groups. The anchors used in their study took major inspiration from the anchors originally designed by the CTGV [7], as well as from recommendations from Pashler et al. [10] and the National Mathematics Advisor Panel (NMAP) [11]. The study involved 25 middle school classrooms in 24 different schools and was designed to answer two research questions:

1. What are the differential effects, if any, of enhanced anchored instruction and business-as-usual instruction on the fractions, computation skills, and problem-solving performances of students with and without disabilities in math in inclusive math classes?
2. Do collaborative instructional strategies moderate the math performances of students with and without disabilities in math and, if so, how?

To answer these questions, the classrooms involved in the study were categorized into two distinct groups. One group experienced "enhanced anchored instruction," which involved specially designed computer activities, anchored videos, hands-on projects, and detailed lesson plans which were given to the instructors of each class. The second group experienced none of these anchored materials and carried on with their district-wide math curriculum. They were categorized as the "business-as-usual" group. Both groups were given the same pre- and post-assessments, and their performances were evaluated using descriptive statistical methods.
The results from the study showed promising improvements in the students who participated in the enhanced anchored instruction cohort. Students who experienced the anchors and had disabilities in math had a mean post-test score that was four points higher than the students who did not have disabilities in math and belonged to the business-as-usual cohort. This increase in performance was directly linked to the students' introduction to anchored lesson plans.

Thus, while anchored instruction has shown promise in many science and mathematics courses, it has not been demonstrated within an engineering context. The purpose of the study described in this paper is to test the pedagogical methods within an engineering context. More specifically, a bridge engineering context due to specific goals of the projects sponsor.

Anchored Learning in the Context of Bridge Engineering

In this ongoing study, deeply contextualizing (anchoring) fundamental engineering principles in two bridge-related case studies throughout students' course of study allows them to apply theoretical engineering concepts to a bridge analysis or design scenario. The instructional anchors are implemented in several consecutive classes within an existing undergraduate civil engineering curriculum (Statics, Mechanics of Materials, Structural Analysis, Reinforced Concrete Design, Steel Design, and Bridge Design). Figure 1 conceptually illustrates how this model of learning was anchored in the context of bridge engineering.

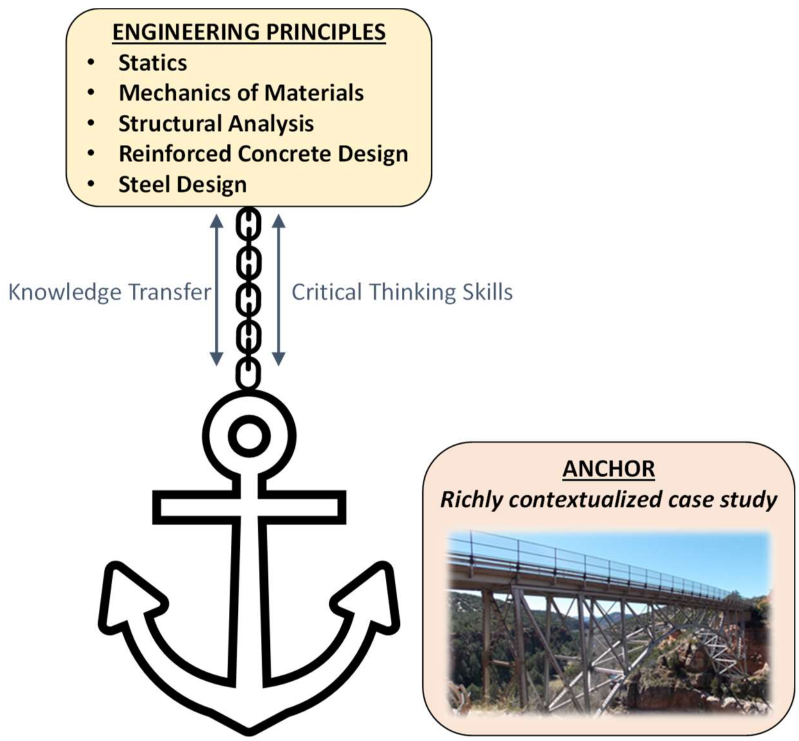


Figure 1: Engineering principles continuously anchored to a contextualized case study.

Methods

The instructional anchors in this study were implemented in the following courses within an already crowded engineering program of study with minimal change to the curriculum, learning outcomes, and learning objectives. The content included in the anchors was already listed in the existing course syllabi, which means the anchored material did not add content but rather refocused the content to be in the context of bridge engineering.

- Statics: Sophomore-level three-credit lecture course that is required and a prerequisite of mechanics of materials for civil and mechanical engineering students.
- Mechanics of Materials: Sophomore-level three-credit lecture course that is required and a prerequisite for structural analysis for civil and mechanical engineering students. Students are also required to co-enroll in a one-credit mechanics of material laboratory course where they conduct experiments to reinforce the concepts discussed in the lecture.
- Structural Analysis: Junior-level three-credit lecture course that is required and a prerequisite for reinforced concrete design for civil engineering students.
- Reinforced Concrete Design: Senior-level three-credit lecture course that is required and a prerequisite for both the civil engineering senior capstone design course and a bridge design technical elective.
- Structural Steel Design: Senior-level three-credit lecture course that is a technical elective offered once per academic year.

Completion of these courses leads students to a comprehensive senior-level three-credit lecture course entitled Bridge Design and Construction, where they demonstrate their ability to apply the skills and knowledge gained in past relevant courses to a complete bridge project.

Anchor Development

Anchors were developed using two bridges near Flagstaff, AZ as case studies. The first bridge is a 240-ft steel truss arch structure that was built in 1938 and is named the Midgley Bridge. The bridge carries AZ 89A over Wilson Canyon located North of Sedona, AZ in Coconino County. There are two primary arches on each side of the bridge that are connected to one another via intermediate bracing and cross-members, as shown in Figure 2.

Figure 2: The Midgley Bridge carrying AZ 89A over Wilson Canyon North of Sedona, AZ. [12]

The second bridge is a three-span continuous steel girder bridge that was originally built in 1967 and is named the McConnell Bridge. The bridge carries I-17 over McConnell Drive and is located on the southwestern corner of Northern Arizona University (NAU).

Figure 3: The McConnell Bridge carrying I-17 at the southwestern corner of NAU. [13]

Three broad categories of anchors were developed and deployed using these bridge case studies:

1. An introductory module that familiarized students with the bridge location, geometry, and structure type, among other things deemed pertinent by individual instructors.
2. Bridge analysis anchors that were deployed in lower-level courses.
3. Bridge design anchors that were deployed in upper-level courses.

Within each category, anchor material was adopted by the instructor as either a learning module (e.g., in-class lecture material, group work, or group-based exercises), assessment module (e.g., homework problem, group-based project assignment, or quiz/exam question), or combination.

The lower-level courses in this study included statics, mechanics of materials, and structural analysis. In these courses, students were introduced to the fundamental engineering concepts shown in Figure 4. These courses introduce critical information that will be built upon in future upper-level courses. The bridge analysis anchors enable application of the tools attained in these courses, where it is critical for students to obtain a strong foundation before advancing through the program. The anchors shown in Table 1 were developed over the spring and fall 2022 semesters for the lower-level courses.

Figure 4: Learning outcomes in lower-level courses.

Table 1: Anchors developed for statics, mechanics of materials, and structural analysis courses.

Bridge	Module Topic and Description
Statics	
Midgley	Sketch the analytical model
Midgley	Determine the statically equivalent resultants applied at each joint location
Midgley	Calculate support reactions and internal member forces
Midgley	Calculate centroidal location and moments of inertia
Mechanics of Materials	
Midgley	Determine normal stress in a member
Midgley	Determine the bolt shear and hole bearing stress at the member connection
Midgley	Compare calculated stress to allowable stress
McConnell	Determine the maximum moment that can be resisted by W-shape
McConnell	Find maximum tensile and compressive bending stresses in a composite section
McConnell	Determine shear and bending moment diagrams for the continuous steel beam
Structural Analysis	
Midgley	Determine whether structure is determinate, indeterminate, or unstable
Midgley	Distinguish internal vs. external indeterminacy
McConnell	Sketch qualitative influence lines for reaction, shear, and moment
McConnell	Determine where to place loads for maximum response given influence lines
Midgley	Calculate the nodal deflection using the method of virtual work

The upper-level courses in this study included Reinforced Concrete Design, Structural Steel Design, and Bridge Design and Construction. The key concepts that are anchored in these courses are shown in Figure 5. Completion of the reinforced concrete and structural steel design courses leads to a comprehensive bridge design course in which students demonstrate their ability to apply the skills and fundamental knowledge gained in past anchored courses to a complete bridge project. The anchors shown in Table 2 were developed over the spring and fall 2022 semesters for the upper-level courses. The structural steel design anchors are preliminary and will be refined when the course is taught during the fall 2023 semester. Each anchor delivered in the classroom is accompanied with a similar assessment, via an in-class assignment, homework, test question, or combination.

Figure 5: Learning outcomes in upper-level courses.

Table 2: Anchors developed for reinforced concrete and structural steel design courses.

Bridge	Module Topic and Description
Reinforced Concrete Design	
Midgley	Create an analytical model used for the flexural design of the slab/deck.
Midgley	Calculate the flexural capacity, ϕM_n, of the slab/deck. Ensure $\phi M_n \geq M_u$.
McConnell	Design a reinforced concrete girder (i.e., dimensions and reinforcement) to carry the superstructure.
McConnell	For the girder you designed, determine the stirrup size and spacing so $\phi V_n \geq V_u$.
McConnell	Ensure the serviceability performance of your bridge by checking the following: i) Slab. Temperature and shrinkage reinforcement and maximum spacing requirements; ii) Girder. Immediate and long-term deflection limits; and iii) Bent Cap. Minimum height and skin reinforcement requirements.
McConnell	Sketch the (ϕM_n,ϕP_n) interaction diagram for a column supporting McConnell Dr. bridge.
Structural Steel Design	
Midgley	Calculate the block shear capacity of a typical connection in the bridge
Midgley	Determine if the diagonal compression member in the truss is slender
McConnell	Calculate the flexural strength of a steel bridge beam
McConnell	Calculate the local buckling strength of a steel bridge beam

Anchor Deployment

The anchors described in Table 1 and Table 2 were deployed according to the course schedule shown in Figure 6. Figure 6 shows the timeline of the project, spanning from fall 2021 to spring 2024, and it highlights the number of students (more than 680) who have interacted with course material anchored to one of the two bridge structures described herein. Each course was taught by one of four different instructors that participated in the study.

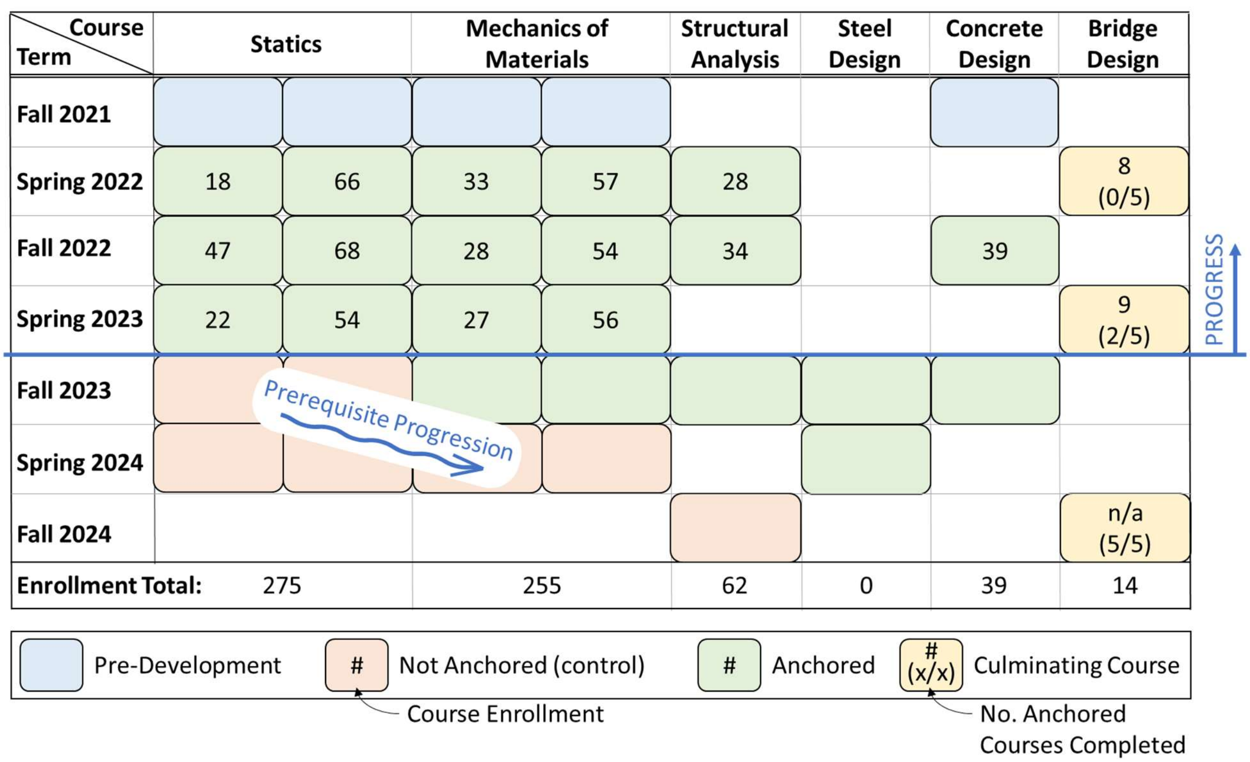


Figure 6: Sequence of anchor deployment.

Deploying the instructional anchors according to the sequence outlined in Figure 6 resulted in three distinct groups of students within the bridge design course. Students who took the course during the spring 2022 semester did not have any anchored interventions in their past classes. Students who took the course during the spring 2023 semester had experienced two out of five possible classes with anchors. Finally, students who take bridge design during the spring 2024 semester may have experienced up to five prior classes with anchored interventions. Students' grades on the design project and final exam in the bridge design course will serve as a metric for determining the effectiveness of the interventions, which can be correlated to the number of anchored courses that they took; this final step of determining effectiveness is beyond the scope of this study.

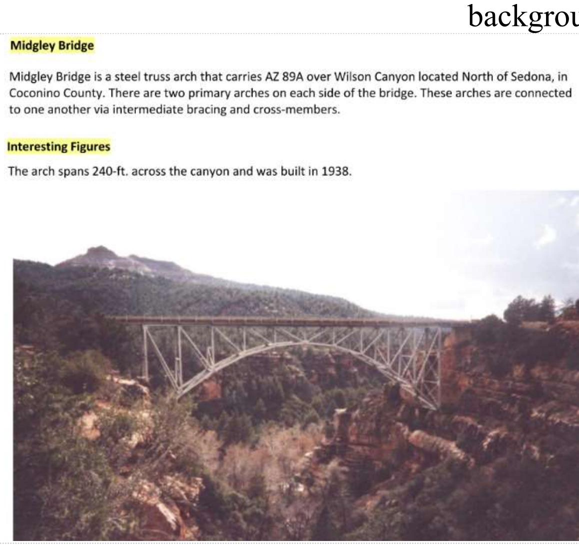
Example of Anchor Material Spanning the Curriculum

The following examples are based on the Midgley Bridge anchor case study and demonstrate how this material was presented in varying contexts and across the curriculum. In this study, Microsoft OneNote was used as the anchor management database due to its flexibility as word processing software and ability to link to outside sources.

Introductory Module

An initial module like that shown in Table 3 contains a plethora of material that introduces students to the bridge anchors. The material contained in this type of module can be directly presented to students or accessed/used by the instructor to store useful items such as pertinent video clips, links to construction drawings, etc. This introductory material was pertinent to each class in the anchored curriculum and was typically used at the beginning of each semester to reintroduce students to the bridge.

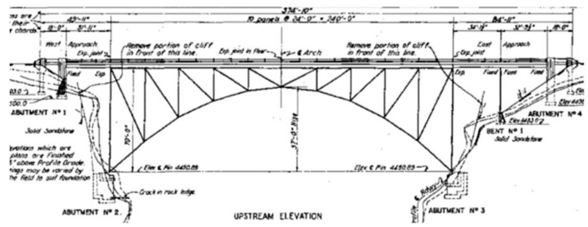
Table 3: Example snapshots from an introductory anchor module containing a plethora of background material.



Engineering Documents

This pdf file is a copy of the original engineering drawings that can be accessed and investigated.

00232-Historical Plans



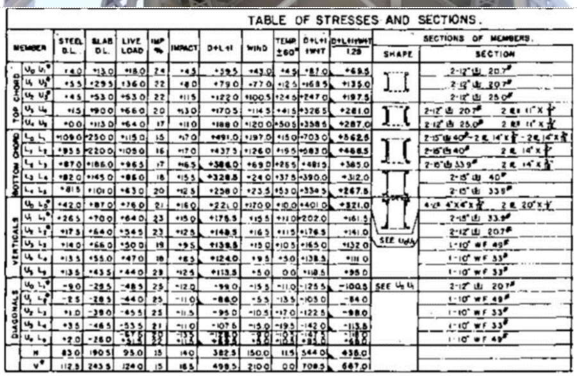


TABLE OF STRESSES AND SECTIONS.

	Member	Steel D.L.	Slab D.L.	Live Load	Imp %	Impact	D+L+I	Wind	Temp ±60°	D+L+I +Wnt	D+L+I+Wnt / 1.25	Shape	Section
TOP CHORD	U0 U1*	+4.0	+13.0	+18.0	24	+4.5	+39.5	+43.0	+4.5	+87.0	+69.5		2-12" ⊔ 20.7#
	U1 U2*	+5.5	+29.5	+36.0	22	+8.0	+79.0	+77.0	+12.5	+168.5	+135.0		2-12" ⊔ 20.7#
	U2 U3*	+4.5	+53.0	+53.0	22	+11.5	+122.0	+100.5	+24.5	+247.0	+197.5		2-12" ⊔ 25.0#
	U3 U4	+1.5	+90.0	+66.0	20	+13.0	+170.5	+114.5	+41.5	+326.5	+261.0		2-12" ⊔ 20.7# 2 ℞ 11" X ½"
	U4 U5	+0.0	+113.0	+64.0	17	+11.0	+188.0	+120.0	+50.5	+358.5	+287.0		2-12" ⊔ 25.0# 2 ℞ 11" X ½"
BOTTOM CHORD	L0 L1	+109.0	+250.0	+115.0	15	+17.0	+491.0	+197.0	+15.0	+703.0	+562.5		2-15" ⊔ 40# - 2 ℞ 14" X ½" - 2 ℞ 14" X ½"
	L1 L2	+93.5	+220.0	+109.0	16	+17.0	+437.5	+126.0	+19.5	+583.0	+466.5		2-15" ⊔ 40# 2 ℞ 14" X ½"
	L2 L3	+87.0	+186.0	+96.5	17	+16.5	+386.0	+69.0	+25.5	+481.5	+385.0		2-15" ⊔ 33.9# 2 ℞ 14" X ½"
	L3 L4	+82.0	+145.0	+86.0	18	+15.5	+328.5	+24.0	+37.5	+390.0	+312.0		2-15" ⊔ 40#
	L4 L5	+81.5	+101.0	+63.0	20	+12.5	+258.0	+23.5	+53.0	+334.5	+267.5		2-15" ⊔ 33.9#
VERTICALS	U0 L0*	+42.0	+87.0	+76.0	21	+16.0	+221.0	+170.0	+10.0	+401.0	+321.0		4-∠s 4"X4"X ½" 2 ℞ 20" X ½"
	U1 L1*	+26.5	+70.0	+64.0	23	+15.0	+175.5	+15.5	+11.0	+202.0	+161.5		2-15" ⊔ 33.9#
	U2 L2*	+17.5	+64.0	+54.5	23	+12.5	+148.5	+16.5	+11.5	+176.5	+141.0		2-12" ⊔ 20.7#
	U3 L3	+14.0	+66.0	+50.0	19	+9.5	+139.5	+15.0	+10.5	+165.0	+132.0	SEE U0 L0	1-10" WF 49#
	U4 L4	+13.5	+55.0	+47.0	18	+8.5	+124.0	+9.5	+5.0	+138.5	+111.0		1-10" WF 33#
	U5 L5	+13.5	+43.5	+44.0	29	+12.5	+113.5	+5.0	0.0	+118.5	+95.0		1-10" WF 33#
DIAGONALS	U0 L1*	-9.0	-29.5	-48.5	25	-12.0	-99.0	-15.5	-11.0	-125.5	-100.5	SEE U4 U4	2-12" ⊔ 20.7#
	U1 L2*	-2.5	-28.5	-44.0	25	-11.0	-86.0	-5.5	-13.5	-105.0	-84.0		1-10" WF 49#
	U2 L3	+1.0	-39.0	-45.5	25	-11.5	-95.0	-10.5	-17.0	-122.5	-98.0		1-10" WF 33#
	U3 L4	+3.5	-46.5	-53.5	21	-11.0	-107.5	-15.0	-19.5	-142.0	-113.5		1-10" WF 33#
	U4 L5	+2.0	-26.0	-67.5 / +51.5	20 / 22	-13.5 / +11.5	[illegible]	[illegible]	[illegible]	-147.5 / +85.0	[illegible]		1-10" WF 49#
	H	83.0	190.5	95.0	15	14.0	382.5	150.0	11.5	544.0	438.0		
	V*	112.5	243.5	124.0	15	18.5	498.5	210.0	0.0	708.5	567.0		

Construction Timelapse

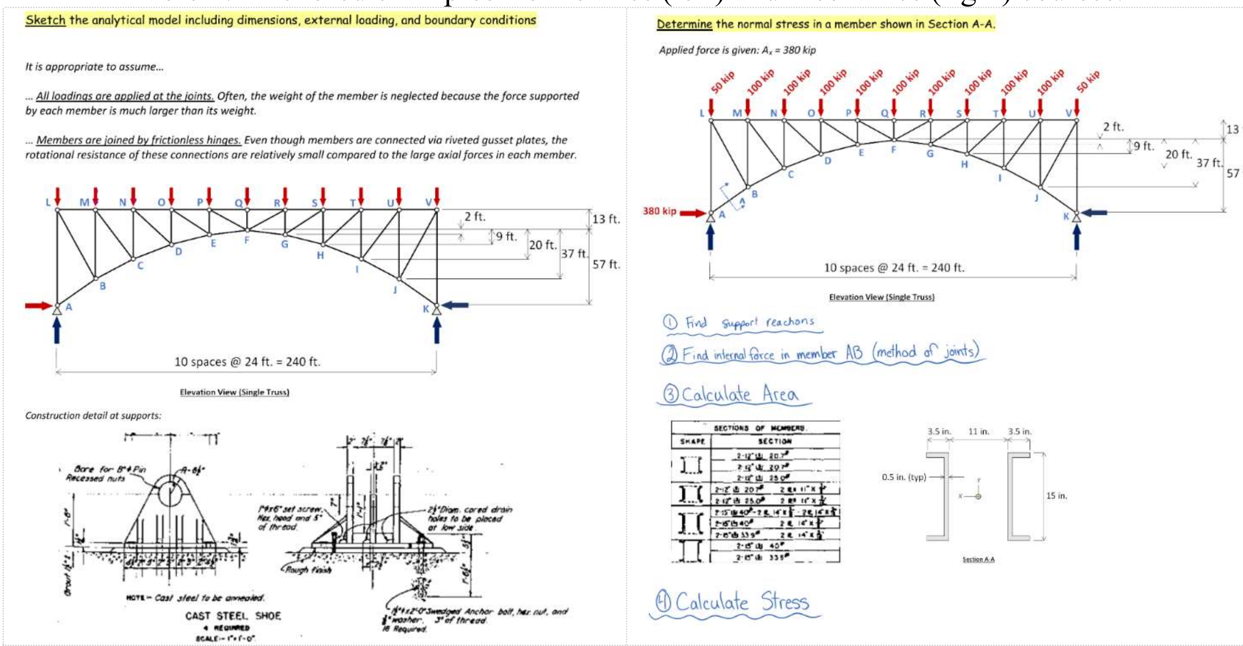
This YouTube video of a similar steel truss arch bridge shows the construction timelapse

Portageville Bridge Replacement Construction Time-Lapse

Statics and Mechanics Anchors

The anchored examples in statics and mechanics introduce students to the fundamental engineering concepts that will be built upon in future upper-level courses. Table 4 shows a statics anchor where students are tasked with sketching the analytical model and a mechanics anchor where students are tasked with determining the normal stress in a member.

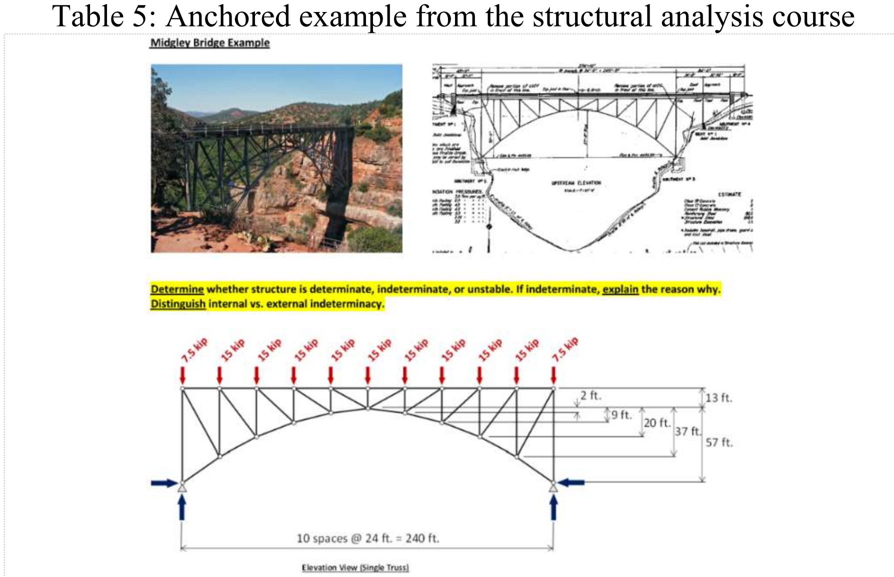
Table 4: Anchored examples from statics (left) and mechanics (right) courses.



Structural Analysis Anchor

In the structural analysis course, one of the anchored in-class examples tasked students with determining whether the Midgley Bridge was determinate, indeterminate, or unstable (Table 5). Students then applied their knowledge of indeterminacy to distinguish between internal and external indeterminacy and explain why this bridge is classified the way it is. At this point in their career, students have likely been exposed to the Midgley Bridge multiple times and do not need significant time to associate the analytical model and actual structure to the new concept they have just learned in this course.

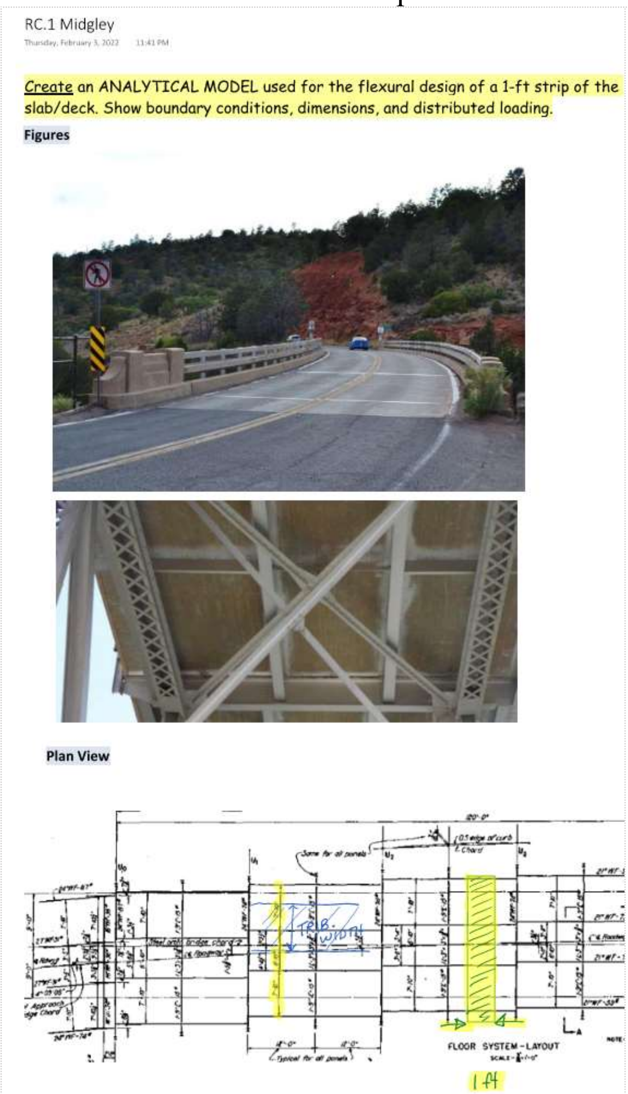
Table 5: Anchored example from the structural analysis course

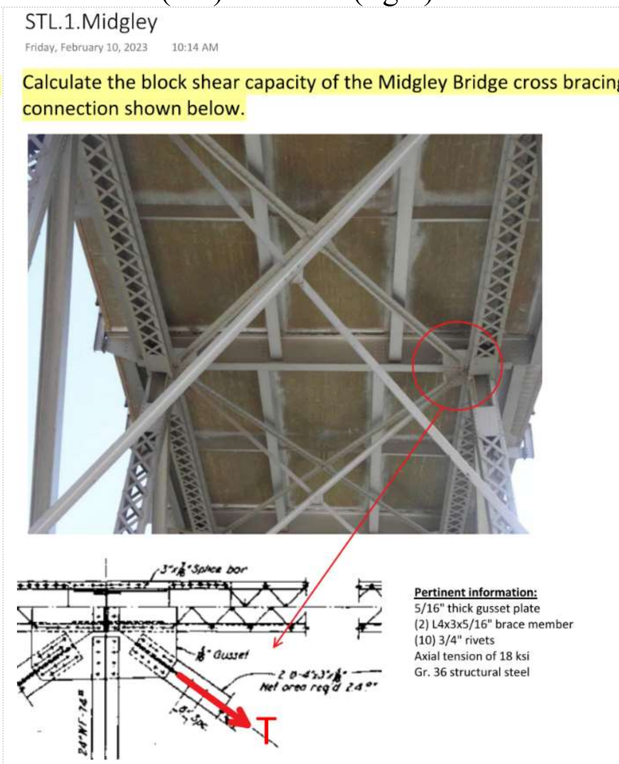


Reinforced Concrete and Steel Design Anchor

The anchored examples in reinforced concrete and steel build upon fundamental concepts learned in lower-division courses. At this point in their career, students have been exposed to the Midgley Bridge multiple times and need significantly less time and information from the plans to implement the new concept they have just learned in this course. Table 6 shows a reinforced concrete anchor where students are tasked with sketching the analytical model needed to design a 1 ft wide strip of the reinforced concrete deck and a steel anchor where students are tasked with determining the block shear capacity of a typical cross bracing connection.

Table 6: Anchored examples from reinforced concrete (left) and steel (right) courses.





Data Collection to Evaluate Anchored Instruction

The effectiveness of teaching structural engineering courses using anchored instruction is measured based on the following quantitative and qualitative measures:

1. Performance in Bridge Design and Construction course.
2. “Fundamental engineering knowledge” assessment.
3. Data collected from survey questions measuring students’ attitude toward a career in bridge engineering (Attitude Survey).
4. Interviews with student focus groups.
5. Interviews with the instructors at the end of each semester.

Bridge Design and Construction

Student performance in this course is measure based on their scores on homework assignments, quizzes, and exams. Because this project is a work in progress, and because the results have not been approved by the sponsor, this data is not ready for public dissemination.

Fundamental Engineering Knowledge Assessment

Only a small number of students typically enroll in the bridge design and construction course (approximately ten) because it is a civil engineering technical elective that is taken during students’ senior year. Thus, to better track the effectiveness of anchored interventions, the authors of this paper developed an assessment tool that can be deployed during students’ sophomore and junior years. Data from the assessment tool project are not ready for public dissemination because the project is a work in progress and the results have not been approved by the sponsor. However, the development of this assessment tool is discussed in a companion paper [14].

Attitude Survey

An attitude survey was deployed at the beginning and near the end of each semester in each of the courses containing anchored material. The goal of the attitude survey was to collect student perceptions related to their attitude toward careers in bridge design before and after their exposure to anchored instruction. The attitude survey questions were crafted based on work conducted by Erkut and Marx [15], who sought to determine the effect that engineering related interventions had on eighth grade students’ attitudes towards engineering, mathematics, science, and STEM fields and careers. The attitude survey contained four Likert-style statements with responses on a scale from 1 to 10 (1 = not at all, 10 = completely), where students were asked to indicate their level of agreement with each of the following:

1. I find bridges interesting.
2. I understand what a bridge engineer does.
3. I believe that I could become a successful bridge engineer.
4. I would consider pursuing a career as a bridge engineer.

The fifth and last question of the survey was a free response that asked students:

5. In general, what is your attitude toward a career in bridge engineering?

Student Focus Groups

At the end of term, between four to six students were recruited from all possible anchored courses and were interviewed in a focus-group setting by a faculty member who was not the instructor of the students' course. Questions posed during the student focus group interviews sought to determine students' qualitative attitude toward bridge engineering after completion of their course. The following yes/no questions were asked of the students:

1. Did you see a recurring theme of bridges in your classes this semester?
2. Did your attitude towards bridge engineering change during this class?

Furthermore, the interviewer also asked students to discuss their answers to the questions on a deeper level. For example, students were asked what led them to answer yes/no.

Instructor Interviews

Instructors who deployed anchors in their classes were interviewed near the end of term. The instructor interviews contained seven questions intended to allow instructors to reflect upon and suggest improvements for anchor deployment:

1. How many anchored lessons did you offer in your course this semester?
2. What did a typical anchor look like in your course?
3. How difficult was it to add anchored lessons into your existing curriculum?
4. What were some challenges you faced when implementing anchored lessons?
5. How did you perceive the students' opinions of the anchored lessons? (i.e., Did they seem to like the content? Did they ask good questions? Were they attentive?)
6. Do you feel that the anchored lessons added positive value to your class? In what way?
7. Any suggestions on how to improve anchors in future semesters?

Results

Attitude Survey

Figure 7 shows the quantitative data from the first four statements on the attitude survey. The figure summarizes three sets of data, which included student survey results prior to being exposed to any anchored material (denoted "pre" and included 134 students), student survey results after completion of one course that contained anchored material (denoted "post 1 anchor" and included 114 students), and student survey results after completion of two courses that contained anchored material (denoted "post 2 anchors" and included 59 students). The box and whisker plots show the quartile-based distribution of data, highlighting the mean (with an X), median (central, interior line), and outliers (dot beyond the T-shaped whiskers). Results in Figure 7(a) indicate that students found bridges slightly more interesting (on average) after being exposed to the anchored learning material, even for a second time. Results in Figure 7(b) indicate that students had a better understanding of what a bridge engineer does after being exposed to the anchored learning material; this was true after being exposed to anchored material once or twice (on average). Results in Figure 7(c) indicate that students believe they could become a successful bridge engineer after being exposed to the anchored material once or twice. Results in Figure

7(d) indicate that students exposed to anchored material once would consider pursuing a career as a bridge engineer more so than students never exposed to the anchored material; considering the median, students were even more likely to consider pursuing a career as a bridge engineer after being exposed to anchored material twice.

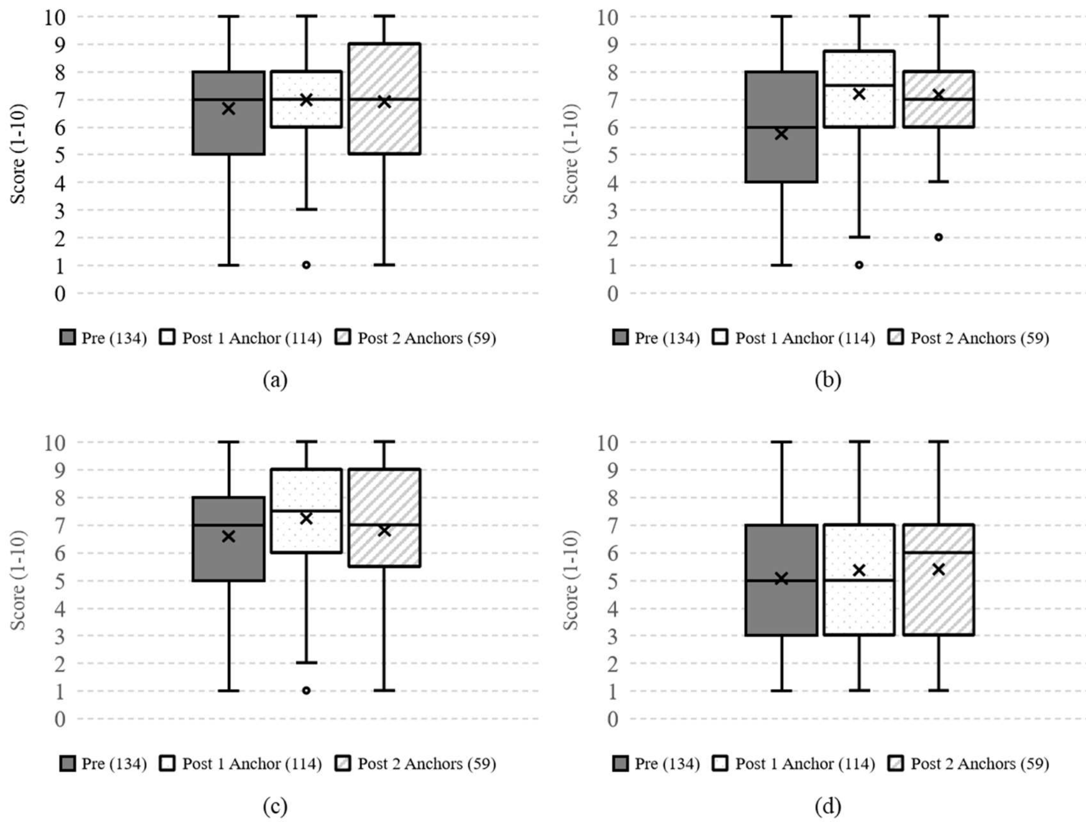


Figure 7: Attitude survey results for the statements (a) I find bridges interesting; (b) I understand what a bridge engineer does; (c) I believe that I could become a successful bridge engineer; and (d) I would consider pursuing a career as a bridge engineer.

The fifth and last question of the survey was a free response that asked students the following question “In general, what is your attitude toward a career in bridge engineering?” Spring 2022 semester results from this question were used to generate pre-anchored material and post-anchored material word clouds using free, online software [16]. The word cloud was customized to include only the 20 most frequent words. Stop words, numbers, and special characters were removed. Word clouds in Figure 8 show the pre- and post-anchored material results. Figure 8(b) include many of the same most-frequent words, but more emphasis (larger words) was placed on the following term in the post-anchor survey: interesting, career, interested, interest. This indicates that more students noted an interest in a bridge engineering career after experiencing the anchored material in the course. Furthermore, three new words of emphasis appeared in the post-anchor survey that indicate students were more interested in bridge engineering: love, structural, design.

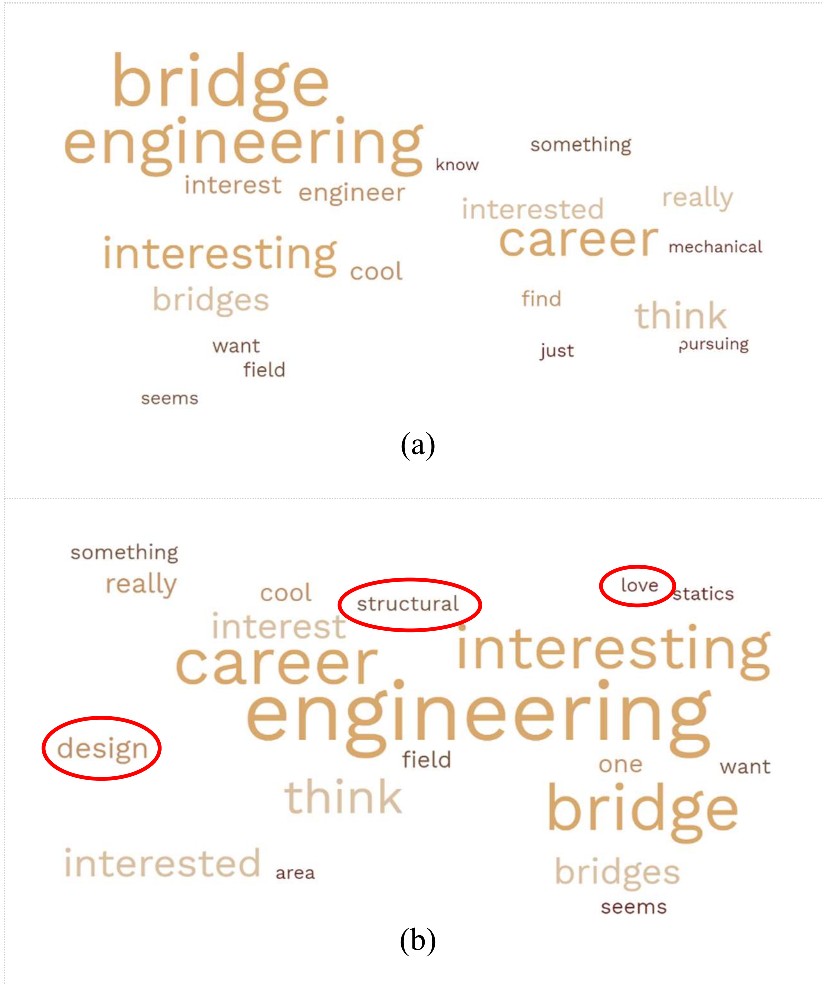


Figure 8: Spring 2022 (a) pre- and (b) post-anchored learning attitude survey results in a word cloud for the free response question that asked students "In general, what is your attitude toward a career in bridge engineering?"

<u>Student Focus Groups</u>

Interviews with two student focus groups were conducted after the spring and fall 2022 semesters. Students were asked to participate voluntarily and rewarded with a $25 Amazon gift card upon completion of the interview. A total of eight students participated; more focus group data will be collected to create a larger sample size as this study continues. However, the goal of the focus group discussions was to provide qualitative context related to the quantitative survey results. Results in Figure 9 show that 100% of the students noticed the recurring theme of bridges in their classes and 63% of students said that their attitude toward bridge engineering changed over the course of the anchored class.

Figure 9: Results from student focus group questions asking: (a) Did you see a reoccurring theme of bridges in your classes this semester? and (b) Did your attitude toward bridge engineering change over the course of this class?

The interviewer also asked students to discuss their answers to the questions deeper, and the following key points were synthesized from their responses:

- Collaboration is highly recommended for improving student engagement and learning; this frequently occurred when completing the in-class anchored exercises.
- Pre-class videos and concept checks could be implemented more often, to complement the anchors.
- The anchors need to be introduced with more details and effort, to make them more memorable and important.
- For students who were deeply rooted in other career paths, the anchors still increased their appreciation and interest in bridges.
- A field trip was highly recommended by the students to increase understanding and interest in the bridge associated with the anchored case study.

<u>Instructor Interviews</u>

The four instructors who taught classes with anchored material were interviewed after the spring and fall 2022 semesters to answer the following questions. The key points are synthesized in blue italicized text after each question.

1. How many anchored lessons did you offer in your course this semester?

   On average, instructors included approximately 4 to 5 anchored learning opportunities per course per semester.

2. What did a typical anchor look like in your course?

   In-class activities (individual or group-based). Conceptual or applied homework problems. Spent extra time orienting students to in-class activities related to the case study.

3. How difficult was it to add anchored lessons into your existing curriculum?

   Not too difficult, very easy, not difficult, relatively easy. Extra effort is needed with the initial introduction of the anchored case study.

4. What were some challenges you faced when implementing anchored lessons?

Diving into or interjecting the anchored in-class activities too fast (more context was needed). In-class activities were beyond the scope of knowledge for an introductory statics class. I chose a nearby bridge for a reinforced concrete example even though it was a steel superstructure – the ability for students to see the structure was paramount.

5. How did you perceive the students' opinions of the anchored lessons? (i.e., Did they seem to like the content? Did they ask good questions? Were they attentive?)

   Relevance of lessons to their career. Practical / real-world examples are more fun. They enjoy relating class topics to the real-world.

6. Do you feel that the anchored lessons added positive value to your class? In what way?

   Relevance / application to the real-world (and regional bridges). Easier to understand an elevation view, cross section view, etc. when the example is real (with pictures).

7. Any suggestions on how to improve anchors in future semesters?

   Continually refine the learning objectives. More pictures and videos of construction. Create a robust introductory module that is easy for students to peruse and understand – background and context are key. Develop the instructor material in more detail.

Conclusions

The objective of this paper was to present a case study in developing and implementing anchored learning interventions related to bridge engineering in traditional structural engineering courses to better teach fundamental engineering principles. Fundamental principles in statics, mechanics of materials, structural analysis, and reinforced concrete design courses were anchored to one of two bridge case studies during the 2022 spring and fall semesters, and more than 680 students were exposed to the anchored material.

Results from survey data collected before and after completion of anchored courses suggested that students found bridges more interesting, had a better understanding of what a bridge engineer does, were more likely to pursue a career in bridge engineering, and believed they could become a successful bridge engineer after being exposed to the anchored learning material. A free response survey question and synthesized data from student focus group interviews indicated that students noticed the change in their curriculum, were more aware of bridges and bridge engineering, and perceived an attitude change toward the field of bridge engineering. Instructors involved with deploying the anchor modules noted that implementation of 4-5 in-class anchored learning opportunities was easy. Inclusion of real-life bridges in the coursework was noted as being highly influential, and students also suggested including a field trip to a local structure if possible. Both the students and instructors involved in this study noted the importance of introducing the anchor case studies with significant detail and effort to make them more memorable and important. Students' ability to transfer fundamental knowledge to an applied bridge engineering context is an important element of this study. These results are forthcoming and will be made available when ready.

Another key feature of this project is that the anchored learning methodology can be implemented within an already crowded engineering program of study with minimal change to the curriculum, learning outcomes, and learning objectives. This aspect is essential for the anchored instruction methodology outlined in this case study to be adopted.

Acknowledgements

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