A PROFESSOR'S PERSPECTIVE

The Balancing Act of Engineering Education

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A challenge I often experience as an instructor is balancing theoretical content with its applications. Too much of one or the other can result in negative learning outcomes. For example, consider derivations in a statics or mechanics of materials textbook. The theoretical model may show a differential area inside a nebulous blob (such as a "pancake" or "potato"), and it is explained in generalized terms. While these types of models are important, I will quickly lose students' attention if I spend too much time deriving, for example, the center of gravity of a potato in terms of numerous variables. It is incredibly difficult for most students to grasp highly abstract conceptual models. On the other hand, simply giving students an equation does not encourage a fundamental understanding of the basis or assumptions of the concepts built into the derivation. Students' engineering successes are not predicated on their ability to remember and repeat information, but rather on their ability to find and use it. We expect engineering students to be able to apply fundamental principles in varying conditions, but if they do not know the basis of these principles because they were simply "given the equation," they will struggle when applying the principles in a new or even slightly altered context. Theory is best learned through and in harmony with applications, yet finding the appropriate balance is a constant challenge that depends on course learning objectives, the topic, and the needs of students.

The purpose of continuously examining this balance between theory and application is ultimately to foster the ability of students to seamlessly and productively transition into their future professions, which will require them to be able to transfer knowledge from the classroom to the office or jobsite. Knowledge transfer is the ability to apply knowledge, skills, and practices across time and contexts.[1] According to Bransford et al.,[2] a person's ability to transfer what they have learned depends on several factors:

- Students come to the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp new concepts and information, or they may learn concepts and information for a test but revert to their preconceptions afterward.
- How instructors assess students' comprehension matters. Many approaches to instruction look equivalent when the measure is based on rote memorization. Instructional differences become more apparent when they are evaluated from the perspective of how well the learning transfers to a new setting.
- Spending a lot of time studying a topic is not sufficient in and of itself to ensure effective learning. Time spent learning for understanding has different consequences for transfer than time spent simply memorizing facts or procedures. For learners to gain insight into their comprehension, frequent feedback is critical.
- The context in which one learns is also important. Students are motivated to spend the time needed to learn complex subjects and to solve problems that they find interesting, particularly opportunities to create products or provide services that benefit others.
- Knowledge that is taught in only a single context is less likely to support flexible transfer (transfer to an unfamiliar context) than knowledge that is taught using multiple scenarios. Students are more likely to grasp the underlying principles with varying contexts. Helping learners choose and adapt tools for solving problems is one way to promote transfer and encourage flexibility.
- A metacognitive approach to teaching is recommended (for example, defining learning goals and allowing students to reflect on their achievement of these goals). One characteristic of experts is their ability to monitor and regulate their understanding in ways that allow them to continually adapt the application of their expertise. Thus, it is important for instructors to model their own inquiries, questioning, and testing of principles, as part of their instruction.

At Northern Arizona University, I am part of a team of structural engineering faculty who are testing instructional interventions intended to create more practice-ready bridge engineers by improving students' ability to transfer knowledge. Our approach is aligned with the previously mentioned factors and the constructivist position that transfer can be facilitated by involvement in authentic tasks anchored in meaningful contexts. Using an approach that is sometimes referred to as "anchored instruction," we repeatedly anchor engineering concepts across the curriculum to actual bridges in the surrounding area. For example, we may have students use the method of joints to analyze internal forces in a truss bridge in their statics class, then determine the factor of safety of each component for the same bridge in their mechanics of materials class, and then use the method of virtual work to calculate structure deflections for the same bridge in their structural analysis class. By repeatedly revisiting the same structure in varying contexts and across the curriculum, we can increase the relevance of the underlying theories and reduce the cognitive load needed to relate an actual structure to its conceptual model. **Figure 1** illustrates the concept of the anchored approach to learning.

We have completed the first year of our four-year project to test instructional interventions. Key considerations and findings that continue to guide our work include the following:

- Instructional materials must be

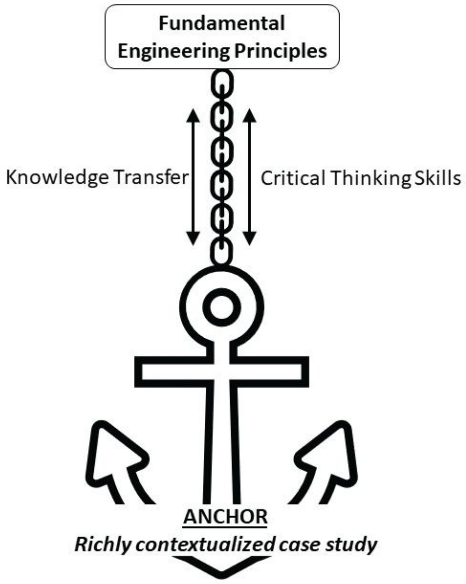


Figure 1. Conceptual model for "anchored instruction." At Northern Arizona University, instructors "anchor" engineering concepts to actual bridges in the surrounding area. All Figures and Photo: Dr. Robin Tuchscherer.

formatted and disseminated in a manner that allows instructors to easily incorporate them into their classes. The civil engineering program is packed full of content, and there is little room for drastic alterations. To improve ease of adoption of our interventions, the materials must be user friendly and intuitive, and have low "overhead," such that there are few additional costs in terms of time or money.

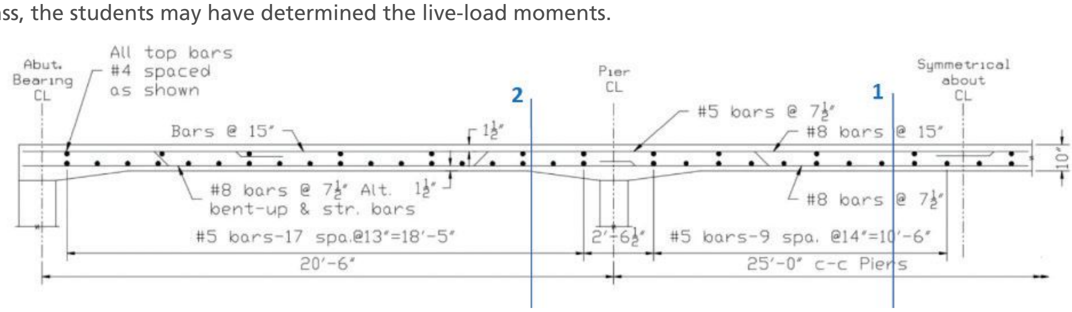
- Grounding the anchor is crucial. In other words, student engagement is higher when the bridge's context is fully described with its location, construction means, fabrication details, and cultural and historical significance (**Fig. 2**).
- An anchor by itself is not effective—providing a concept in only one context does not encourage students to apply the concept in other contexts. To encourage transfer and abstraction of principles (such as flexible transfer), the instructor should integrate each concept along with several contextual variations.
- The level of student engagement in learning depends on the proximity of the anchor. For example, we have discovered that although a bridge students walk under every day on their way to campus is fairly ordinary, it has a lasting impact on students' interest and motivation to learn the associated concepts.
- Students' attitudes toward the bridge engineering profession seem to be positively and significantly influenced by their exposure to bridges through the anchored instruction approach in the classroom.

When thoughtfully executed, anchored learning can be an effective means of harmonizing the balance between theory and practice. The success of any intervention requires instructors to continuously hone their craft for the benefit of learners. Teaching and learning are complicated. Instructors, like other professionals, attain expertise through years of practice, experience, and, most importantly, their motivation to improve. Focusing on how people learn will help instructors move beyond the "either/or" dichotomies that have plagued the field of education, such as whether one should emphasize "the basics" or teach problem-solving skills. Both are necessary. Students' abilities to acquire skills are enhanced when they are connected to meaningful problem-solving activities and when they are helped to understand why, when, and how those facts and skills are relevant. Attempts to teach thinking skills without a strong base of fundamental knowledge does not promote problem-solving ability or support knowledge transfer to new situations.[2]

References

1. Ertmer, P. A., and T. J. Newby. 1993. "Behaviorism, Cognitivism, Constructivism: Comparing Critical Features from an Instructional Design Perspective." *Performance Improvement Quarterly* 6 (4): 50–72. https://doi.org/10.1111/j.1937-8327.1993.tb00605.x.
2. Bransford, J. D., A. L. Brown, and R. R. Cocking, eds. 2000. *How People Learn: Brain, Mind, Experience, and School: Expanded Edition*. Washington, DC: National Academies Press. https://doi.org/10.17226/9853.

Figure 2. At Northern Arizona University, a team of structural engineering faculty is testing strategies to create more practice-ready bridge engineers. One approach is to enhance students' abilities by revisiting the same structure in varying contexts and across the curriculum. In this assignment, the students are tasked with determining the flexural capacity of the two-span Earp Wash Bridge. In a previous class, the students may have determined the live-load moments.



Determine the positive and negative flexural capacity for the bridge at Sec 1 and 2, respectively. f'_c = 4 ksi fy = 40