



## Conceptual Change Across Engineering Disciplines

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## Introduction

Existing research on conceptual change (i.e. the effortful process of revising or changing one's fundamental understanding of something) has drawn from various disciplines including physics, biology, mathematics and history. Little research has been done, however, investigating how *differences in content* may affect conceptual change in the various disciplines <sup>[1]</sup>.

## Methods

The research described here investigates this question by analyzing data on student understanding of engineering concepts from multiple content areas within the broad discipline of engineering: mechanics of materials, Boolean logic, fluid mechanics, and transportation engineering. In total, this work includes more than 200 interviews with engineering students who were asked to answer questions about problem sets and explain their reasoning. These interviews were originally conducted with the intent of characterizing student understanding of the various topics, and all use a semi-structured, clinical interview format that allowed the interviewer to ask follow-up questions to uncover students' conceptual understanding of basic principles <sup>[2-17]</sup>.

These interviews were re-analyzed using an amplified secondary data analysis <sup>[18, 19]</sup>, a novice-led paired thematic analysis <sup>[20]</sup>. The purpose of the secondary analyses reported here are to **identify commonalities** in student understanding of these core "engineering" concepts in order to **illuminate a developing theory of engineering-specific conceptual change**.

## Results

Intriguing commonalities in students' conceptual understanding of diverse engineering sub-topics have been identified. Through our analysis, a theme emerged which begins to address our research question, "What are the patterns in engineering students' conceptual understanding across concepts from four engineering sub-disciplines?" One striking pattern was the tendency of students to inappropriately group dissimilar phenomena, processes, or features. Though this happened in distinct ways across each of the four fields, it was a common tendency. This paper, based on our poster presentation, will illustrate each of these fields with a figure explaining important concepts being addressed and a table that summarizes key concepts and student conceptions.

## Mechanics of Materials

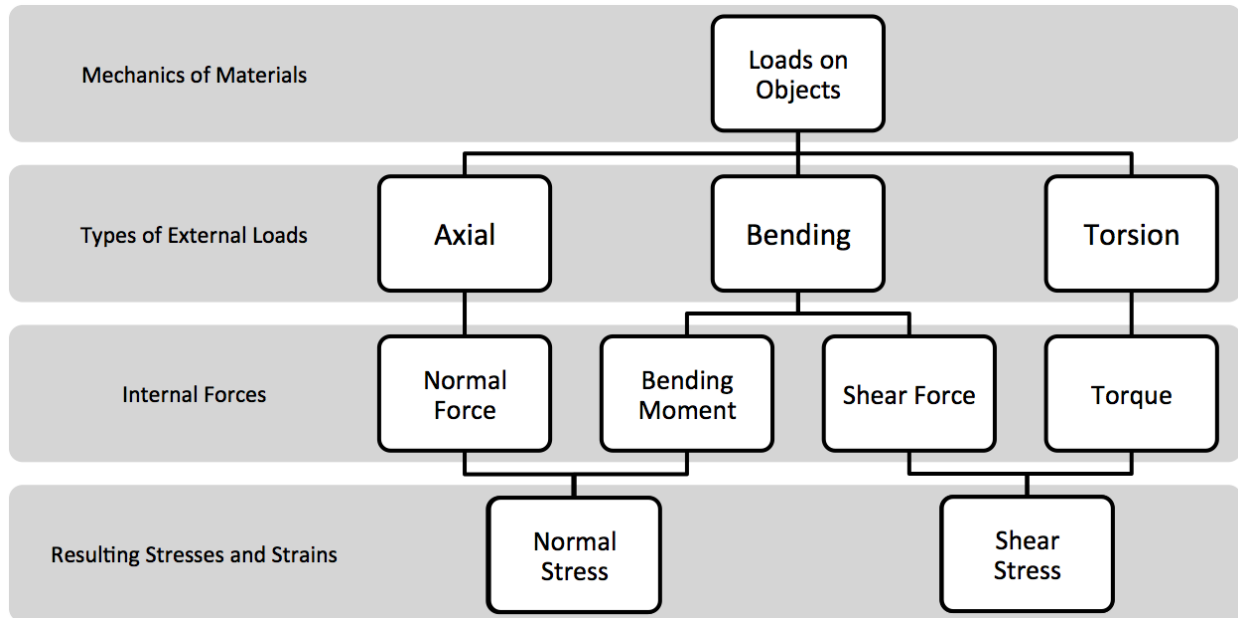


Figure 1. The authors' high-level representation of the important distinctions in mechanics of materials.

Concepts	Student Conceptions
<p>When an object is subjected to forces, internal reactions occur.</p> <p>There are a number of important distinctions to be made as to the type of external force, and the different types of internal reactions.</p>	<p>“Normal” versus “shear” is the most important distinction to be made.</p> <p>All forces and deformations are essentially “normal” or “shear”</p>

Table 1. Summary of student understanding of the hierarchical relationships between external forces and internal reactions in mechanics of materials

The secondary analysis of the interviews revealed that students maintained strong distinctions between the concepts of “normal” and “shear,” but usually did not distinguish between stress, strain, force, or deformation. They instead preferred to reason with aggregated concepts of “normal” and “shear” (see Table 1 for a summary). For example, students would unknowingly discuss forces or deformations when asked about stresses or strains. Alternatively, most students neglected to use terms other than shear or normal. For example, whether they were discussing normal force, stress, strain, or deformation, their dialogue relied only on terms like “normal” or “the normal,” as in “it’s just normal, there’s no shear.”

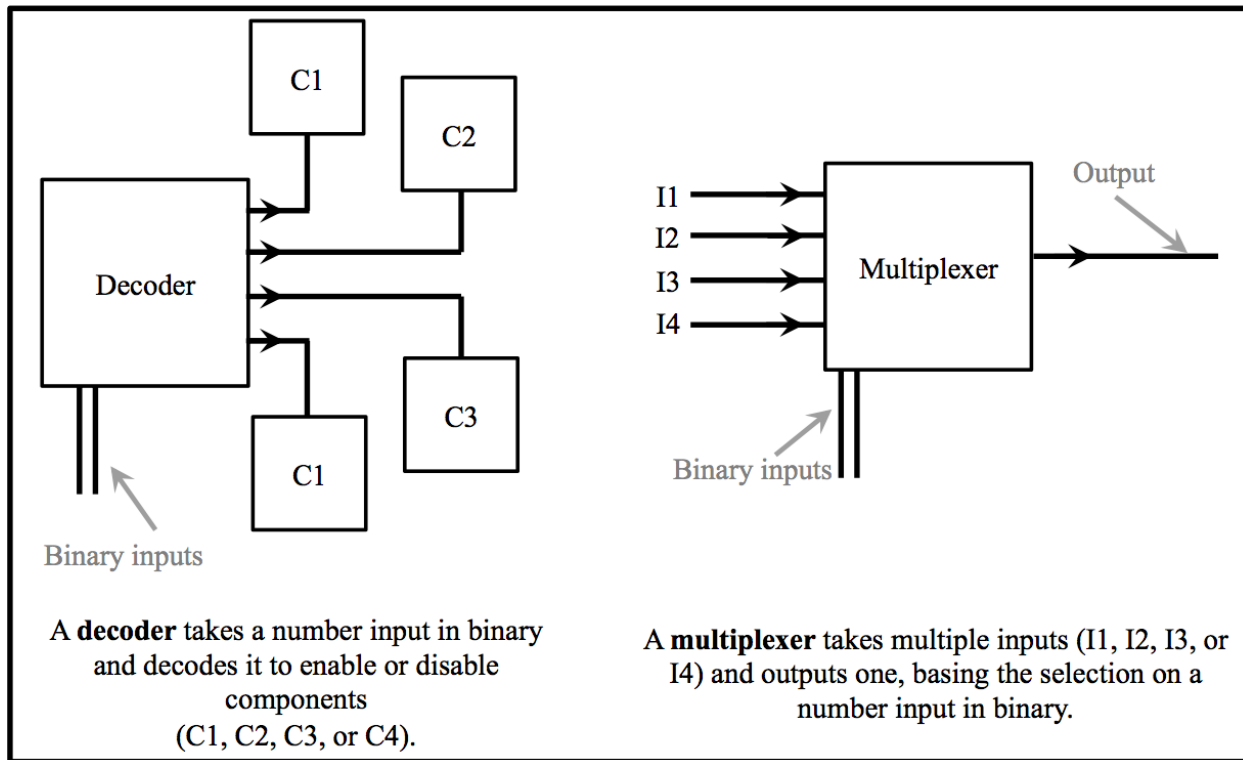


Figure 2. Summary of the differences between decoders and multiplexers.

Concepts	Student Conceptions
<p><b>Multiplexer:</b> a combination of smaller circuit components that selects between multiple data inputs via selection inputs, outputting only one data signal</p> <p><b>Decoder:</b> a combination of smaller circuit components that activates or deactivates other components based on an encoded binary input signal</p>	<p>Multiplexers and decoders are basically the same, except that multiplexers have multiple inputs and decoders have multiple outputs.</p>

Table 2. Summary of student understanding of the differences between multiplexers and decoders.

In our data, we found that students tended to inappropriately conflate multiplexers and decoders based on their superficial similarities such as appearance or temporal proximity of learning, rather than distinguishing them based on function or structure (see Table 2 for a summary). By inappropriately grouping multiplexers and decoders, many participants limited their ability to make sense of either concept. For example, when asked about the general purpose of decoders, many students tried to explain them in terms of contrasts with multiplexers, but failed due to their assumption of fundamental commonalities. One student responded, “a multiplexer is an

electronic component that...let's see...it basically takes ...how would I describe this...it takes a couple wires in, it takes like N wires in and spits out 2 to the N wires? [...] A decoder is another component [draws box] it has a bunch of wires going into it and...well, it's got a bunch of wires going into it, and some of which are used to select what's passed out...now that I think about it...I'm not entirely sure if I mixed up decoder and multiplexer or not." Many students, like this one, focused on the physical appearances of the multiplexers and decoders as they are presented in class, discussing "wires" that go "in" or "out" rather than on the purpose or functionality of the components.

### Fluid Mechanics

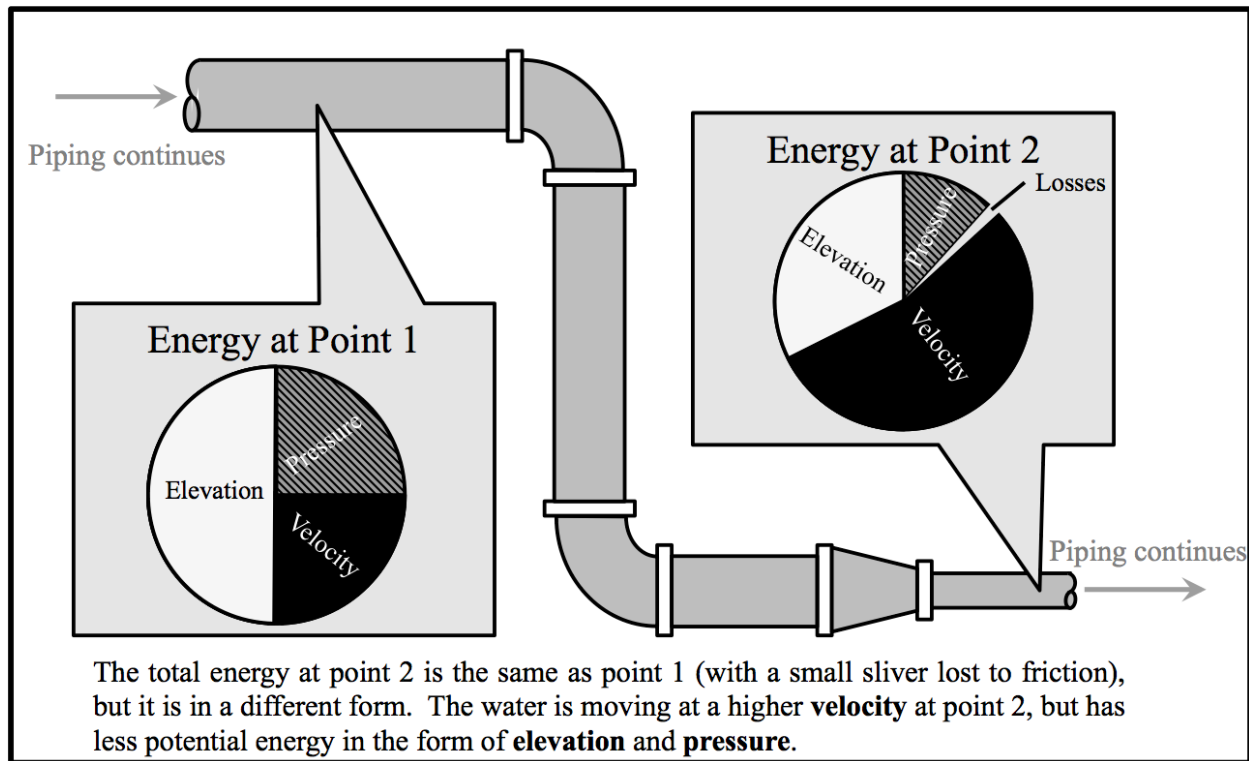


Figure 3. Summary figure presenting fluid flow as an equilibrium between three different forms of energy in the flowing fluid.

Concepts	Student Conceptions
<p>Fluid flow is a dynamic equilibrium of mass and energy</p> <p>Energy is balanced between kinetic (the velocity of the flow), potential (the elevation) and pressure</p>	<p>Fluid flow is a combination of pressure, velocity, elevation and depth</p>

Table 3. Summary of student understanding of the characteristics of fluid flow

In fluid mechanics students are often asked to relate various characteristics of a flowing fluid to one another. Most often these characteristics are volumetric flowrate, velocity, pressure and

flowing area (i.e. the size of the pipe or channel conveying the flow). Based on the conservation of energy, it is possible to relate any two of these characteristics if the third is constant for the two points being compared. Figure 3 presents an example of how these concepts are balanced and connected through the conservation of energy. In our interviews students often struggled to understand this balance however, and often used an aggregated concept of “flow” which seemed to include elements of pressure, volumetric flowrate, and velocity. These characteristics are closely related, but students would gloss over distinctions by occasionally treating them as interchangeable or synonymous (see Table 3).

Transportation Engineering

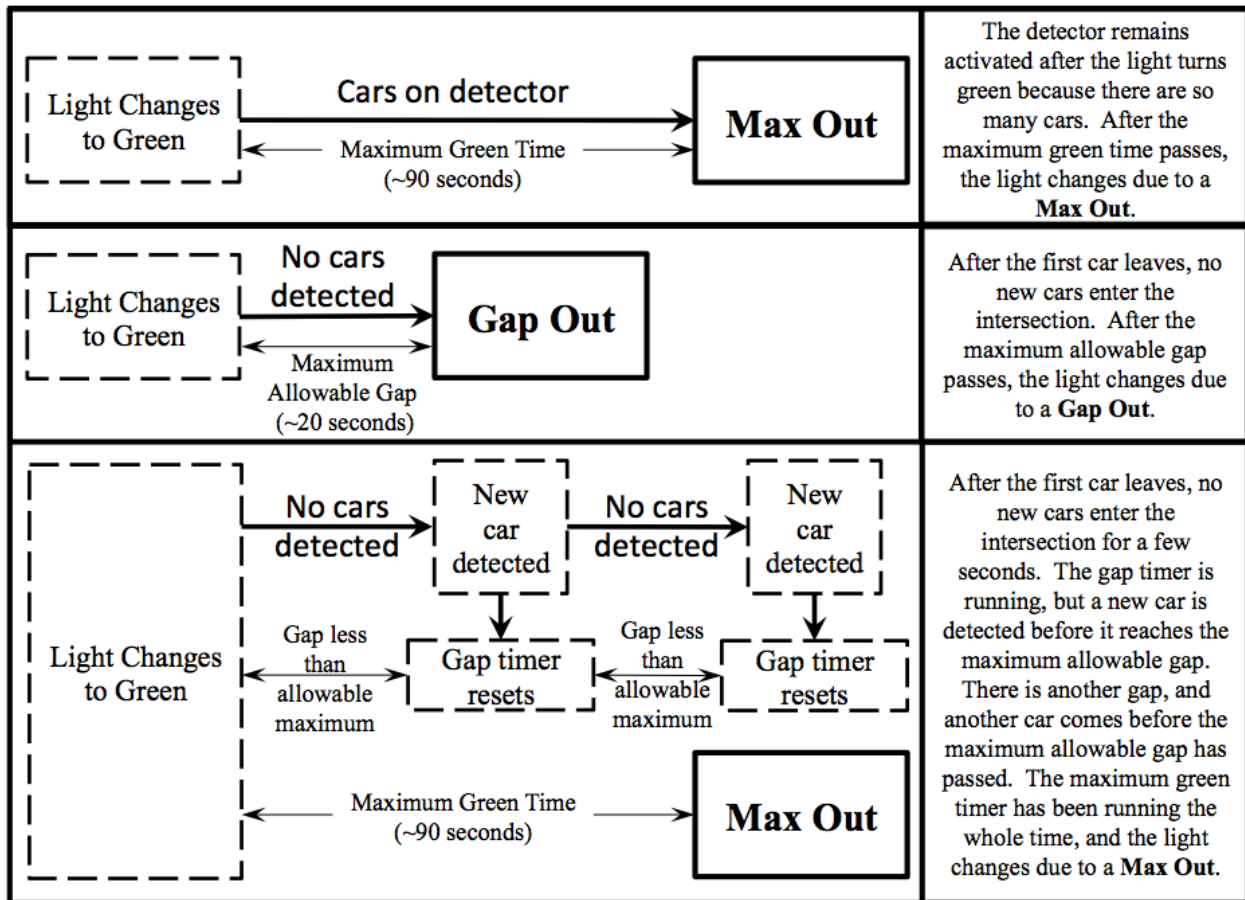


Figure 4. Three examples of how a controlled intersection could end a green light.

Concepts	Features of Student Understandings
<p>Two events are used to cause the lights to change in an intersection controlled by sensors and traffic lights:</p> <p><b>Gap out</b> occurs where there is too large of a gap between cars going entering the intersection</p> <p><b>Max out</b> occurs when the green light has been green for the maximum amount of time allowed for a single green light</p>	<p>Gap outs, max outs and cars waiting are forms of failure for intersections</p>

Table 4 Summary of student understanding of how the lights change in an actuated signal

In intersections that are controlled by traffic lights with sensors (rather than just timers), two different events can cause the green indication to change: a gap out and a max out. A gap out occurs when too much time elapses between the sensors detecting new cars approaching the intersection (i.e. the “gap” between cars is too large), and a max out occurs when a predefined maximum amount of time passes without a gap out. The only way a green light can change is through either a gap out or a max out (see Figure 4). In this study we found that students inappropriately associated both gap outs and max outs with a failure of the intersection (see Table 4). Although many students were easily able to explain the differences between gap outs and max outs, they were often unable to predict which would occur in a given situation, especially when those predictions carried implications of design flaws or failure.

### Discussion

We believe our data and analyses support our initial argument that examination of conceptual change within a single theory or discipline could miss key elements of students’ conceptual change and that an integrated approach is needed. The theme of students inappropriately grouping dissimilar phenomena, processes, or features (as with other themes not discussed in this paper) was more readily apparent in some disciplines than others. For example, students’ grouping of multiplexers and decoders in Boolean logic as opposites is stark because the terminology and function of these concepts are different and the description of the concepts as opposites would be startling to an expert. In contrast, students’ conflation of loads and stresses was not as readily apparent since an expert could easily and inappropriately infer students’ intentions to discuss loads versus stresses based on an implicit expectation that students possess the same distinctions as an expert. Identifying a theme in students’ misconceptions in one discipline can guide identification of that theme in other disciplines.

Examining data across disciplines also facilitates answering new research questions. Whereas conceptual change research within a discipline naturally begins to focus on “what is difficult?” studying data across discipline forces the research to focus on the more transformative and difficult question “why is it difficult?” While this trans-disciplinary research is only at the

doorsteps of answering this latter question, it offers deeper insights into how to pursue this question. Why do students inappropriately group dissimilar concepts? Is the grouping of words, phenomena, processes, and features an unavoidable first step of the learning process that is later followed by creating appropriate distinctions? Is this behavior the result of pedagogical choices and assumptions implicitly shared by engineering faculty? Is this behavior alternatively the mark of cognitive apprentices who are simply learning how to navigate the social and linguistic norms of a new community<sup>[16]</sup>? This new approach creates new avenues for research and a fertile new way to understand the underlying social, motivational, and cognitive dimensions of conceptual change.

## References

1. Streveler, R., T. A. Litzinger, R. L. Miller and P. S. Steif (2008). *Learning conceptual knowledge in the engineering sciences: Overview and future research directions*. Journal of Engineering Education **97**(3).
2. Brown, S. and D. Lewis (2007). *Student Understanding of Normal and Shear Stress and Deformations in axially loaded members*. ASEE Annual Conference & Exposition, Louisville, KY.
3. Brown, S., D. Montfort and K. Findley (2007a). *Development, Implementation, and Assessment of a Bending Stress Tutorial*. ASEE/IEEE Frontiers in Education Conference. Milwaukee, WI.
4. Brown, S., D. Montfort and K. Findley (2007b). *Student understanding of states of stress in mechanics of materials*. ASEE Annual Conference & Exposition. Honolulu.
5. Brown, S., D. Montfort and K. Hildreth (2008). *An investigation of student understanding of shear and bending moment diagrams*. Innovations 2008: World Innovations in Engineering Education and Research. W. Aung, J. Mecsi, J. Moscinski, I. Rouse and P. Willmot, Begell House Publishing: 81-101.
6. Montfort, D., S. Brown and D. Pollock (2009). *An investigation of students' conceptual understanding in related sophomore to graduate-level engineering and mechanics courses*. Journal of Engineering Education **98**(2).
7. Montfort, D. and S. Brown (2011). *Building fundamental engineering knowledge: Identification and classification of engineering students' preconceptions in mechanics of materials*. Annual Conference of the American Educational Research Association, New Orleans, LA.
8. Andrews, B., S. Brown, D. Montfort and M. Dixon (2010). *Student understanding of sight distance in geometric design: A beginning line of inquiry to characterize student understanding of transportation engineering*. Transportation Research Record **2199**: 1-8.
9. Davis, S., S. Brown, R. Borden and D. Montfort (In Press). *Embedded knowledge in transportation engineering: Comparisons between engineers and instructors*. ASCE Journal of Professional Issues in Engineering Education and Practice.
10. Nicholas, C., S. Brown and M. Kyte (In Press). *Evaluating the Effectiveness of Dynamic Traffic Simulations: A Case Study in Transportation Engineering Education*. ASCE Journal of Professional Issues in Engineering Education and Practice.
11. Easley, A., S. Brown, J. Adam, D. Montfort and B. VanWie (2012). *Open channel flow misconceptions and ontological categories*. ASEE/IEEE Frontiers in Education Annual Conference, Seattle, WA.
12. Goldman, K., P. Gross, C. Heeren, G. Herman, L. Kaczmarczyk, M. Loui and C. Zilles (2010). *Setting the scope of concept inventories for introductory computing subject*. ACM Transactions on Computing Education **10**(2): 1-29.
13. Herman, G., C. Zilles and M. C. Louis (2011). *How do students misunderstand number representations?* Computer Science Education **23**(3): 289-312.
14. Herman, G., M. Loui and C. Zilles (2011). *Students' misconceptions about medium-scale integrated circuits*. IEEE Transactions on Education **54**(4): 637-645.
15. Herman, G., M. Loui, L. Kaczmarczyk and C. Zilles (2012a). *Describing the what and why of students' difficulties in boolean logic*. Transactions on Computing Education **12**(1): 1-28.



16. Herman, G., R. A. Streveler, D. Montfort and S. Brown (2012b). Work in Progress: *Do students need to learn to speak "Engineering-ese?" Conceptual change as language acquisition in engineering*. IEEE/ASEE Frontiers in Education Conference, Seattle, WA
17. Herman, G., C. Zilles and M. Loui (2012). *Flip-flops in students' conceptions of state*. IEEE Transactions on Education **55**(1): 88-98.
18. Heaton, J. (2004). *Reworking qualitative data*. Thousand Oaks, CA, Sage.
19. Leech, N.L. and Onwuegbuzie, A. J. (2008) *Qualitative data analysis: A compendium of techniques and a framework for selection for school psychology research and beyond*. School Psychology Quarterly **23**(4):587-604.
20. Montfort, Herman, Brown, Streveler Matusovich, (2013). *Novice-led paired thematic analysis: A methodological approach to conceptual change in engineering*, Proceedings- American Society for Engineering Education Annual Conference and Exhibition, Atlanta, GA.