CONCEPTUAL AND EPISTEMOLOGICAL UNDERCURRENTS OF LEARNING AS A PROCESS OF CHANGE

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CONCEPTUAL AND EPISTEMOLOGICAL UNDERPINNINGS OF LEARNING AS A PROCESS OF CHANGE

Abstract

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In the preparation and education of civil engineers it is essential to both increase student knowledge of the world (conceptual understanding), but also to establish and develop new ways of thinking (epistemology). Both of these processes of change can be considered learning, but they are vastly different in the time, energy and resources they require to accomplish. The second type of learning (conceptual change) is more difficult, and is only rarely accomplished in traditional university education. The purpose of this research is to apply existing research approaches from cognitive science and educational psychology to explain why by investigating conceptual change in the contexts of student learning and faculty adoption of new pedagogies. In each context, the difficulty with conceptual change was associated with the ways in which people categorize fundamental phenomena in the world around them, and with epistemological expectations of how those categorizations should be applied in new contexts. While attempts to encourage change often focus on “educating” people by providing them with more knowledge, the change processes seem to be primarily limited by people’s existing knowledge and how it is structured. Because civil engineers interact closely with societal goals and processes (such as human safety and environmental policies), they adopt epistemological stances that are as-yet unaccounted for in most research on the subject, which assumes a strong
distinction between epistemological stances toward the physical world compared to the social world. These differences suggest that civil engineers’ conceptual change could be enhanced by more directly addressing their particular epistemological stances – which incorporate high needs for certainty in guaranteeing human safety, as well as high flexibility when being applied to human systems.
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Introduction

I. Background

In the preparation and education of civil engineers it is essential to both increase student knowledge of the world, but also to establish and develop new ways of thinking. Of the 17 criteria ABET requires civil engineering students to meet, only three refer solely to possessing knowledge (general criteria (f), (h) and (j) which require that students have “an understanding”, “broad education” and “knowledge,” respectively), while the rest specify skillful ways in which students should be able to use knowledge (ABET Accreditation Commission, 2010). Although the emphasis is clearly on applying knowledge (i.e. on ways of thinking), recent research has shown that in many scientific fields universities are much more successful at increasing students’ knowledge than in teaching them how to apply it (Hake, 1998; Streveler et al., 2004; Vosniadou, 2008).

A foundational part of most approaches to this problem is the constructivist approach to learning. Constructivism is a contemporary cultural movement that defies convenient summaries, but the aspect most relevant to this research are its emphasis on learners’ previous knowledge. In the constructivist approach, learning is a complex process where information interacts with learners’ previous knowledge (including ways of thinking, beliefs, motivations, goals and a host of other cognitive and social constructs). The outcome of this interaction is called learning when the students’ previous knowledge is altered. From this viewpoint it is slightly more intuitive that changing civil engineering students’ ways of thinking would be more difficult than simply adding to their knowledge, but this explanation just rewords the core question to “why is some of the civil engineering curricula simply added to students’ knowledge, while other aspects require fundamental changes?”
A response to this problem has been to further investigate different types of learning processes, with the particular goal of identifying and explaining why some types of learning are harder than others. This dissertation is situated in this broader problem, and applies the theoretical approaches of conceptual change and personal epistemology to progress toward solving it.

II. RELEVANT FIELDS

Two distinct theoretical approaches guided this research. A primary potential theoretical contribution of the work is the combination or relation of these approaches, as will be discussed in the Conclusions section. Although they are presented as monolithic in this section, these “approaches” are actually made up of a number of contradictory or competing theoretical frameworks for approaching their central question. The theoretical differences within fields that are deemphasized here are addressed in more detail in the papers to follow.

A) Conceptual Change

This theoretical approach addresses the mechanisms of student learning. Throughout its development, this field has always been interested in the core question of why some concepts are harder to learn than others. The characteristic approach to this question is to describe learning as a cognitive process that favors some types of learning over others. Although, increasingly, there are linkages between conceptual change theories and theories that address student motivation and epistemology, the core of this field remains focused on individual cognition.

B) Personal Epistemology

This field is focused on the question of how individuals’ beliefs about knowledge and the nature of knowing (a philosophical pursuit called “epistemology”) affect various aspects of their lives. A central branch of this field is specifically focused on the potential links between
personal epistemology and learning. A small number of researchers have proposed links between personal epistemology and conceptual change, and have primarily done so in the guise of “motivated” or “intentional” conceptual change theories. In this work, personal epistemology is typically one feature among many that are suspected to influence an individuals’ motivation to learn or undergo conceptual change.

III. Outline

This section is intended to introduce the five sections of this dissertation, and briefly suggest how each will contribute to the general theoretical contribution of this research. Additionally this section will briefly address the style and formatting differences between the sections, and the attribution of work among works with multiple authors.

A) Conceptual Change and Understanding in Mechanics of Materials

In the broader context of this dissertation, the purpose of this study is to collect and apply the theoretical approaches to conceptual change research to the discipline of civil engineering. This study reflects the iterative approach taken to the process of applying existing theories to civil engineering topics, in that the analysis was informed by theories of conceptual change, but was also expected to inform them.

This section was formatted and styled for submission to the Journal of Engineering Education. Some research in conceptual change has been published in this journal, but the theoretical discussions are usually limited and no single paper has yet addressed the potential contradictions between different theoretical approaches. Therefore, one purpose of this paper was to broadly introduce theories of conceptual change to engineering educators, and to show that those theories have important implications for engineering instruction.
Secondary authors on this paper include Shane Brown and Dean Lewis. Dr. Brown contributed most substantially to the original outlining of the project where his greater experience of the field of engineering education was helpful in better crafting the reporting of the research to the target audience. Dean Lewis contributed to the data collection by conducting interviews with students.

B) Personal Epistemology in Civil and Environmental Engineering

As a field of research personal epistemology is limited by theoretical divisions that lead to methodological challenges. Within the larger goal of the dissertation, then, the purpose of this study is to develop methods to describe and measure personal epistemology that are particularly well suited to civil engineers. This paper intends to combine and develop theories of personal epistemology by applying them rigorously to a new area, just as “Conceptual Change in Mechanics of Materials” did with theories of conceptual change. The differences between the two papers can be linked to the different states of the underlying theoretical fields they deal with: while conceptual change research has progressed for decades based primarily on the same methodological approaches and theoretical emphases (despite disagreements many conceptual change theorist agree on tracing learning difficulties to cognitive mechanisms), the field of personal epistemology does not have an agreed-upon data collection method or theoretical foundation. Additionally, although conceptual change research is broadly recognized as important in the field engineering education, personal epistemology is less generally recognized.

This section was styled and formatted for submission to the annual Frontiers in Education conference jointly hosted by two national associations of engineering educators. As a conference publication, the length limitations required less theoretical depth. Because personal
epistemology is not as widely recognized as conceptual change as an important research topic in engineering education, one intent of this publication is to increase interest in this vital area.

Secondary authors on this paper include Dawn Shinew and Shane Brown. Dr. Shinew contributed to the development of the research design through her extensive experience facing similar methodological challenges in this field. Dr. Brown similarly contributed to the methodological development, as well as by providing insights into methods best suited for a civil engineering audience.

C) Scientists Learning Policy: Four Case Studies of Doctoral Students Learning Policy-

Relevant Nitrogen Science

In the context of the broader dissertation this paper’s purpose is to begin to link the constructs of personal epistemology and conceptual change. As will be further argued in the Conclusion section, this linkage is proposed in this work as a means to further relate the cognitive and social (motivational) aspects of the guiding question. The methodological challenges in studying personal epistemology and conceptual understanding, as well as the fact that there are no established theoretical approaches linking the constructs requires an exploratory approach. This exploratory approach allowed for a further theoretical development in this dissertation: namely the connection between learning as a process of change and the role of epistemology in the interface between science and policy. This was not originally a focus of the research. but, in this case, the interactions between (1) conceptual understanding of the nitrogen cycle, (2) changes in personal epistemology and (3) conceptual understanding of public policy were so closely intertwined that an effort to explain one by necessity included reference to the other two. This theoretical linkage will be further discussed in the Conclusion section.
This paper was styled and formatted for submission to the Journal of Environmental Science and Policy. The diversity of this audience and the word limits on their submissions led to a condensed presentation of a synthesized theory of conceptual change and personal epistemology. This combination of the two theoretical frameworks guiding this dissertation will be expanded upon in the Conclusions.

D) Comparison of the Diffusions of Innovations Theory and the Concerns-Based Adoption Model in Engineering Education

In the broader context of the dissertation, this paper serves as a case study of how conceptual and epistemological features affect processes of change beyond learning. In this context the process of change is the adoption of an educational innovation. More explicit links between the findings of this paper and the frameworks of conceptual change and personal epistemology will be discussed in the Conclusion section of this dissertation.

This paper was styled and formatted for submission to the Journal of Engineering Education. Diffusion of Innovations theory and the Concerns-Based Adoption Model have already been introduced in this field, so the specific intent of the paper was to develop those introductions and to compare the two frameworks.

Secondary authors of this paper include Shane Brown and Jerine Pegg. Dr. Brown and Dr. Pegg helped with the selection and application of the adoption-specific theoretical frameworks applied in this paper, as well as providing alternative codings for use in inter-rater reliability. Dr. Pegg’s greater expertise with the Concerns-Based Adoption Model also contributed to the analysis by identifying areas of greater theoretical interest.
E) What is Cyberlearning: Practitioners’ and Experts’ Perspectives

This final paper is an additional case study of conceptual and epistemological features of change processes. This case compliments the previous one in that while the previous case studied the adoption of an existing innovation (an assessment instrument), this project instead focused on the diffusion of a less-well defined idea: cyberlearning. Again, explicit links between the findings of this paper as reported for the target audience and the theoretical frameworks of conceptual change and personal epistemology will be drawn in the Conclusions section of this dissertation.

This paper was written as a project report for an NSF Program Officer who was nominally responsible for the internship under which it was performed. One of the project participants expressed interest in reviewing the work for inclusion in a journal for which he was co-editor, and subsequently the work was also formatted for submission to the Journal of Science Education and Technology. Neither of these audiences was believed to be substantially interested in the theoretical underpinnings of the work, and therefore no explicit mention of the adoption theories guiding the work was included.

Shane Brown is the only secondary author on this paper. Dr. Brown contributed to the development and application of survey methods. He also contributed to the structuring of the report through review processes intended to help identify potentially important or broadly interested aspects in the data.
IV. REFERENCES


Conceptual Understanding and Change in Mechanics of Materials

I. INTRODUCTION

Conceptual change is a changing field characterized by important theoretical disagreements and few or mostly tacit methodological principles. In part, the field’s dynamism is due to wide recognition of its importance in achieving fundamental educational goals (Bruner 1960; Bransford, Brown et al. 2000). For example, the National Research Council has called for “identifying and addressing preconceptions by field,” because “…new learning is built on the foundation of existing knowledge and preconceived notions regarding the subject of study” (Donovan, Bransford et al. 1999). The relationship of existing knowledge to learning is a central focus of conceptual change research. One task for engineering education researchers then, is to incorporate this fundamentally constructivist approach to learning into our unique domain and contexts.

In a recent study of science education research topics (Chang, Chang et al. 2010), “conceptual change and concept mapping” research was found to be consistently the most studied topic in the last 20 years. Conceptual change research has been similarly popular in the cognitive sciences during the previous decades, and the result is a broad and challenging literature. One challenge are the differences in emphasis between science education and cognitive science researchers. Most of the research based on science education focuses on students’ understanding of fundamental concepts like acceleration (Trowbridge and McDermott 1981), heat transfer (Midkiff, Litzinger et al. 2001; Meltzer 2004), natural selection (Bishop and Anderson 1990; Anderson, Fisher et al. 2002) or geologic time (Dodick and Orion 2003; Libarkin, Anderson et al. 2005). In engineering education efforts have similarly focused on
understanding of the “foundational” concepts, as evidenced by the Foundation Coalition’s work to measure student understanding in a range of engineering disciplines (Foundation Coalition). In cognitive science, however, laboratory-based studies allow researchers to focus more on the processes of change and the cognitive mechanisms that could describe trends in student understanding. A secondary challenge is the breadth of unresolved debates in the field that leave an instructor with no clear recommendations for how to address the preconceptions and existing knowledge students bring to their classrooms.

This paper intends to build upon and organize the applications of conceptual change research to engineering by focusing exclusively on the content area of Mechanics of Materials (MoM). Additionally, this work intends to not only borrow from conceptual change research, but to feed back into it by tracing the key debates in that field through the findings about student understanding of MoM. The theoretical challenges facing engineering educators attempting to apply conceptual change research in their classrooms or research projects can only be addressed through such iterative cycles of application and readjustment of the theoretical approach.

II. BACKGROUND ON MECHANICS OF MATERIALS

Mechanics of Materials (MoM) is also frequently called Solid Mechanics (in contrast to Fluid Mechanics) and is the study of how structures bend, stretch or experience stresses when under loads. MoM is rich area for conceptual change research because it involves fundamental concepts from previous and concurrent courses as well as presenting new concepts which will be foundational to later studies. MoM is a particularly important engineering course to study because it (a) relates to many engineering disciplines; (b) covers topics fundamental to understanding the physical world; (c) addresses those topics in an organization typical to
engineering, and (d) is placed early in the engineering curriculum, often during the critical sophomore year (Seymour and Hewitt 1997).

The remainder of this paper makes frequent reference to MoM concepts. In particular this research focused on student understanding of axially loaded members and bending beams, as shown in Figure 1. There is no bending or twisting, so the member and the forces are aligned along the same dimension, which makes most analyses of axially loaded members very simple. When a member is subjected to axial loading it develops a uniform distribution of normal stress and strain, assuming that the localized effects of the load application are negligible. In other words, the normal stress and strain are the same at every point in the member. The analysis becomes more complicated when one wants to consider stresses acting in different directions. The stress element in Figure 1 shows how the stresses in any part of the member depend on the orientation of the frame of reference. There is an important distinction to be made between normal stresses (which push or pull against the flat faces of the stress elements in Figure 1) and shear stresses (which act along the edges of the stress elements). Depending on the orientation of the stress element, there are differing amounts of shear and normal stresses. Mohr’s circle is an analytical tool that represents the relationships between normal and shear stress at any orientation. One of the reasons this is important is that some materials are able to withstand certain types of stress more than others, and they can therefore fail in shear, even when under an axial load.

Bending beams, in principle, are familiar to anyone who has ever placed a board over a gap to serve as a bridge. As one walks across it, their weight makes it sag in the middle. Because the board has become an arc, the inside of the arc is now shorter and experiences compressive normal stress. The outside is longer and experiences tensile normal stresses. As
shown in Figure 1, the “sagging” of a bending beam is caused by a moment, or bending force. The downward forces on the bending beam also create internal shear forces and stresses. Both the normal and shear stresses vary along the horizontal and vertical axes of the beam. These distributions are shown schematically in Figure 1.

![Figure 1](image)

**Figure 1.** Summary of key MoM concepts relevant to this study.

### III. Literature Review

This review of the literature will first present a summarized interpretation of conceptual change research as it pertains to engineering education, followed by a more specific focus on previous research in MoM.
A. Conceptual Change Research

Conceptual change research addresses one of the central questions of the constructivist paradigm of learning. As written by Carey (an early and important theorist combining cognitive science and science education),

All good teachers have always realized that one must start ‘where the student is.’ Since the 1960s, we have come to a completely new understanding of what this means. Back then, it was defined in terms of what the student lacked… Now we understand that the main barrier to learning… is not what the student lacks, but what the student has, namely, alternative conceptual frameworks…” (Carey 2000).

Conceptual change theorists agree that learners’ previous experience with content plays a vital in their learning and must be addressed during instruction, but there is little agreement beyond that. There are three primary areas of dissention in the existing research on conceptual change that limit its application to new content in new fields (such as MoM in engineering): how concepts are related, how consistent conceptual understanding is and why conceptual understanding is important. The following sub-sections will present previous research that bears on each of these theoretical debates. In order to tie together theoretical, cognitive research with more applied, pedagogical interests, the discussion of each of these areas of dissention within conceptual change research will begin with a list of practical questions that cannot be fully answered without reference to the theoretical constructs being discussed. Note that these questions are not all intended to be addressed by research design, but are instead meant to ground the theoretical discussion in instructional matters of a more general interest.
1) How are concepts related?

- Do students have a single concept of “stress” that underlies their use of the term in multiple courses?
- Are there “natural” groupings of concepts that would make it easier for students to learn them, or particular connections that are difficult to make even if the concepts are clear?
- Is it helpful for students to recognize inconsistencies in their own explanations?

The question of how concepts are related to each other underlies a great deal of what is sometimes referred to as the “pieces versus coherence” debate (diSessa 2008). The “pieces” position argues that most conceptual change research overestimates the structure of naïve knowledge (diSessa 1993). While much research is intended to describe common or characteristic ways of thinking among students (see Vosniadou 2002 for a theoretically explicit example), diSessa (1993; 2002) argues that this approach misses the most important features of naïve conceptual understanding: its fragmentation and spontaneity. Other researchers (for example Vosniadou 1994; Chi 2008) use patterns in student difficulties to try to uncover underlying causes which can then be used to guide pedagogy. More recent work has argued for a moderate approach, questioning the completeness of assuming either complete disorganization or complete coherence in student knowledge (Ozdemir and Clark 2009; Gupta, Hammer et al. 2010).

Even among the “coherence” side of this debate, however, there is disagreement about how concepts are related. Early science education theorists emphasized the “theory-like” nature of student conceptions and drew parallels between descriptions of changes in scientific theories
(Kuhn 1996) and an individual’s process of conceptual change (Carey 1985). Later theorists have focused on the descriptions of different types of concepts (i.e. “cognitive entities” such as beliefs, experiences and mental models as well as more general “theories”) and how they interact (Strike and Posner 1985). Vosniadou (1994; Vosniadou, Vamvakoussi et al. 2008), for example, organizes cognitive entities into increasing levels of generality and abstractness where beliefs are the most concrete and specific, mental models are more abstract constructions made from connected beliefs, and more general framework theories describe how the world works in particular domains. Others focus more on the hierarchical organization structure used to sort and recall concepts and perceptions, and therefore define conceptual change in terms of how concepts would be reorganized or organizational structures would be changed (Chi and Roscoe 2002; Chi 2008). Chi’s work suggests that the most difficult and important type of conceptual change involves “ontological shifts,” which require learners to re-categorize a concept at a very high organizational level (Chi and Roscoe 2002; Chi 2005).

2) How consistent is a person’s conceptual understanding?

- Do interviews (or any other method) access the same cognitive phenomena as are used during learning, problem-solving, communicating or designing?
- How is conceptual understanding and conceptual change different in different academic disciplines?
- How different can a students’ conceptual understanding of MoM be in different situations?

At the core of this debate are questions of how contexts of different types affect conceptual change and conceptual understanding. In some ways it is closely related to the
previous argument because proponents of more structured conceptual understanding usually argue that it is also more durable than suggested by those who argue from the “pieces” perspective (for examples see Carey 2000; diSessa 2008). Some researchers, drawing on the traditions of social constructivism and situated cognition argue that the entire debate about “cognitive structures” is unproductive because it ignores the essential role of interpersonal communication in all measures and expressions of conceptual understanding (Säljö, 1999; Ivarsson, Scholtz and Säljö, 2002; Halldén, Haglund and Strömdahl, 2007). From this perspective conceptual change is described as the development of “discursive tools” (Säljö 1999). The Piagetian clinical interview is based on the idea of the interviewer encouraging the interviewee to reveal conceptual structures through reasoning aloud (Piaget 1970; Ginsburg 1997). Säljö argues for a shift of the emphasis from what is revealed (or inferred) to what is enacted. The questions researchers are investigating therefore would shift from “what do students’ know?” to “what can students explain?” This shift isn’t limited to the field of conceptual change and is part of a larger debate concerning the socially constructed nature of knowledge (see for example Lave and Wenger 1991). Regardless of individual researchers’ particular stances on this larger debate, the questions about the role of communication in conceptual understanding have significant methodological implications. Although some of the previously cited conceptual change theorists have incorporated elements of situated cognition into their approaches (diSessa 2007; Vosniadou 2007; Chi 2009), the role of situated and social cognition remains an important and divisive question in conceptual change research.

The growing sub-field of “intentional conceptual change” offers a moderate stance between laboratory-based descriptions of cognition and the entirely social cognition of Säljö’s approach. This field draws heavily on the work of Pintrich, whose impact was recently
described as a “‘warming trend’ in conceptual change” (Sinatra 2005). The argument behind this approach is that conceptual change is sufficiently difficult that it requires students to be motivated, and motivation is typically described as a social phenomenon. In order to understand this motivation (or “intention”) conceptual change research must therefore be situated in the learners’ social contexts, including engagement, personal relevance, strength of instructional argument (Dole and Sinatra 1998), efficacy beliefs (Gregoire 2003) and epistemological beliefs (Leach and Lewis 2002; Hammer and Elby 2003). Although it is not clear what affective aspects are important (Sinatra 2002), there is a rising acknowledgement of how models of cognition incorporating such elements could fill in frustrating holes in the explanatory power of the conceptual change approach.

Finally, some researchers are concerned with what could be called students’ cognitive contexts (as opposed to the social contexts discussed above). The different cognitive contexts are often called “domains” (see for example the sections on "domain-specificity" in Schnotz, Vosniadou et al. 1999; Limón and Mason 2002). As an example of the potential differences across domains, consider why it seems perfectly natural to hope to learn about nuclear fission by reading books and articles, but is less common to try to learn about forming friendships in the same way. Learners have different expectations in different domains (for example, expectations of how similar their own experience of a phenomena would be to an unknown author’s), and therefore different requirements in supporting their learning. Although it is generally assumed that the physical and social worlds are different domains (Vosniadou, Vamvakoussi et al. 2008), the exact definitions and boundaries of domains remain unclear. Many researchers instead look for differences in learning in different academic disciplines, which do not necessarily correspond to different cognitive domains. For example, in investigations comparing conceptual change in
math, history and the physical sciences, Limón has shown that the norms of an academic discipline and the ways in which students interact with it in their daily lives result in considerably different conceptual change processes and therefore require different pedagogical approaches (Limón 2002; Limón Luque 2003). In general there is little direct investigation of how understanding and change is different in different domains, although the theoretical works cited above often include diverse learning content in an attempt to draw generalizable conclusions. This question is of particular interest for STEM educators because of the prevalence of work focused on concepts from physics. Much of the theoretical work cited above draws on physics concepts, and research-based pedagogical materials designed for the entire introductory physics curriculum (McDermott 1996). It is unclear how broadly or accurately the findings from this research can be applied to learning in other disciplines.

3) Why does conceptual change matter?

- Does increased conceptual understanding correlate with increases in any skills of interest, for example those embedded in ABET criteria?
- When is conceptual understanding more valuable than memorized, algorithmic knowledge? Which is more important in the context of standards-based engineering design?

As might be expected, the possible unimportance of conceptual change as a field of inquiry is rarely addressed explicitly. Instead, this dimension of difference divides researchers based on their approaches. These divisions tend to coincide with disciplinary boundaries as well; science education researchers attribute one value to the research while cognitive scientists attribute another.
For some (mainly researchers of STEM education), conceptual change is important because of the skills it could provide to new graduates. This is an important feature in the development of concept inventories, which are fundamentally attempts to quantitatively measure conceptual understanding for research and pedagogical purposes (Foundation Coalition; Evans, Midkiff et al. 2001). The emphases in using these tools have been on the “average” student score or increase (Halloun and Hestenes 1985; Hake 1998; Krause, Decker et al. 2003; Jordan, Cardenas et al. 2005), and how those scores correlate with other skills (Steif 2003; Steif, Dollar et al. 2005; Steif and Hansen 2006; Clarke Douglas, Santiago Roman et al. 2010). From this standpoint, the capability to measure conceptual understanding is a vital element in determining its value; the ability to operationalize and define it as an objectively existing phenomenon reflects its usefulness and reality. It should be noted that while significant questions remain about the causal specifics of the links, there is a range of studies linking experts’ abilities in their fields with their conceptual understandings (Adelson 1981; Chi, Feltovich et al. 1981; Silver 1986; Koedinger and Anderson 1990).

For others (mainly those in the cognitive sciences), conceptual understanding is a layer in the understanding of the mind, and as such is inherently interesting (Margolis and Laurence 1999). Because it is situated within larger areas of study in this way, the need to define “conceptual understanding” more specifically is less pressing. The term is defined by its relationship to other fundamental constructs in cognitive science. In some approaches conceptual understanding is presented as the intermediary between perceptions and knowledge (Strike and Posner 1985; Kalekin-Fishman 1999), and Mason (2002) similarly describes it as one of the three basic layers of cognition. Through these related concepts (e.g. perceptions, cognition, knowledge) the study of conceptual understanding is closely tied to philosophical
stances on the nature of knowledge and knowing. In other words, although the exact meaning and utility of conceptual understanding is currently in flux, it will always be a construct worthy of study because it brackets phenomena that are intuitively important as a part of the understanding of the mind.

These two approaches are not mutually exclusive. The history of the field is full of examples of science educators who have made significant theoretical contributions and cognitive scientists who are concerned with teaching and education. Indeed the distinctions between the two are often fuzzy. The importance of the distinction remains, however, in how research on conceptual understanding and conceptual change is distributed and received. A theoretical investigation meant to contribute a single statement to the decades-long discussion of constructivist cognition is likely to be very different from a classroom-based study intended to lead to pedagogy with specific outcomes, although both studies might list “conceptual understanding” as a keyword.

B. Previous Educational Research in Mechanics of Materials

Research investigating student understanding of MoM concepts is sparse. An exhaustive search for any articles dealing with learning in MoM resulted in 86 articles. This literature search included specific searches of the Journal of Engineering Education, the International Journal of Engineering Education, Computer Applications in Engineering Education, the proceedings of the Frontiers in Education Conference, the proceedings of The American Society for Engineering Education Annual Conference, and general searches of the Web of Knowledge, Education FullText and ERIC EBSCO databases using the search terms “mechanics of materials,” “solid mechanics,” and “strength of materials.” The majority of the articles (78 of those 86) reporting educational research about student learning are intended for an audience of
instructors, and focus on describing practices. The remaining eight articles address student understanding of MoM concepts.

Mechanics of materials was one of the content areas targeted by the Foundation Coalition for the development of a concept inventory (Foundation Coalition; Evans, Gray et al. 2003), and two articles report on this work (Richardson, Morgan et al. 2001; Richardson, Steif et al. 2003). The concept inventory is still in development, and is currently based on the developers’ characterizations of common student difficulties (some of which can be found at http://somci.eng.ua.edu). These characterizations are extensive, but have not been collected, organized or empirically verified. Sweeney, Englund and Edwards (2007) implemented a concept inventory in order to assess teaching improvement, but it is unclear how it was developed or how it is related to the one developed by Richardson et al.

Other work relies on qualitative means to assess student understanding of the following MoM concepts: states of stress (Brown, Montfort et al. 2007), shear and moment diagrams (Brown, Montfort et al. 2008), beams in bending (Montfort, Brown et al. 2009), axially loaded members (Brown and Lewis 2010) and shear stress (Creuziger and Crone 2006). These studies found that students had consistent difficulties with the most fundamental and important concepts of MoM as identified in a recent Delphi study (Streveler, Geist et al. 2006). Students were unable to relate types of stress (i.e. normal or shear) to loading conditions or to compare the stresses at different points in a member (Brown, Montfort et al. 2007). Students expressed substantial confusion when trying to explain the relationship between loadings, internal forces and stresses (Brown, Montfort et al. 2008; Brown and Lewis 2010). Although students seemed to have more difficulty understanding shear stress (Creuziger and Crone 2006; Brown, Montfort et al. 2008), these studies also revealed substantial student difficulties relating to normal stress,
even in the simplest loading cases. Although most of these studies focus on sophomores because MoM is typically a sophomore-level course, Montfort, Brown and Pollock (2009) found that the conceptual understanding of graduate students is not significantly different than that of sophomores. CrueziGER and CRone’s (2006) investigation of student understanding of shear stress was intended to discover “Whether this difficulty [with shear stress] is due to a single fundamental difficult topic, a variety of difficult topics, or some other factor” (pg. 1). Their findings point to multiple underlying causes of difficulty, but no other work has been done to investigate causes of student difficulties across content areas in MoM.

There is some work in closely related fields that may bear on understanding of MoM concepts. Krause’s work on student misconceptions in Materials Science generally supports the findings cited in the previous paragraph by highlighting the difficulties students have in understanding the implications of materials’ internal structures (Krause, Decker et al. 2003; Krause, Decker et al. 2003; Krause, Birk et al. 2004; Krause, Tasooji et al. 2004; Krause, Tasooji et al. 2004; Kelly, Corkins et al. 2009). Kitto’s (2007; 2008) studies of students’ writing about materials shows that students often fail to differentiate between similar terms such as “strength” and “stiffness,” regardless of the important theoretical differences. Roylance, Jenkins and Dieter (1999) highlighted the connections between MoM and materials science, and argue that MoM education would be substantially improved by the inclusion of more materials science concepts. Steif’s work in Statics (Dollar and Steif 2002; Steif 2002; Steif 2003; Steif and Dollar 2003; Steif, Lobue et al. 2010) suggests that students have fundamental difficulties combining vector notation with a meaningful understanding of the actual interactions it is intended to represent. In particular, Steif notes that emphasizing the role of “bodies” in statics (i.e. the actual objects that are in physical contact) seems to improve the development of conceptual understanding (Steif,
These difficulties may play a role in students’ confusion about how external loads relate to internal forces and stresses.

Finally, although Streveler’s work investigating conceptual understanding in engineering does not explicitly include MoM concepts, her findings and theoretical developments have relevance across the engineering curriculum. One line of this work is explicitly based on Chi’s approach to conceptual change, and has investigated the importance of “emergent processes” in engineering (Streveler, Nelson et al. 2004; Streveler, Geist et al. 2006; Yang, Santiago Roman et al. 2010). In her work investigating ontological shifts, Chi has found that many challenging concepts relate to the ontological category of “emergent processes.” Emergent processes are those which have observable outcomes determined by unobservable, undirected interactions (Chi 1992). Students often base their understanding of emergent processes (such as heat transfer or electricity) on substance-based direct process models (such as fluid flow) (Reiner, Slotta et al. 2000; Chi 2005; Streveler, Geist et al. 2006). Streveler’s work has identified important emergent processes underlying student understanding in thermodynamics, fluid mechanics and electrical circuits. Figure 2 below summarizes the relevant findings presented in this literature review.
Figure 2. Summary of relevant findings from literature review

C. Summary of the Need for Conceptual Change Research in Mechanics of Materials

In Carey’s words, educators need to know “where the student is” in order to achieve learning objectives. Although there is an existing research base introducing students’ understandings of MoM concepts and effective teaching practices, it remains disjointed and incomplete due to a lack of common theoretical reference points. Furthermore, this knowledge base remains distances from practical application by the same lack of theoretical grounding. A large body of effective practices may exist, but will remain untapped until they can be integrated into an organizing structure such as the one provided by theories of conceptual change and understanding. If conceptual change theorists and researchers cannot even agree on definitions of the field (indeed there are passionate disagreements about the meaning both the word
“concept” and the word “change” in this context), it may not be immediately clear how their work can improve the teaching and learning of MoM. However, disagreements and uncertainty are only harmful to inquiry when they are unrecognized or ignored. The disunity of conceptual change research can aid the study of student understanding of MoM most of all by helping to identify all of the assumptions underlying such a research endeavor. Forty years of debate may not guarantee any clear winners, but it does cause the few points of agreement to become all the more significant for their rarity. Two of these rare points of agreement are that students bring their own understandings to learning, and that these understandings and the ways they interact with the learning process are different in different domains. There is a need for research investigating how students understand MoM concepts, and in order for this research to be effective it must be carefully positioned in the existing theories of conceptual change and understanding.

IV. PURPOSE AND RESEARCH QUESTIONS

The purpose of this study is to use previous conceptual change research to inform the study of how students understand mechanics of materials, and to use current and previous findings about student understanding of mechanics of materials to inform conceptual change research. These purposes will be addressed by answering the following research questions:

1. How do students understand the core concepts of mechanics of materials?

2. How do the features of their understanding relate to previous findings and existing theories of conceptual change?
V. METHODS

The purposes of this study require a methodology that describes students’ understandings meaningfully without limiting the potential of the data to provide insight into the theoretical divisions characterizing conceptual change research. As diSessa (2004) writes, “… it is possible that different results are more the result of asking different questions, in different ways, of different subjects.” The research design therefore emphasized triangulation. Two distinct constellations of concepts were investigated in different contexts, using different resources, with different students and in different applications. The data collection progressed in phases in which a particular interviewer would interview a group of students using a particular interview design. The four general phases of this research are summarized in Table 1.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Interview Content</th>
<th>Emphasis</th>
<th>Number of Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bending Beams</td>
<td>Construction of shear and moment diagrams</td>
<td>24</td>
</tr>
<tr>
<td>2</td>
<td>Bending Beams, Axially Loaded Members</td>
<td>Understanding of normal stress</td>
<td>21</td>
</tr>
<tr>
<td>3</td>
<td>Bending Beams</td>
<td>Relation of external forces and internal reactions</td>
<td>31</td>
</tr>
<tr>
<td>4</td>
<td>Axially Loaded Members</td>
<td>Relation of external forces and internal reactions</td>
<td>49</td>
</tr>
<tr>
<td></td>
<td><strong>Total Number of Students</strong></td>
<td></td>
<td><strong>126</strong></td>
</tr>
</tbody>
</table>

Table 1. The five phases of data collection included in this research.

The remainder of this Methods section will focus on the overarching design of this research as a single study and therefore deemphasize the differences between the phases described in Table 1 unless those differences are theoretically or methodologically important. The section will end with a brief discussion of how the design of this study is based on and related to the conceptual change theories described in the literature review.
A. Sample Selection

The students in this study were chosen to allow for generalizations by including groups that are likely to be different. This approach, called “maximum variation sampling” (Patton 2002) supports the identification of meaningful trends because any patterns found that apply to this intentionally homogenous sample are likely to apply to a more general population. The students in these samples ranged from sophomores to graduate students, and had consequently varied coursework on related concepts. Some students were in the process of their first exposure to these concepts in a Mechanics of Materials course, while others had since taken up to four closely related courses and were involved in related research. All of the interviewees, however, had covered their interview’s content in class (including lecture, homework and exams) prior to being interviewed. Students were drawn from two public universities of approximately 25,000 and 12,000 undergraduates, a private university of 5000 undergraduates, and a community college of 6000 undergraduates. Finally, with the help of course instructors, participants were chosen from a range of academic grades.

B. Selection of Content Areas

Axially-loaded members and bending beams were chosen as the content for this study because of their centrality and ostensible simplicity, as well as based on the results of previous research and pilot studies. Because all of the external loads and primary internal reactions occur in the same dimension, axially-loaded members are often used as the simplest possible example of stress in MoM (Hibbeler 2002). Student understanding of this topic, then, represents an important indication of the range of their understanding of other topics. The topic of bending beams was chosen because students exhibited a number of surprising difficulties during pilot
interviews around this topic. The fact that the primary stresses and internal forces act in a
different direction than the external load provides more complicated context within which to
examine student conceptual understanding. These topic areas cover most of the central concepts
of MoM, provide multiple perspectives on student understanding of the relationship between
external loading and internal reactions, and introduces a minimum of extraneous conceptual
content.

C. Interview Methodology

Data was collected on student understanding through artifact-based clinical interviewing.
Similar interviews have been used throughout the history of conceptual change research as the
primary means of accessing student understandings (Piaget 1963; McDermott and Shaffer 1992).
The purpose is to provide students with a context in which to solve problems while thinking
aloud or explaining their methods. Later, careful analysis of recorded student utterances and
work reveals students’ reasoning, beliefs and assumptions (Ginsburg 1997).

The context, type of problem, resources available and the interviewer themselves can
affect the ways in which students express their conceptual understanding (Ivarsson, Scholtz et
al. 2002; diSessa 2007). In order to minimize or at least expose these effects, this research
design incorporated multiple contexts, problem types, resources and interviewers. Table 2
summarizes the various approaches used in this study. Each item will be explained in more
detail in the following sub-sections.
As shown in Table 2 the interviews included four types of tasks: ranking tasks, explanations, predictions and calculations. Ranking tasks provide a comfortable intermediate between calculations and open-ended reasoning (O'Kuma, Maloney et al. 2003; Brown and Poor
Students were presented with a diagram representing a loading situation, and asked to rank various characteristics. For example, in these studies, students were often presented with a beam like the one shown in Figure 3, and asked to rank the magnitude of the normal stress that would develop at each point.

![Diagram](image)

**Figure 3.** Ranking task in which students were asked to rank the normal stress at each point

Students were frequently asked to explain phenomena. For example, students were presented with an axially loaded member and asked to “describe the stresses that are present.” Similarly, students were asked to predict behavior, for example how the stresses would change if the loadings changed. The distinction between these two terms is important in this work because the term “prediction” is reserved for observable phenomena such as deformation or failure, while “explanation” can apply to unobservable or intangible phenomena such as stress or strain. Students’ explanations and predictions are highly mediated by their mental models of a phenomenon (Vosniadou 2007), and therefore provide a useful means to investigate how
students relate and utilize concepts. Students were also asked to perform calculations while explaining their reasoning out loud. This primarily took the form of asking students to construct shear and moment diagrams, but in some cases students also chose to approach ranking tasks through calculations.

2) Representations

Two general types of representations were provided to students during the interviews: physical demonstrations and schematic diagrams. In the interviews concerning axially loaded members, students were asked to stretch a small square of rubber (a physical representation of a member) and discuss the stresses and strains developing. Some interview tasks were conducted without any reference to a specific representation or object. For example, at the beginning of many of the interviews students were asked to provide their own definitions of key concepts such as normal stress and strain. The remainder of the interviews questions referred to diagrams on interview packets such as the one shown in Figure 3. Some of these represented only two-dimensions, as in Figure 3, while others depicted three-dimensional phenomena (Figure 4). Finally, in interviews about axially loaded members students were presented with pictures of compressive testing of concrete cylinders, as shown in Figure 5.
Figure 4. An example of a diagram used in interviews representing three-dimensional phenomena
Figure 5. Representation of a concrete cylinder that has failed due to shear forces caused by compression, as presented to interview participants.
D. Analyses

The primary form of analysis in this research was thematic qualitative analysis (Braun and Clarke 2006). This approach to analysis is the basis of much qualitative research (Maykut 1994; Leydens, Moskal et al. 2004; Maxwell 2005; Creswell 2007), and is very common in interview-based studies of conceptual change (Trowbridge and McDermott 1981; Streveler, Nelson et al. 2004; Kautz, Heron et al. 2005; diSessa 2007). The first step in this analysis, called “classifying” (Patton 2002) or “pattern coding” (Miles and Huberman 1994), involves labeling sections of text based on their content. In this case this meant labeling students’ utterances based on the concepts referred to, and grouping them based on the task and representation which elicited them. For example, at this stage a grouping was created for all student references to “Poisson’s ratio” made when they were stretching the rubber square. The students’ written work, including drawings, were also organized in this manner. Next, these student utterances were compared to experts’ understandings of the concepts to identify common areas of student difficulties. This stage of analysis provided some of the more basic findings through the use of comparative matrices (Miles and Huberman 1994). Table 3 shows a small excerpt from one such matrix (the full matrix is 50 by 18 cells) which supported results reporting the prevalence of students’ abilities to correctly use Mohr’s circle.

<table>
<thead>
<tr>
<th>Student</th>
<th>Correctly drew diagonal stress element (Question 4)</th>
<th>Correctly drew shear stress distribution</th>
<th>Correctly drew Mohr’s circle (Question 7)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
As shown in Table 3, these matrices did not lend themselves to nuanced analysis of students’ reasoning. Instead, these labels and groupings were used to build interpretations about the relationships between students’ discussions of specific concepts. In this stage the student statements in potentially related groupings were compared to test the strength of the proposed relationship. For example, Table 3 might suggest that incorrectly drawing a diagonal stress element without normal stress is related to incorrectly drawing the shear stress distribution. The next stage involves testing the proposed relationships with the actual student statements that were represented by their labels in the matrices. In other words, the phrases “no-wrong normal stress” and “no shear” in Table 3 are connected to actual student statements, and it was these statements that were compared to test the strength and relevance of any relationships suggested by the matrices. This reliance on the actual recorded data throughout increasingly interpretive layers of analysis is called the constant comparative method, and is a cornerstone of rigorous qualitative analysis (Maykut 1994).

E. Relationship to Literature Review

The primary methodological considerations raised in the literature review were the following: (1) context affects student understanding; (2) the relationship between student

<table>
<thead>
<tr>
<th>#</th>
<th>Question 4</th>
<th>(Question 4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>yes</td>
<td>unable</td>
</tr>
<tr>
<td>02</td>
<td>no-wrong normal stress</td>
<td>no shear</td>
</tr>
<tr>
<td>03</td>
<td>no-wrong normal stress &amp; no shear</td>
<td>no shear</td>
</tr>
<tr>
<td>04</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>05</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>06</td>
<td>no-wrong normal stress</td>
<td>no-unable</td>
</tr>
<tr>
<td>07</td>
<td>no-wrong normal stress</td>
<td>no-equation</td>
</tr>
</tbody>
</table>

Table 3. An excerpt from a comparative matrix used in early stages of analysis
communication abilities and conceptual understanding is uncertain; and (3) because interviews are social interactions, student statements are affected by the interviewer in various and complex ways. The first concern was directly addressed by investigating student understanding of a small set of concepts in multiple contexts. The second and third concerns were taken as limitations of the study and addressed indirectly two primary ways. First, the emphasis of all data collection and analysis was on establishing the means for triangulation of findings to minimize the potential effects of misinterpreting student statements. Secondly, distinctions were made in the analysis and the reporting of the results between what students actually did and said during the interviews and their inferred conceptual understandings.

VI. RESULTS

As described above, the purposes of this research are to describe student reasoning and compare it to theoretical explanations of conceptual change and understanding. These two purposes are covered in the Results and Discussion sections, respectively. This section will present the broad trends in student difficulties. It does not describe every student’s conceptual understanding. More detailed accounts based on this data have been published by the authors elsewhere, or are part of an unpublished thesis which will be published soon. The examples and student quotes presented were chosen both for their representativeness of the larger trend and for their clarity. Many students, for example, may express a belief with a sketch and a statement like “it goes this way.” Although this form of expression is more common, a student who expresses the same belief more explicitly through verbalizations (e.g. “the stress will be primarily vertical”) would be quoted here. Pronouns referring to student gender do not relate to the actual students quoted, but have been chosen so that they alternate.
A. General Summary

Previous findings describing student understanding of MoM concepts were supported here. Less than 10% of the students interviewed consistently identified the types of stresses that would be present in axially loaded or bending beams. This figure stands in stark contrast to the approximately 30% of students who correctly drew Mohr’s circle for an element under axial loading, or the 40% who were able to correctly construct shear and moment diagrams (although not all of these students could productively interpret the figures they created). Stress transformations using Mohr’s circle were often cited during the interviews as being “harder” than the other questions, which were referred to as “the basics” or “fundamental stuff.” This again supports the now familiar trend in conceptual change research where students’ computational abilities far outstrip their conceptual understanding (Hake 1998; Steif 2003), but with the added facet of the students’ own awareness of at least some element of this disparity. Students were often uncomfortable when confused by the “fundamental stuff,” but were more relaxed when they encountered difficulties with Mohr’s circle. When asked about his confidence in his understanding after the interview, for example, one student said “When we were learning, it was a lot of equations and sometimes I think we miss out [on] getting the broader picture. Even though they throw a bunch of equations at us, it’s like ‘oh you memorize the equations and you’ll be fine for the tests,’ but when you actually ask us about it, I feel that [we] don’t understand as much.”

Because the overarching interest behind this research is in addressing areas of student difficulty, the emphasis here is squarely on what students did not know, or could not do. Areas of student competence are therefore minimized except in the role they play in further
illuminating students’ difficulties. This emphasis will be addressed in the Conclusion as a potential direction for future research.

B. Axially Loaded Members

Students had the most consistent and pertinent difficulties in the following three contexts: distributions of stresses, visualization of stresses, Poisson’s effect, and stress elements. These difficulties are most interesting in light of the areas of common student ability. Although only a small number of students could consistently and accurately describe the stresses that develop in a given loading situation, most students were comfortable describing and calculating the normal stresses and strains that would develop. Nearly all the students were confident and adept at performing equilibrium analyses to determine the internal reactions to an external load. It was mainly after these analyses that students encountered difficulties. The relationships between what students’ understood and what they did not will be discussed in more detail in the Discussion section.

1) Distributions of Stresses

Only seven of 49 students asked were able to correctly draw or describe the shear stresses that would develop on an angled plane in an axially loaded member, compared to 27 of 49 students who could correctly draw or explain the normal stresses. In many cases this difficulties seemed related to assertions that stress was “force over area,” because students were often unable to identify an area over which to consider the force. About the same number of students (approximately 7 of the 49 students asked) could not even begin to describe the distribution due to confusion over the concept of shear stress itself. These student responses were often particularly abrupt and lacked the usual impulse to “explain around a question” that was
characteristic of student explanations in most other contexts. One student, for example, when asked about shear stresses on an angled plane in an axially loaded member said, “I dunno know what shear would look like, but there’s a shear force.” Some of these students simply refused to discuss shear stress, although it is not completely clear why. When asked how he would calculate shear stress, for example, one student repeated his explanation of how to calculate normal stresses. When asked again he repeated the explanation, and when asked a third time to explain how to find “each type of stress,” he said, “Yeah, we do normal stress, P/A and then yeah also I think…So that one to figure out the normal stress.”

Students often overestimated the importance and influence of point loads. This tendency held despite the way these localized stresses and deformations are broadly ignored in most MoM courses and texts, and despite encouragements from the interviewers to “ignore those localized effects,” or “assume everything is evenly distributed.” One line of questioning was specifically designed to discourage students from discussing these effects by (1) verbally telling students to treat point loads as distributed forces and to ignore localized deformations or stresses, and (2) representing one of the external loads as a distributed load (see Figure 6). Even in this case a small number of students described the normal stress distributions as being affected by the point loads. Figure 6 shows both the problem as presented to students, and one students’ drawing of the normal stress distribution. Interestingly, most of the students from the private university drew the distribution of normal stresses as a single arrow, despite describing it as “evenly distributed.” This contradiction was not probed during the interviews and it is not clear how these students understood the distribution of normal stresses.
Figure 6. Representation intended to minimize student attention to localized effects of point loads, and one student’s sketch of the distribution of normal stresses.

In explaining the failure of the concrete cylinder in compression, many students implied a “stress concentration” model by explaining the failure in terms of reasons that the failure region would be weaker or experience higher stresses than the rest of the member. When asked, “why do you think this specimen failed in this manner,” one student said

Student: Well...they could have put something in the specimen to just slightly weaken it on that plane. Uhm. Perhaps maybe, like, very small
pieces of string or something. Uhm. It could have also induced a strain in that direction uhm by weakening the sample before stress testing it. Orrrrr. Uhm. Just the nature of the material and how they, uh, produced it, may have caused that.

Despite the focus of the interviews on stresses and stress distributions, most students used similar reasoning to focus on microscopic phenomena that would result in stress concentrations to describe failure.

2) Visualizing Shear

In response to follow up questions about the failure of the cylinder, the student quoted above reasoned,

**Interviewer:** Okay, and so what stresses do you think caused this failure?

**Student:** Uhm, well, mainly the shear stresses.

**Interviewer:** Okay, and why's that.

**Student:** Uhm. Well because you can see this plane here and if you imagine, I'll draw it over here, this plane here, and if you imagine another plane here from the other piece of the specimen, and the force is pushing down here and the force is pushing up here, uh, there's gonna be, uhm...a lot of shear force here, opposing each other as well as normal forces to that plane.

**Interviewer:** Okay. So is it the shear force of the normal force that caused that failure?
Student: Well. Both of them participated but I would say the shear force because of the direction of the element.

This students’ reasoning is particularly interesting because it is an example of how many students attempted to connect their knowledge (the student quoted in the example was comfortable with stress transformations and the presence of stress in axially loaded members) with visualizations of the physical processes being represented. This student had previously clearly explained the relationship of normal and shear stresses in a beam, and generally relies on that understanding to answer the questions here. It is only when visualizing the failure plane (“…see this plane here and if you imagine..”) that the student is confused about the role or normal stresses.

Although it is not an axially loaded member, student reasoning about the member shown in Figure 7 was particularly revealing of the ways in which students relied on visualization to analyze shear. One student reasoned, “Obviously you have a cross-section at each point. It will be the same. But. The force is what’s gonna be different. Uhm. Oh shoot. So on this one you’re gonna have a component of the force over one area, so like…the part that’s pulling down would act over one area and then…the force pulling out would act over a different area.” By trying to combine his definition of stress as “force over area” and his knowledge that normal and shear stress would be acting, this student visualized different areas resisting the forces. These examples are somewhat rare in that only a few students expressed high understanding in any context. Students with other conceptual difficulties also struggled with visualizing shear stress, but the importance of the visualizations was less apparent against the backdrop of their other conceptual difficulties.
Finally, students who struggled with stress transformations used a range of explanations for how the shear stresses would change as a stress element was rotated in an axially loaded member. While more proficient students talked about shear “going to zero,” confused students said it would “disappear” or “go away.” Similarly, some students reasoned about shear as a component of the normal forces that “go along the sides” of the stress element, or are “running on each side of the square taken out of the member.” This reasoning often confused students as they were trying to compare the magnitudes of shear stresses on horizontal and angled elements, as they discussed different ways the shear might “pull along the edges.”

3) Poisson’s Effect

As described above, when most materials are stretched they also shrink in the direction perpendicular to the elongation due to what is called Poisson’s effect (see Figure 1). In one line of reasoning, students were encouraged to note those deformations (by being asked to describe deformations in the “horizontal and vertical dimensions”) before being asked about stresses present on an element in the middle of the member. A small but significant portion of students

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**Figure 7.** A vertically cantilevered bending beam presented to students during interviews.
included vertical compressive stresses in their reasoning and justified them based on the observed deformations. They consistently returned to including the vertical stresses based on the presence of the vertical deformations, despite obvious discomfort with the idea of the vertical forces. After drawing vertical stresses on a stress element, for example, one student said “I don’t know if that’s right, but since it’s elongating its gonna be getting [trailing off] skinnier…vertically. I don’t know.” Another student said, “Well because there is strain and elongation then there will be shear stresses in the vertical direction because of the decrease in diameter.” When asked, “For strain does there have to be a stress,” the student responded, “Um. Yes. Well…just thinking back to…Strain in the longitudinal direction is going to be caused by either 1) a change in length, which has to come from an applied force, or 2) it will come from a change in temperature, which, when its fixed on both sides and uh, there'll still be a strain inside of it. [correcting himself] Or there will still be a stress inside of it.” This quote is particularly enlightening because thermal expansion due to a “change in temperature” is another case where strain can occur without stress. Stress can be generated, however, if the member is not allowed to expand (if it is “fixed on both sides”). It is exactly this lack of constraint that explains why Poisson’s effect does not involve stresses. More than any other student, this student approached the correct explanation of this phenomena. A small error in reasoning, however (apparently assuming that the axially loaded member was constrained in some way), confirmed the student’s strong intuition that strain must be caused by stress in the same direction, and therefore this line of reasoning was concluded.

4) Stress Elements

The outstanding feature of students’ understanding of the concepts involved in stress elements is the lack of interrelatedness. Students —whether they were successful at completing
the tasks or not – reasoned about stress elements without reference to related concepts. This lack of relationship worked both ways – students failed to use related understanding to help them explain stress elements as well as failed to use their understanding of stress elements to help them explain related phenomena. In the course of their interview, students deal with stress elements in four ways: as a horizontal stress element, an angled stress element, in the construction of Mohr’s circle, and when describing the failure of the concrete cylinders. Figure 8 below summarizes one interpretation of the related concepts students were asked about in the interviews. The important point of this figure is that any aspect could be used to help explain any other. Mohr’s circle could be used to help draw the forces on horizontal stress elements, for example, or knowledge of horizontal stress elements could used to help in the construction of Mohr’s circle.

![Figure 8. Relationship of concepts related to stress elements.](image-url)
For comparison, Figure 9 below shows the relationships between students’ uses of the concepts. A bold arrow indicates that most students (more than 75%) who were able to accurately explain one situation (at the source of the arrow) were also able to describe another (at the point of the arrow). The gray arrows represent the same type of relationship, but one that is weaker (around 50%). The relationships pointing toward “shear failure of a concrete cylinder” can largely be explained by the fact that most students demonstrated understanding in that area, so, logically, most of the students in any sub-group would also have had that understanding.

That leaves a somewhat counterintuitive constellation of relationships in which describing a horizontal stress element is more closely linked to being able to construct Mohr’s circle than describing an angled stress element. This is counterintuitive because horizontal stress elements can be (and often were) drawn correctly using overly simplistic reasoning; one student for example assumed that the stresses on the stress element would always be the same as the loading on the member. Correctly identifying and drawing the stresses on an angled stress element, however, would be expected to coincide with greater understanding of the relationship between normal stress, shear stress and orientation of the a stress element, and it is this relationship that defines Mohr’s circle.
This lack of interrelatedness can be summarized in a different way by saying that students did not seem to understand the purpose of stress elements. Part of their proficiency with equilibrium of forces was the recognition that “making a cut in a member” and calculating internal forces was a broadly useful analytical tool. The fact that most students did not use equilibrium-based reasoning in the context of stress elements suggests that they did not see them in the same light as an analytical tool. In support of this finding is the fact that many students’ analyses of stress elements contradicted their other reasoning, but was not questioned. Several students, for example, who defined normal stress quite accurately with reference to it acting “perpendicular to a face,” drew normal stress on an angled element as shown in Figure 10. Similarly, many students who explained that the concrete cylinder failed in shear did not draw shear on any stress elements during the interviews. Interestingly, 37 of the 49 students described the failure of the concrete cylinder as being caused by shear. Even students who had denied the
presence of shear stress throughout their interviews made this connection, and some even related it to the 45 degree angle and the “maximum shear.” In other words, some students who seemed otherwise unaware that shear stress even existed in the member were able to reach conclusions based on the relationship between shear and normal stresses, or at least remember those conclusions more easily than they could remember the existence of the phenomena that support them. This implies a fundamental disconnect between students’ reasoning about stress elements and other concepts.

![Diagram of normal stresses on an angled stress element](image)

**Figure 10.** A student’s representation of normal stresses on an angled stress element.

### C. Bending Beams

Three patterns of student understanding of bending beams are particularly prevalent: their difficulties with point loads, their tendency to not associate bending with normal stress, and their difficulties visualizing distributions. As in the context of axially loaded members, these patterns are emphasized by the students’ areas of high ability. Many students were able to construct important diagrams, and all students could draw the deformed shape of a beam under a point load.
1) **Point Loads**

In the construction of shear and moment diagrams, students were often confused about how to incorporate the beam’s supports, which act as point loads and moments applied at a point. Even though students generally approached these diagrams with an idiosyncratic set of memorized relationships, the affects of point loads at supports were consistently not included in that set. After rapidly running through an algorithm for constructing shear and moment diagrams, one student was asked to clarify his reasoning about what the diagrams show at the ends of the beams, where the supports are. He said,

**Student:** Every time we start from zero. I don’t know how, but somehow it works. Then we drop straight down and we have another area. On this we one I am pretty sure, but on this one I have doubts.

**Interviewer:** What are your doubts?

**Student:** My doubts are two things, where I started from, where I ended is always right because it should be on zero, but where to start from and was I right on the areas, or not. But, where to start from is my question.

This student’s “doubts” were commonly repeated by other students, as well as the purely process-based approach and terminology (i.e. saying “we start from zero” instead of referring to the actual effects of the supports as point loads on the values being diagramed).

When asked to compare the normal stresses developed on a bending beam in a ranking task like the one shown in Figure 3, more than half of the students based their ranking on distance from the point load: “Uhm, I’m gonna say the one that’s farthest away is gonna be the least. [Interviewer: Farthest away from…?] From the, the point load, P… Because it, at the point load P it seems like it should be the max…cuz this is… it’s gonna be really deformed.”
Although some students, like the one quoted, were not very confident in this reasoning (relating closely to their understanding of normal stress in bending as discussed in the next section), it was by far the most common method for completing the ranking.

2) Normal Stress Due to Bending

In some contexts, many students reasoned that beams in bending did not experience normal stress because the direction of the load. This seemed to be supported in part by their definitions of normal stress, which depended on concepts of direction. One student said, for example, “I would say normal stress would be like an axial force, but it’s not force. It’s force over area or something,” or “It's the stress that basically the distribution of force over area and force is normal to the surface or perpendicular to it.” These definitions didn’t apply cleanly to bending beams, and one student was able to articulate his confusion, highlighting the importance of direction in students’ reasoning about normal stresses. He said, “I guess I'm just confused about what it [normal stress] is. I thought- I'm just not sure if normal stress corresponds to the axial load, axial stress. Because everything we've been doing looks just going up and down but like I know we've done stuff like this and you get pulling stuff like that [indicating axially]. And that's what we were talking about. I'm just confused about it as a concept right now.”

In almost every case, however, this reasoning was contradicted by students’ understandings of deflection or internal moment. For example, the majority of students asked about a beam’s deflection drew the beam’s deflected shape and noted that the top of the beam experienced compression and the bottom experienced tension. For example, one student reasoned the following:
**Student:** Given a stress distribution of the bending moment, the top of the beam’s going to be in compression and the bottom’s going to be in tension. […]

**Interviewer:** All right. And then go ahead and rank the points based on their magnitude of normal stress.

**Student:** Believe they will all be equal…I’m pretty sure that they’re all zero because there’s no normal force along the beam.

Although few students contradicted themselves as immediately as the quoted student, a more dispersed form of this reasoning was still a very common trend in the data.

When asked first about moment and equations for normal stress, however, many students could be led to describe the normal stresses in a beam due to bending. For example, consider the following exchanges with one student (these questions all occurred with five minutes of each other):

**Interviewer:** how would you define bending moment?

**Student:** Bending Moment. It’s one of the internal forces that causes the beam to bend.

[…]

**Interviewer:** Okay, and how would you define normal stress?

**Student:** Normal stress is the internal force in the beam caused by loading that is perpendicular to the cut.

**Interviewer:** Okay and any equations or computations for that?
**Student:** I think all we’ve had to work with is the average normal stress. Which is the normal force over the surface area of the cut. The other one is stress caused by bending moment.

[…]

**Interviewer:** And then go ahead and describe the normal stresses in the beam and where they would be maximum and minimum.

**Student:** Uhm, the normal stresses, there wouldn't be any since there’s no horizontal loading on the beam.

[…]

**Interviewer:** Go ahead and rank the points based on their magnitude of normal stress?

**Student:** Normal stress? You have the bending moment there, so the stress distribution of normal stress is like this. And the bending moment's down, causing the top to be in tension. Bottom is in compression. So, from positive to negative values, A would be the greatest, and just A, B, C, D, E. A being the greatest, C being zero E being equal to A but negative.

This student clearly linked bending with moments, and moments with normal stress. Even after drawing the shear and moment diagram for the beam presented, however, he still reasoned that there were no normal stresses in the beam. A few minutes later, however, when presented with a beam under a distributed load instead of a point load, he was able to quickly and confidently use his moment diagram and knowledge of the vertical distribution of normal stresses to rank the points on the figure.
Familiarity with the pertinent equation didn’t necessarily correlate with understanding the relationship between normal stress and bending. In the following reasoning, for example, the student deduces the presence of normal stresses due to moment at a cross-section, but does not relate the distribution of moments (which he’d successfully described in a previous example) to the distribution of normal stresses along the length of the beam.

**Student:** Since I define normal stress kind of like applied along the beam, I don’t see any normal forces on there. Like my initial thought of normal stress is like a axial load.

**Interviewer:** Is there any other types of normal stress that you can think of?

**Student:** Well, I guess line-- if you cut the beam then there's-- because of the moment there’d be a force applied on that plane. So it'd be at the very top and bottom of the beam. […]

**Interviewer:** Okay, okay. And so how do the normal stresses change as you go from either end of the beam from support to the middle back to the support?

**Student:** I remember it kind of-- it's not as straight and regular as that and evenly distributed. But we haven’t really been specifically taught that it'd be more curved I think.

Similarly, one student, when unable to explain what caused normal stresses in bending beams, said with some exasperation that he’d be able to calculate the deflections, draw shear and moment diagrams and identify where the beam was in compression. The interviewer then asked, “So which of those relates most strongly to the normal stress here [pointing to the part of the
beam the student had identified as being in compression]?” The student responded, “The shear. [Interviewer: Why’s that?] Well. Because it gives you the loading at each point in the beam in kips or pounds or Newtons or whatever you’re working in. Whereas the moment would be, uh...the force times the length. So it’d be kip-feet or kip-inches. And that wouldn’t be very helpful in determining the normal stress.” This students’ reliance on a computational approach led to the mistaken assertion that moment is related to shear instead of normal stress. Finally, recalling or not recalling the pertinent equation for normal stress due to bending didn’t seem to relate very strongly with understanding normal stress due to bending because significant numbers of students both understood the phenomena without reference to the equations and recalled the equations without understanding the phenomena.

3) Visualizing Stresses

Students had difficulty visualizing the stresses in bending beams in two distinct ways. First, the presentation of some interview questions involved a three-dimensional representation of a beams’ cross-section with an internal loading applied. The second case was when students attempted to relate their visualization of axially loaded members to the context of bending beams.

Students were introduced the figure and it was explained with a statement like, “Now what we’re trying to represent is a beam that’s been cut and the only forces that we are showing are just the moment acting about the X axis at this cross-face.” Some represented internal moments (without reference to a bending load) and others represented internal shear forces. Some students struggled particularly with distinguishing between true relationships and familiar coincidences. One student, for example, reasoned that moment caused shear forces in one instance, and that shear forces cause moments in another (although neither shear forces nor
moments were related to any types of stress). The most common difficulties were simply applying familiar analytical techniques to a “distribution.”

There were two places where these distributions derailed students’ reasoning – regardless of how capable they were in more familiar representations. First, students struggled with the problem presentation starting with the internal force or reaction instead of the external load. Many were not able to skip this step, and would attempt to relate the internal loading given to another internal load as a parallel to the analysis of relating an external loading to the internal loads. One student, for example, related the applied internal moment to shear force, and later related an applied internal shear force to internal moment. The second place these representations interfered with student reasoning was in their ability to distribute internal forces and stresses. Many students seemed to hold simultaneous, contradictory models of how the stresses and forces would be distributed: one similar to their previous reasoning, for example that normal stresses are compressive on the inside of a bending beam and tensile on the outside, and the other based on visualizations of how the forces or stresses would “smear” across the cross-section. The second model usually assumed even distributions, and students often went back and forth between the two models without being able to reach a conclusion.

A few students seemed to revert to models of axially loaded member when trying to visualize bending beams. One student, for example, when asked “So what causes normal stresses in the bending beam?” responded “I’m still stuck on that idea of the plane. That it’s caused on, and that it would bend.” The interviewer asked, “is that plane idea from the first problem [which represented a plane of interest and asked students to predict the stresses acting on it] or is it something that you usually carry with you?” and the student replied, “It’s something I usually carry with me when someone ever mentions the word stress. I think about planes.
Uhm…but if I were to do that in this problem…it would be bad.” At this point, the student attempts to abandon this reasoning and recall calculations he had used previously on homework problems. This line of reasoning is obstructed by the student’s visualization of stresses as well. Even though all of the forces drawn in the problem are vertical bending loads, the student reasons, “that’s just kinda getting into the difference between the shear and the normal force. Now you’re applying the more of a, more of a shear force on this [indicating a distributed load], like this you’re applying a shear force on this.” He eventually concludes with the inappropriate emphasis on the effect of point loads discussed above, saying, “I guess I, what I would do, if it was stress, being forces to answer this problem, I would go with exactly how much force is on that point, and then rank ‘em like that.”

Some students also attempted to analyze the normal stresses in beams through the use of stress elements. When asked to rank points in a bending beam based on normal stress, for example, one student grew frustrated:

**Student:** And. I just don’t feel like this is right. For some reason.

**Interviewer:** What, what part of it?

**Student:** This…drawing [scribbling] that I’m just drawing. I just don’t think it’s right.

**Interviewer:** How big are these little squares that you’re drawing?

**Student:** Tiny infinite, small.

**Interviewer:** Okay.

**Student:** I’m just trying to figure out the tiny little, like how the little molecule things are acting in, on it. Cuz that’s what we were, or at least that’s what I was taught in mechanics. Is that you, you know, you look
at your square. For your normal forces. However they’re acting….uhm…so I’m unna draw the deformed shape. They’re all gonna deform the same way.

The emphasis on the “deformed shape” also led this student to reason that the points closest to the point load would experience the most stress.

Table 4 summarizes the general trends identified in the Results section.

<table>
<thead>
<tr>
<th>Content</th>
<th>Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axially Loaded Members</td>
<td></td>
</tr>
<tr>
<td>Distribution of Stresses</td>
<td>Unable to explain shear stress distributions more often than normal stress distributions</td>
</tr>
<tr>
<td>Visualizing Shear</td>
<td>Proclivity and inability to explain shear stress through visualizations</td>
</tr>
<tr>
<td>Poisson’s Effect</td>
<td>Confusion about strains occurring without stress in the same direction</td>
</tr>
<tr>
<td>Stress Elements</td>
<td>Abilities to explain “complex” phenomena does not relate to ability to explain underlying or “simpler” phenomena</td>
</tr>
<tr>
<td>Beams</td>
<td></td>
</tr>
<tr>
<td>Point loads</td>
<td>Overestimation of importance of point loads in overall behavior</td>
</tr>
<tr>
<td>Normal Stress</td>
<td>Lack of association of normal stress with bending, despite associations between bending and moments, and moments and normal stress</td>
</tr>
<tr>
<td>Visualizing stress</td>
<td>Lower understanding when referring to three-dimensional representations, difficulty with shear stress</td>
</tr>
</tbody>
</table>

Table 4. Summary of the patterns in student understanding as reported here.

**VII. DISCUSSION**

The purpose of this Discussion is two-fold: to determine how the recent theoretical advancements can help inform this study of conceptual change in engineering, and to determine how this study can inform developments in conceptual change theories. These aims will be addressed separately in different sub-sections.
A. How can conceptual change theories inform the findings?

Two themes in the data will be presented and theoretically based explanations will be explored. In keeping with the purpose of this paper to build connections between engineering education and conceptual change research, these themes in the data will be presented in the form of practical questions of interest to MoM instructors and engineering educators before being addressed by conceptual change theories.

1) Why do students understand shear less than normal stress?

Confusion about shear stresses was a consistent theme in the results. Students seemed to struggle more to remember shear stress distributions than normal stress distributions, and most of the conceptual difficulties in stress transformations involved shear. This trend can be reinterpreted and subsequently explained by reference to Chi’s theory of ontological shifts and emergent processes.

Recall that Chi argues that many of the greatest conceptual difficulties experienced by students trying to learn science involve emergent processes which are miscategorized as direct processes or substances. The difficulty stems from the cognitive process of recategorizing something at such a fundamental (ontological) level, but also from the fact that many students do not have an ontological category for emergent processes in the first place. Table 5 below summarizes the differences between emergent and direct processes, and shows how stress is emergent.
By Chi’s theory, students do not actually struggle more with shear than normal stresses. The reason that it appears so is that students’ descriptions of stress as a “direct process” are superficially correct in the case of normal stresses in axially loaded members. In the direct process model, a loading is kind of a specialized element that produces a compatible observable phenomena in normal stresses acting in the same direction. This model does not work with any of the other loading conditions investigated here, which meant that students either had to apply a different model, fill in gaps, or try to explain away the contradictions.

This approach connects students’ difficulties with shear to other trends in the data. The direct process model of stress would work better for shear stress in bending than normal stress. This was the case when students were asked to generally predict the existence of such stresses, but was reversed when students were asked to describe the distributions. In looking at students’ descriptions of the distribution of normal stresses, however, it is again based on a direct process model: student descriptions focused on the moment (again, as a special causal agent) pushing or

<table>
<thead>
<tr>
<th><strong>Direct Process</strong>*</th>
<th><strong>Emergent Process</strong>*</th>
<th><strong>Stress</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Caused by a special element (agent) pursuing an observable, macro-scale goal</td>
<td>Caused by the interaction of all elements reacting to local conditions</td>
<td>Caused by the local interaction of molecules</td>
</tr>
<tr>
<td>Specific elements interact sequentially until completion of the process results in observable phenomenon</td>
<td>Observable phenomenon is the result of continuous interactions of random elements</td>
<td>All elements experience stress and interactions do not end until conditions change</td>
</tr>
<tr>
<td>Observable pattern is similar to local interactions of elements</td>
<td>Observable pattern is dissimilar to local interactions of elements</td>
<td>“Direction” of stress is an average not reflecting the actual directions of individual elements</td>
</tr>
</tbody>
</table>

*Table 5.* Summary of stress as an emergent process. *Description of direct and emergent processes adapted from (Chi 2008, pg 74, Table 3.1).*
pulling the cross-section to result in forces that match in direction. There is no similarly effect
direct process description for shear stress distributions. As further support, students did a better
job of predicting the stresses in a bending beam when the force was angled (Figure 7)– although
they still relied on a direct process model. More students recognized the normal and the shear,
but, like the student who struggled to explain the “plane” on which they each act, they were often
confused about how they act together.

There is additional evidence that students have ontological category errors in their
discussions of shear stress. When students explained the “movement” of shear stresses (as
“going” or “pulling” along the edges of a stress element) they were treating it as a substance
instead of a process. While it makes sense for a process to start and stop, it is more unsettling to
learn about a physical substance that appears and disappears. It is possible that student
difficulties with stress transformations are caused by a combination of miscategorizations as
direct processes and as substances. These two types of ontological shifts may require different
kinds of encouragement.

Poisson’s effect is a further example of the emergent nature of stress and strain. The
students who could not accept strain without stress implied a direct causal relationship between
stress and strain in place of an emergent one. It is interesting that some students chose to include
a force that contradicted their direct process model of loading and stress. This explanation was
not universal for students confused by Poisson’s effect, however, and this study did not further
investigate the differences in reasoning that would lead students to choose one explanation over
another.
2) *Why is it so difficult for students to relate some concepts, but not others?*

The findings reported above emphasized the ways in which students seemed to fail to make connections between concepts they understood. In particular, student understanding of stress transformations and normal stress in bending beams was, at the individual and the sample size level, studded with points of high understanding and coincidence points of confusion. At first it can seem counter-intuitive that students can have high understanding of the distribution of normal stresses on a bending beam, while simultaneously doubting whether or not those normal stresses exist. It is not simply that students are unable or disinclined to relate knowledge, however, as is shown particularly vividly in the study by students’ high awareness of the connection between the failure of a concrete cylinder and shear stresses.

Vosniadou’s framework theory approach provides a further means of distinguishing between areas of high student understanding and confusion. Vosniadou argues that conceptual difficulties arise when there is a mismatch between beliefs or mental models and the more fundamental understandings they are built upon. These fundamental understandings are called “framework theories,” and they are different in different domains. As a simplistic example, consider a student working on a homework assignment. At the end of a lengthy series of calculations the student finds that the answer is exactly 100. The student finds this number suspiciously even, and begins to check her calculations. After a time she finds that she had applied the wrong equation and used the wrong value for an empirical constant, and now ends up with a more satisfying empirical-sounding 46.3. In Vosniadou’s language, the students’ framework theory resulted in a sense of what would be reasonable for the outcome of her calculation, and caused her to reevaluate her mental models (corresponding to which equations she used) and her beliefs (corresponding to the value of the empirical constant). The students’
suspicion of the original result is entirely dependent on the domain she was working in. This example is intended to show the subtle but powerful effects of framework theories.

The concepts that students struggled with were the ones that did not obviously belong to one single domain or framework theory. For example, it is not immediately clear whether rotating a stress element is meant to represent a physical change in the system, or is merely an analytical exercise. These two approaches to the same process may reside in different framework theories. The first is in the domain of the physical world, and would be expected then to follow all the rules students have learned intuitionally about the physical world. If it is the second approach, however, it is more closely associated with the psychological domain, and it must therefore fit in with what the student knows about people and why and how they do calculations and analyses. This theoretical approach is supported by the fact that students often did not associate their construction of Mohr’s circle with the physical world of the member under loading, but instead associated it more with psychological world of frames of reference and stress element orientations. These students – the ones who believed that Mohr’s circle would have be redrawn to consider a stress element at a different orientation – typically did not relate their knowledge across these contexts. So, student difficulties clustered around these areas where they weren’t firmly in one framework or another, and this switching may have led to the inconsistencies.

B. How can the findings inform conceptual change theories?

1) How are concepts related?

The explanatory power of Chi’s ontological shift and Vosniadou’s framework theories approach support the argument that students’ conceptual understanding of MoM is characterized
by an overarching hierarchical organization. Despite being frequently contradicted (even by the students’ own reasoning) some incorrect beliefs persisted through graduate-level education in structural engineering. This finding is particularly significant for the way it applies across concepts and fits broadly with the data because previous empirical support has been more closely focused on a single concept (for example Vosniadou and Brewer 1992; Ioannides and Vosniadou 2002).

“Knowledge-in-pieces” theorists argue that misconceptions arise from accumulated life experience as opposed to consistent cognitive structures (diSessa 2008). Although diSessa has acknowledged that the “Knowledge in Pieces perspective was developed specifically to deal with experientially rich domains, such as mechanics. Application to other domains is at least somewhat speculative, and possibly even doubtful, without that inherent richness” (diSessa 2004, p. 888), it is unclear if MoM could be considered an “experientially rich domain.” It is tempting to assume it is not, because students cannot see or experience stresses in their everyday lives. This assumption implies that students’ identification of cognitive domains exactly matches experts’, however, and the findings of this study suggest that that implication should be seriously questioned. While experts make strong distinctions between observable phenomena such as deformation and the unobservable processes which cause them, the students in this study consistently failed to make such distinctions. This means that, from the perspective of students, their life experiences could be related to stress and internal forces. Students’ misconceptions of emergent processes could lead them to inappropriately apply life experiences to phenomena that experts would assume are decidedly unfamiliar to them. Therefore, the interaction of students’ life experiences with their understandings is complicated by the different ways in which students define the phenomena being experienced or understood. This study suggest, then, that
knowledge-in-pieces approaches to conceptual change may not be appropriate in MoM until the relationship between life experiences and persistent student beliefs is more fully understood.

2) How consistent is understanding?

The findings reported here highlight the importance of context-dependent conceptual understanding in parallel with broader trends of conceptual change. Inconsistency in student reasoning has often been interpreted as contradictory to approaches to conceptual change (such as Chi and Vosniadou’s) that assume cognitive structures (diSessa 2004; Ozdemir and Clark 2009). In this data, however, the inconsistencies and context-dependency of individual students’ reasoning coexists with the finding that most students struggled with the same concepts, in the same ways. Inconsistent reasoning does not necessarily contradict the cognitive-structure approach to conceptual change, but it does emphasize an area of the approach that is currently lacking in theoretical elaboration.

Knowledge-in-pieces theorists have established the construct of “conceptual ecology” to describe the complex interactions of cognitive elements, which includes perceptual processes as the mechanism causing context-specific reasoning (Posner, Strike et al. 1982; Strike and Posner 1985; Strike and Posner 1992). The explanation is that students’ perceptions (of the problem description, the purpose of the interview, the interviewer, and a number of other poorly understood elements) define the context in which they are reasoning, so that small changes in the context (for example a slight shift in the interviewer’s aspect, or different representations of the same physical situation) could lead to drastically different student reasoning. Although they are not theoretically mutually exclusive, these perceptual processes are typically not emphasized in theoretical approaches that also emphasize cognitive structures. The findings of this study highlight ways in which aspects of the cognitive-structures and knowledge-in-pieces approaches
to conceptual change could be combined to better match observed trends in student understanding. The rich explanatory framework of conceptual ecology could be used to describe the interaction of perceptual processes with cognitive categorization hierarchies assumed in Chi’s ontological shifts model. This combination could help explain both the broad consistencies in students’ reasoning, and the processes that lead to individual students’ inconsistencies.

Recall that some students seemed to understand stress elements and Mohr’s circle more as human artifacts created for computational convenience than as reflections of real, physical processes. Therefore, some students interpreted them from within the psychological domain while others interpreted them as from the physical domain. This study proposes such unclear domain definitions as a new potential source of conceptual difficulty, and therefore a new potential target for efforts to promote and understand conceptual change. Furthermore, these findings are also consonant with the importance of context noted above. While the conceptual ecology approach is typically associated with knowledge-in-pieces theories, the same basic approach could work within Vosniadou’s framework approach. Small changes in perceptions lead students to activate different mental models, and in some cases (such as with stress elements and Mohr’s circle), different framework theories. In cases of high conceptual understanding, there is a stronger link between a broad range of contexts and the appropriate cognitive structure, so the perceptual processes are less important and the inconsistencies are minimized. This line of reasoning is promising in terms of a recent theoretical debate about the flexibility of ontological categories (Gupta, Hammer et al. 2010; Slotta 2011) because it suggests a theoretical means through which to explain the different ways in which experts discuss emergent processes.
3) Why does conceptual change matter?

Due to the distinctiveness of engineering as a domain, engineering education research is in a particularly interesting position from which to contribute to this conversation by posing a number of new questions to guide productive future research. Despite robust findings that students rarely graduate with high conceptual understanding of fundamental engineering topics including MoM, common experience shows that most engineered structures are successful. The question becomes, then, do young engineers gain conceptual understanding in the workforce, or is conceptual understanding simply not important in light of the highly codified, standardized and rigorously double-checked nature of engineering practice? Even if this question were answered and we gained a better understanding of how the system is working, there are equally important questions about how the system might work best.

At a more concrete level, it is possible to compare the types of tasks the students struggled with in the interviews with the types of tasks that might be important in engineering design. As one example, students struggled with applying their knowledge across different contexts, even when the contexts were only subtly different (such as the representations of bending beams as three-dimensional shapes). This lack of transferability is a defining feature of naïve conceptual understanding. This process – the identification of a particular context with more generalized rules or understandings – is exactly the role engineering knowledge plays in highly standardized and codified fields, such as structural engineering.
VIII. CONCLUSION

A. Summary and Implications

Student understanding of concepts in MoM is limited by their ability to understand, visualize and explain the microscopic processes that result in observable phenomena, as well as challenges in identifying the appropriate contexts in which concepts apply. Discussions of Poisson’s effect and shear failure in concrete cylinders seem to encourage students toward more effective mental models, and therefore have high potential as entry points in addressing these difficulties in the context axially loaded members. Similarly, discussions about how stress elements and Mohr’s circle relate to physical reality could help students clearly identify which domain a particular mental model should be applied to.

Although the additional theoretical layer may seem like unnecessary complication of what is primarily a practical problem (how to teach MoM), it was the application of conceptual change theories allowed for the condensed description of student understanding in the previous paragraph and led to the practical suggestions for how to improve it. Theoretical complexity can further help address practical problems by suggesting ways in which the identified student difficulties can be addressed in the classroom. One final conclusion to be drawn from this work is that conceptual change research can help engineering education research, and vice versa.

For example, Steif’s work with “body-centered talk” in statics has been successful in increasing student understanding (Steif, Lobue et al. 2010). Steif identified and addressed statics students’ difficulties in mentally modeling the interactions between bodies as the forces they impart. These difficulties parallel MoM students’ challenges in related external loads to internal stresses. Steif’s approach, however, is not directly applicable to MoM because, unlike statics, MoM is primarily concerned with phenomena that occur inside the “body” or member. This is
where the explanation of student difficulties based on Chi’s emergent processes approach can again be used to relate previous research to new problems: Steif’s approach can be explained in theoretical terms, which will allow it to be applied to MoM. “Body-centered talk” prevents students from making easy, direct process explanations of phenomena in statics by forcing students to focus on the physical interactions of two objects, instead of the effect of a direct causal agent on one object. The common shorthand of replacing physical objects with arrows representing forces privileges one object as a causal agent, while centering the analysis on the other object as the system being affected. This imbalance of causation is a defining feature of direct processes. The interactional approach encouraged by “body-centered talk,” however, is a characteristic of emergent processes in which all parts of the system interact equally to create the observed pattern. In MoM, similar educational effects could be accomplished by asking students to ignore the external load during some analyses. If students are forced to ignore the external load, they will not be able to use it as a causal agent in direct process explanations of the internal stresses. For most phenomena of interest, it is not technically the load that causes a stress at any point, but the interaction of the elements of the material. Excluding the external load from student reasoning would force them to face this.

Similarly, the importance of context-specificity in these findings suggests that the moderately effective efforts and ontology training (Slotta and Chi 2006; Yang, Santiago Roman et al. 2010) could be improved by emphasizing the development of skillful application of different ontological models, as opposed to only on the development of awareness of the ontological category of emergent processes. Additionally, ontology training efforts that explicitly acknowledged the important social aspects of context (e.g. who a concept is being
explained to) could help students address both ontological and domain-specific conceptual challenges.

**B. Future Research Directions**

In an effort to be theoretically non-specific, this study did not fully address the methodological issues raised by social constructivist approaches to conceptual change. Of the unaddressed issues, of particular importance for engineering education is the question of whether an individuals’ ability to describe their reasoning accurately reflects their ability to reason consistently and accurately, or if the causal linkage is reversed (i.e. that increased ability to communicate leads to increased understanding). This is of particular interest in engineering because of the increasing attention being paid to engineers’ communication skills, and they various ways in which the development of those skills is being addressed. If a clear connection between student understanding and communication could be established, there could be increased synergy between the efforts to accomplish and assess various ABET criteria.

It is unclear how these phenomena under investigation (i.e. axially loaded members and bending beams) were described in class. Recall the example of the students from the private university that usually depicted the distribution of normal stress as a single arrow. The interactions of student, instructor, homework, textbook and grader are complex enough, but are further complicated by the introduction of the researcher. Future work in this area must carefully and thoroughly track the contexts created throughout the students’ exposure to the material, including the tacit, socially mediated expectations of the interview process. Taber (2001) noted that some impediments to learning arise during the course of instruction. Gupta et al. (2010) similarly noted that experts use various ways of discussing phenomena that can, at times, seem to support misconceptions. It is also unclear how much effect different instructional explanations
within the same pedagogical approach can affect conceptual understanding. Although it has been widely shown that traditional, lecture-based instruction does not significantly improve student understanding as measured by a standardized assessment (Hake 1998), there is little research investigating how pedagogical approaches affect the expression, development or change of misconceptions. This area is difficult one for research since it calls for comparative approaches that are impractical in educational settings. Instead, ethnographic or experimental cognitive science approaches could be used to collect and collate data on how students’ understandings of phenomena are related to the ways in which they are explained to them.

Past research in physics education suggests a potentially fruitful approach to questions about domain- and context-specificity. Chi et al. (Chi, Feltovich et al. 1981) found that students categorize problems in very different ways than experts. Similarly, Chase and Simon (1973) found that experts actually perceive situations differently than novices. Future research focusing only on how students and experts perceive problems and questions in MoM could lead to further insights into the relationships between context, perceptions and conceptual understanding. The findings of this study show that such perceptual differences may be particularly important for how students perceive bending beams and point loads. Future research could comparatively investigate aspects of the representations of these constructs to see how they influence student reasoning and ability to recall and apply related knowledge. For example, students could be interviewed with diagrams showing bending beams with and without deflection shown, to see how this affects their discussion of normal stresses, or point loads could be represented in number of ways to either emphasize or deemphasize the particular point of application.

Research in conceptual understanding and change is understandably focused on areas of student difficulty. Indeed, one of the foundational questions of the field is concerned with why
some concepts or topics are more difficult for learners than others. However, as emphasized by the areas of theoretical significance not well captured in this study, there is clearly a connection between “correct” student understanding and “incorrect” understanding. Perhaps a focus on more holistically describing student’s conceptions could more directly address important theoretical questions (particularly those concerning the consistency of conceptual understanding). Increased awareness of what students understand well would also be beneficial in most approaches to increasing students’ understanding of other topics – as potential areas to build analogies on, or benchmarks, or to further clarify how individuals switch from one version of understanding to another in the course of problem solving, communicating or learning.

Finally, a great deal of progress in conceptual change in engineering education (as well as conceptual change research) could be made by studying engineers in practice. A central part of engineering education involves the training and preparation of engineers, and therefore the conceptual understanding of practicing engineers is a vitally important endpoint against which to compare students’ conceptual understandings and changes.
IX. REFERENCES


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The Personal Epistemologies of Civil Engineering Faculty

I. INTRODUCTION

Knowledge and its creation are central to the practices of education and research. Epistemology, the study of knowledge and knowing, has been called “education’s most basic and central concern” (Cunningham & Fitzgerald, 1996, p. 39). A recent line of work has argued that such epistemological concerns are particularly important in the field of engineering education due to its position at the interface of the very different fields of engineering and education (Borrego, 2007; Borrego & Newswander, 2008; Borrego, Streveler, Miller, & Smith, 2008; Douglas, Koro-Ljungberg, & Borrego, 2010; Jesiek, Newswander, & Borrego, 2009). In addition to its inherent importance to the knowledge-based practices of research and education, individuals’ epistemologies have been correlated to a number of other important constructs. Students’ epistemologies have been shown to affect their learning and achievement (Brownlee, Walker, Lennox, Exley, & Pearce, 2009; Mason, 2002; Muis, Bendixen, & Haerle, 2006), and teachers’ beliefs about knowledge and knowing have been shown to affect their pedagogy (Lederman, 1992) which may in turn further affect student outcomes (Abd-El-Khalick & Lederman, 2000; Lederman & Zeidler, 1987; Muis & Foy, 2010; Pajares, 1992). Its central position and relation to so many important aspects of engineering education make characterizing an epistemology of engineering education an important goal for the field. The purpose of this paper is to contribute to this goal by investigating the application of theoretical approaches to epistemology research to the field of engineering education.
II. **BACKGROUND**

Although there is extensive research investigating the “personal epistemologies” of various groups, theoretical challenges in the field complicate the application of this research to engineering education. First, there are no broadly applicable means of measuring epistemologies. Quantitative measures of personal epistemology have generally failed to provide acceptable levels validity or reliability (DeBacker, Crowson, Beesley, Thoma, & Hestevold, 2008; Duell & Schommer-Aikins, 2001; Greene, Torney-Purta, & Azevedo, 2010; Schraw, Bendixen, & Dunkle, 2002; P. Wood & Kardash, 2002; Phillip Wood, K. Kitchener, & Jensen, 2002). This difficulty in measuring the construct is likely due the relative newness of the field itself, which has been described as “in its infancy” (Schraw et al., 2002, pg. 273). This newness means that there is no unifying theory of “personal epistemology,” and instead each researcher seems to pursue his or her own preferred approach. This variability extends to the definition of personal epistemology itself, which some researchers present as a set of independently evolving beliefs (Hammer & Elby, 2002; Schommer-Aikins, 2002), while others it present more as a “theory of knowledge” (Hofer, 2002) or a type of cognition (Kuhn, 2000; Kuhn, Cheney, & Weinstock, 2000; Mason, 2002). Across these differences, however, there has been general agreement about the substantial dimensions of personal epistemology since Perry’s (1970) groundbreaking study of “intellectual and ethical” development. Although the universality of the stages in Perry’s developmental scheme have been questioned (Baxter Magolda, 1992; Belenky, Clinchy, Goldberger, & Tarule, 1986; Hofer, 2000; Muis et al., 2006; Schommer-Aikins, 2002), most empirical and theoretical approaches to personal epistemology since then have verified and reestablished a similar set of fundamental dimensions of personal epistemology.
(see for examples Hofer, 2002; 2004; King & K. S. Kitchener, 1994; 2004; Kuhn et al., 2000; Kuhn & Weinstock, 2002). Table 1 summarizes these dimensions.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Example Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nature of knowledge</td>
<td>Is knowledge made up of discrete pieces (facts) or is it more of a continuum? Is knowledge more of a substance or a process? Is new knowledge created, attained, acquired or communicated?</td>
</tr>
<tr>
<td>Nature of certainty</td>
<td>Is absolute truth attainable? What is the relationship between knowledge and reality?</td>
</tr>
<tr>
<td>Nature of justification</td>
<td>How does one evaluate or establish certainty? What is the relationship between evidence and certainty? What determines the strength of evidence?</td>
</tr>
</tbody>
</table>

**Table 1.** Summary of the general dimensions included in most personal epistemology research.

The second challenge of applying existing research to engineering education is that the domain-specificity of personal epistemology is currently poorly understood. There is growing evidence that individuals’ express different personal epistemologies in different contexts, and that training in academic disciplines leads to some regular differences in epistemology (Hofer, 2000; Muis et al., 2006; Sandoval, 2005; Stathopoulou & Vosniadou, 2007). The differences identified, however, typically compare “science” to a different field such as history or psychology. The differences between disciplines are often tacitly assumed, and it is therefore unclear where engineering would fit into these descriptions of “science.”

Work in engineering philosophy can inform the study of engineering educators’ epistemologies by outlining ways in which engineering is epistemologically distinct from other fields. A growing and diffuse field of researchers is working to understand engineering in philosophical terms. Central to many of these efforts are epistemological questions about what constitutes
engineering knowledge, and how engineers’ relationships with knowledge and certainty differentiate them from other scientists or technologists (Figueiredo, 2008; van de Poel, 2010; Vincenti, 1990). As summarized by Pirtle (2010, pp. 95-96), “In particular, engineering is philosophically interesting because of the ways it differs and is similar to a long-cherished philosopher’s conception of what scientific theorizing and explanation looks like.” Efforts to distinguish engineering from other disciplines, including the sciences in general, often emphasize two seemingly contradictory facts about the practice of engineering: first, that engineers are more involved with the “real world” than academic scientists, and secondly that their interactions with knowledge and certainty are nearly always colored by the subjective or normative demands of a society.

In a representative example of the first argument, McCarthy writes (note that the European spellings of some words are in the original), “Engineering is a practical pursuit, ultimately focused on the real world, not the idealised conditions explored in the lab or the armchair. Its very nature and purpose requires that engineering deal with complexity, contingency and context” (2010, p. 266). In this argument, the “contingency” of the problems engineers face discourages the type of general law-making that typically characterizes science. In terms of the frameworks of personal epistemology discussed above, this implies that interaction with engineering problems may encourage movement away from the “absolutist” or “dualist” positions. The need for engineers to “deal with” that complexity, however, implies that the movement toward relativism that follows rejection of absolutism in most approaches to personal epistemology is equally discouraged. Due to the nature of real-world problems, engineers are not likely to fit well into either the “absolutist” or “relativist” categories.
As many engineering philosophers note, however, engineering knowledge is often enacted in response to societal problems. While the theories and facts of traditional science definitely play a role in engineering, so too do the desires and values of a society. As Goldman writes, “The definition of engineering problems, as well as of what will count as acceptable solutions to them, explicitly depends on highly contingent value judgements that are external to the technical expertise engineers command. These value judgments derive from the projected economic, social and/or political consequences of the implementation of solutions to engineering problems” (2004, p. 166). Goldman argues that this means that engineers are using scientific knowledge as “tools” in order to achieve goals that are “external” to the fields of science or engineering. This subtle but important distinction is significant because of the way personal epistemology theorists tell us people move out of relativist views of knowledge. As shown in the last row of Table 1, the theorists often resort to scientific language when describing this epistemic stance in which people use “evidence” to support “plausible claims.” This description relies on an attitude toward knowledge that is typical of the sciences in which the careful generation of knowledge is a worthy ultimate purpose for inquiry. What Goldman argues, however, is that engineering distinguishes itself by interacting with an entirely different metric for measuring the value of “commitments within relativism.” At least in their role as societal problem-solvers, engineers must evaluate knowledge based on its usefulness in achieving the goals of people. In a potentially related argument, some engineering philosophers argue that engineering is characterized by a different dimension of knowledge known as “intuitive judgement” (Vincenti, 1990), or “know-how” (McCarthy, 2010).
A. Summary of Need and Challenges

The personal epistemologies of engineering faculty have not yet been described. Descriptions of engineering processes including teaching, learning, communication and problem-solving could be enriched with the addition of epistemological considerations. Additionally, the importance of domain- and context-specific differences in individuals’ personal epistemologies, coupled with the differences between engineers and the populations on which most theories of epistemology are based means that there is no validated framework for assessing the personal epistemologies of engineering faculty. In other words, previous research clearly underlines the importance of epistemology, but cannot offer a proven measurement instrument or framework for application to engineering education.

III. PURPOSE

The purpose of this research is to describe civil engineering educators’ epistemologies in a way that builds on existing theory and findings, but is applicable to the approaches of philosophical, research and personal epistemology studies. This purpose will be achieved by answering the following research question:

1. How are civil engineering educators’ epistemologies different from general characterizations of “scientific epistemologies?”

IV. METHODS

A. Theoretical Approach to Measurement

In order to achieve the goals of this research an approach to personal epistemology must be taken that meets the following criteria: (1) it needs to broad enough to ensure that the true range of
engineering epistemologies is captured; (2) it needs to be transferable to existing frameworks in order to facilitate comparisons to existing findings; (3) it needs to be able to distinguish between epistemologies at a finer resolution than can be achieved by generalizing across theoretical approaches to personal epistemology, and; (4) because it is the application of a new method of measurement to a new set of measurements, it needs to include some internal forms of triangulation.

This study is therefore based on the theoretical approach to personal epistemology established by Fitzgerald and Cunningham (1996; 2002). Their framework was developed to address a similar problem (adapting personal epistemology research to research on reading) and therefore aims to achieve the breadth and depth required for this study. They describe personal epistemologies as “stances” taken on seven key epistemological issues which have been defined through thorough review of philosophical epistemological debates ranging from Plato to Chomsky. The appeal to philosophy does not come at the expense of losing touch with practical differences, however, because, as noted by the authors, the goals of their research exist “…in a tension between recognizing legitimate complexity and fostering practical applications” (Cunningham & Fitzgerald, 1996, p. 39).

Each of the seven key epistemological issues is complex in its own right, and therefore only the four most relevant to this research will be presented here. Table 2 presents each issue as it is phrased by Cunningham and Fitzggerald (1996), and offers a brief description of the various possible stances.
<table>
<thead>
<tr>
<th>Epistemological Issue</th>
<th>Summary of Stances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Where is knowledge located relative to the knower?</td>
<td>Dualism, the most common stance, assumes that people and the things they know about are fundamentally separate</td>
</tr>
<tr>
<td></td>
<td>Discovery of knowledge implies that it existed previous to being known, and that all people would know objectively the same thing</td>
</tr>
<tr>
<td>To what degree is knowledge discovered versus created?</td>
<td>Creation of knowledge implies that individuals may generate different knowledge from the same phenomena</td>
</tr>
<tr>
<td></td>
<td>The most common stance assumes that knowledge is true when it best matches reality</td>
</tr>
<tr>
<td></td>
<td>Other stances base truth on usefulness or coherence with existing bodies of knowledge</td>
</tr>
<tr>
<td>What primary test must knowledge pass in order to be true?</td>
<td>Based on a question of whether observing something or reasoning that it must be so is a more important source of knowledge</td>
</tr>
<tr>
<td>What are the relative contributions of sense data and mental activity to knowing?</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Brief summary of four the seven key epistemological issues identified in (Cunningham & Fitzgerald, 1996).

A separate theoretical approach is necessary to enrich the data and add strength to the comparisons forming the purpose of this research. This second stream of data is based on the participants’ descriptions of their approaches to research. Because individuals’ approaches to research are basically enactments of their beliefs about knowledge, research practices can provide a direct insight into the practical epistemologies individuals use in their lives (Sandoval, 2005). In this study, the participants’ approaches to research will be linked to their epistemologies through reference to the explicitly epistemologically different approaches to research identified in the educational research literature.
For better or worse, educational research is epistemologically diverse. Ongoing debates, often recorded in the journal *Educational Researcher*, touch on the same epistemological issues described by the personal epistemology theorists cited above. Couched at various times as a “paradigm war” about research approaches (Gage, 1989; Salomon, 1991), or as reactions and responses to “science-based education” policies (Feuer, 2006; St. Pierre, 2006), these debates offer a uniquely explicit source of information on the range of epistemic positions academic researchers take, and how those positions interact with their research (Willower, 2001). This field can advance the study of engineers’ personal epistemologies by linking research practices and perspectives (which are relatively easy to measure) to established epistemological stances (which have proven difficult to measure).

Guba and Lincoln (1994; 2005) have set the standard for defining the range of approaches to research (paradigms, in their terminology) in broad use in educational research. They divide the field into examples of the five different paradigms presented in Table 3. Note that the descriptions provided here are necessarily abbreviated and focus primarily on the differences of each stance from the postpositivist stance, which is commonly associated with engineering research.

<table>
<thead>
<tr>
<th>Paradigm</th>
<th>Summarized Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positivism</td>
<td>A simplified, traditional view of science in which the scientific method is used to remove sources of human bias and error with the goal of better understanding reality</td>
</tr>
<tr>
<td>Postpositivism</td>
<td>Similar to positivism, but with less faith that findings are objectively true due to the inherent complexity of the world</td>
</tr>
<tr>
<td>Constructivism</td>
<td>Emphasizes the individuality of human experiences, which removes the emphasis on reality and focuses on interpretation</td>
</tr>
<tr>
<td>Critical Theories</td>
<td>Shifts the focus of research to social action based on ethics of equity</td>
</tr>
<tr>
<td>Participatory</td>
<td>Continues the trend set by critical theories, but additionally removes the divide between “researcher” and “subject”</td>
</tr>
</tbody>
</table>

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Table 3. Summary of the five general research paradigms described by Guba and Lincoln (1994; 2005).

Guba and Lincoln distinguish the five paradigms based on a set of 10 issues, or features of research done within the paradigm. The four most relevant to this research are listed in Table 4, again with an emphasis on the postpositivist paradigm.

<table>
<thead>
<tr>
<th>Issue</th>
<th>Postpositivist Approach</th>
<th>Other Paradigmatic Approaches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Criteria for Quality</td>
<td>Avoidance of bias, closeness to reality</td>
<td>Pluralism of methods without an obvious “best” method</td>
</tr>
<tr>
<td>Nature of knowledge</td>
<td>Collection of facts and theories established through verification of claims</td>
<td>Socially or historically validated consensus of individual interpretations</td>
</tr>
<tr>
<td>Ethics</td>
<td>Ethical obligations constrain research</td>
<td>Ethical considerations are an integral part of shaping research</td>
</tr>
<tr>
<td>Values</td>
<td>Values are excluded from research</td>
<td>Values are incorporated into research</td>
</tr>
</tbody>
</table>

Table 4. Summary of four issues used by Guba and Lincoln to distinguish between different research paradigms.

B. Sample Selection

The sample purposefully selected to address the challenges of collecting data on epistemology, and allow for meaningful results. All of the research faculty in the Department of Civil and
Environmental Engineering at Washington State University were invited to participate in the study, and 26 of the 30 possible candidates did participate in interviews.

As discussed above, it is difficult to measure personal epistemology in part because of the challenge of discussing deeply-held and often tacit beliefs. In research on conceptual understanding, which investigates such beliefs about science phenomena, the approach is to encourage participants to talk aloud during problem-solving activities (see for example McDermott & Shaffer, 1992), and some success has been achieved adopting similar methods in studies of personal epistemology (King & K. S. Kitchener, 1994). Such descriptions, however, are strongly colored by the particular epistemological problems posed in the same way that studies of conceptual understanding are colored by the particular concepts under investigation, but in epistemology there is no strong link between the conceptual (i.e. Fitzgerald and Cunningham’s seven epistemological issues) and practical level (i.e. epistemological problems posed during interviews). Therefore the problem can be described as one of access: what interview processes are best suited to access participants’ epistemologies? Because personal epistemology is more entwined with personal identity, ethics and values than concepts of physics, the conceptual understanding “clinical interview” approach was inappropriate because it imposed the interviewers’ interpretation onto participants. The approach adopted then, focuses on the co-construction of stances (Fontana & Frey, 2003).

An equally important concern as access was one of relevance. Describing the personal epistemologies of the civil engineering faculty in one department does not allow for generalizations of an “engineering epistemology,” nor does it necessarily allow for general
characterizations of civil engineers. This sample, does however, have the potential to highlight potentially important differences in the epistemologies of engineers compared to the “scientists” discussed in the literature. Civil engineering, in particular, provides a potentially insightful case because of the range of research topics and content including structural, hydrological, wastewater, geotechnical, and transportation engineering. Additionally, in addressing these facets of engineering, the civil engineers in this sample involved themselves to varying degrees in scientific fields including geology, meteorology, chemistry, physics, biology, materials science, and forestry. Finally, the participants engaged in a broad spectrum of research practices representative of engineering research including the construction and evaluation of measurement and analysis instrumentation, the writing of design codes, and interactions with multiple levels of environmental policymakers.

C. Data Collection and Analysis

Data was collected in this study through semi-structured interviews (Patton, 2002) based on both theoretical frameworks described above. This was accomplished by situating the interviews in the context of the participants’ research. This addressed issues of the potential domain-specificity of personal epistemology by intentionally limiting the discussion to the domain of engineering research. Additionally, this choice of topic made it possible for the two frameworks guiding this research to overlap in some questions, where participants’ discussions of their research also revealed their epistemological stances.

The interview guide consisted 25 questions mapped to both Cunningham and Fitzgerald’s seven epistemological issues and Guba and Lincoln’s ten features of a research paradigm. Several steps were taken to facilitate the participants’ discussion of epistemological issues. First, three
pilot interviews were conducted with two participants which resulted in broad changes to the interview guide. After these pilots, fixed groupings of questions based on their similarity in terms of the theoretical constructs being probed were replaced with a more flexible system of groupings of questions and prepared transitions. For example, the questions “how do you know something is true?” and “Do scientific findings reflect reality?” were both intended to probe participant stances on issues of certainty. In the piloting process and early interviews, however, it became clear that most participants considered these to be very different topics, and had difficulty answering them if the interviewer implied that they were related. Therefore, the questions were more loosely grouped based on the content of the question, and adjusted in the course of each interview to match the terminology and approach of the interviewee. As mentioned, most participants did not link questions about “truth” and questions about “reality,” but a few did, and this revised structure allowed the interviewer to take advantage of both types of connection. This combination of structure and flexibility is characteristic of semi-structured interviews (Ginsburg, 1997; Greenspan, 2003) and explicitly acknowledges the ways interviewers affect the interview experience, without allowing inappropriate influence over interviewee responses (Baxter Magolda & King, 2007; Fontana & Frey, 2003).

The interviews were audio-recorded and transcribed. The transcripts were analyzed in three successively interpretive phases, following broadly accepted qualitative analysis methods (Braun & Clarke, 2006; Maykut, 1994; Miles & Huberman, 1994; Patton, 2002). Wolcott (1994) describes these three phases as “description, analysis and interpretation.” In this study, description meant coding the participants’ responses in terms of the question asked and the intended mapping to the two theoretical frameworks used. The “analysis” phase, which in
Wolcott’s terminology is reserved for algorithmic, more quantitative processes and may compose greater or smaller portions of the overall process depending on the purpose of the research, was iteratively coincident with the “interpretation” phase. In these processes the participants’ responses to each question were grouped based on content, and then counted to determine which of these groups was predominant. Once the most common types of responses were identified, they were analyzed more interpretively to reveal if the content, which was superficially similar based on the initial grouping, was actually referring to similar epistemological or research paradigm constructs. This led to a new set of groups based on epistemological similarities across questions. Similarly, this reevaluation of what constituted a “similar” response required reinterpretation of the initial groups to see if any superficially different responses actually referred to underlying constructs of interest. Finally, the common epistemological and research paradigm responses were compared to each other.

V. RESULTS AND DISCUSSION

Two themes rose to prominence in defining the differences between civil engineering educators’ epistemologies and the generic description of a “scientific” approach to knowledge and knowing. These themes were chosen for their commonality and strong presentation in the data, but they are also important for how they capture essential elements civil engineering as a discipline. These are not small differences in peripheral matters, but epistemological consequences of the ways of thinking that are central to the practice of civil engineering.

A. Knowledge in Tools and Processes

Many of the civil engineering faculty interviewed here included analytical tools and procedures in their definition of the knowledge that is created through research. When asked about the
“purpose of research,” the majority of participants used phrases like “create new knowledge” or “increase our understanding.” A significant number (about a third), however, explained that “knowledge” and “understanding” were defined more broadly than is typically assumed. For example, one participant responded, “Well, in a very simple generic way, I'd say the purpose is to just expand our capabilities and depth of knowledge in a real general sense. It's to learn what we didn't know already or to be able to develop tools that we didn't already have to do.” When asked if knowledge is created during research, this participant said, “Knowledge? There is. I believe that there is some form of knowledge. Not necessarily new understanding of the laws of physics, underlying understanding of how we understand the world. But knowledge can be also understanding of how to create that certain thing as an engineer, understanding of how to build a new tool or new equipment.” Not all participants explicitly stated that “know-how” or “tools” were a form of knowledge, but instead implied it by using terms like “knowledge,” “tools,” “technology” or “product” interchangeably. For example the following exchange shows how this participant did not strongly distinguish between “knowledge” and “technology:”

Participant: I think to me [the purpose of research] is trying to advance the technology, because many things we need to do is trying to, through the research type of activities or work, is advancing the science, mechanics and technology-wise, and to make the understanding of the world, or whatever subject is better. Yeah–improve the understanding.

Interviewer: With a focus on technology?

Participant: Yeah, I think practice, technology, science-- yeah, all different aspects, really depending on your discipline. Yeah.
**Interviewer:** So do all those different purposes, do they all create knowledge?

**Participant:** Yeah, creating knowledge. Sometimes it's an innovative type of knowledge – it's creating. Sometimes it's improving the current technology and making it work better. So yeah, all kinds of ways. And even some type of research has this implementation, how to implement a certain technology or knowledge into the real world is also kind of research. Yeah.

For some participants this definition of knowledge was elicited by questions about the “engineering approach to research.” For example, one participant said, “And for an engineer it's often-- at least for me it's often to develop a better way to design or improve material for an application, or an improved way of monitoring material properties; again, for an application of grading, or for defect detection. Whereas in science it's just, ‘Boy that's a cool thing. Why is that happening?’ And it's just about discovery.” In a similar way some participants defined the products of their research (which were more broadly defined as knowledge) as helping practicing engineers. For example, one participant said, “But most of my research would be more development of analysis methods that an engineer could use…or else, you know, evaluating a phenomenon or something that needs to be understood better or something like that would be more the focus.” For this researcher, increasing understanding (a more stereotypical definition of “knowledge”) is roughly the same as developing an “analysis method” for use in consulting.

This viewpoint was slightly more prevalent among participants who were heavily involved in the development and application of computer models. The participants were typically the ones who,
like the first quoted example, explicitly addressed the question of whether a “tool” such as a model could be considered knowledge. This makes sense in that, in some cases, “models” are as much an output of an intensive investigation as a published summary of findings.

In terms of Fitzgerald and Cunningham’s seven epistemological issues, the participants’ tendencies to define knowledge in a way that included tools or methods was visible in their stances on the issue Where is knowledge located relative to the knower, and To what degree is knowledge discovered versus created. In Fitzgerald and Cunningham’s summary of historical stances on the seven issues, they note that the idea that only people have knowledge “has so permeated Western thought that many educated people never question it.” Defining “tools” and procedural know-how as knowledge questions this assumption, however, because it describes a form of knowledge that exists outside of the people involved in its creation and use. Imbuing the products of research with the status of “knowledge” also informs a stance on the issue of whether knowledge is discovered or created. If an analytical model is knowledge, then at least some forms of knowledge can be created instead of discovered. While this type of reasoning was most common among modelers, as quoted above participants defined knowledge to include a variety of other tools including design standards, methods and even consumer products.

From the viewpoint of Guba and Lincoln’s research paradigms, this definition of knowledge applies most directly to the nature of knowledge dimension. Although Guba and Lincoln describe the constructivist paradigm as probably incommensurable with postpostivism, the constructivist description of knowledge could be equally well applied to the participants’ views of models: “Individual and collective reconstructions sometimes coalescing around consensus”
Guba and Lincoln equate postpositivist views of reality and research (which the participants generally agree with) with a definition of knowledge based on proven hypotheses (which the participants generally did not agree with). Although the language used in philosophical discussions of research paradigms understandably does not match the tone and vocabulary of civil engineering faculties’ discussions of computer models, the central themes are the same. Perhaps Guba and Lincoln’s claim of incommensurability can still stand, however, because the participants in this study do not take this view of knowledge to mean that truth is not available and a worthy aim of research, as constructivists often do. This is an area where the frameworks break down when applied to civil engineers, because they cross some fundamental boundaries but not others.

B. Knowledge Applied to Society

As noted above, many of the discussion of knowledge as a “tool” directly referenced the interactions between civil engineering research and the practice of civil engineering design. In some of those discussions, and in about half of the interviews overall, participants referred to “benefiting society” or “improving human lives” as part of the purpose of their research, or as a means to evaluating its quality.

Many participants used the value of findings to society as the primary means of evaluating the quality of their research. One participant said, for example, “Good research first of all I think needs to be something that benefits society, benefits people or the environment.” Other participants did not directly refer to benefitting society as a metric for evaluating research, but did place their research into a larger framework that eventually led to societal benefits. It was common, for example, for participants to describe themselves as “problem-solvers,” and when
asked to further describe the problems they addressed, to link them to societal issues. For example one participant said, “I wish for my efforts in research to contribute to something that I think is some kind of positive in terms of some value system that I subscribe to.” Similarly, some participants emphasized the ways their research relates to engineering practice, and thereby benefitted society. On participant said that doing good research “means doing research that has an impact, has a meaningful impact or leads to meaningful change, and for me specifically in engineering, you know, I'm not motivated to be involved in something that seems to be answering what I consider to be a trivial or unimportant question….to me good engineering research ought to have an impact on the engineering profession.” Taken all together, this means that more than two-thirds of the participants included social constructs (including benefit, ethics or values) in their means of evaluating knowledge.

In the “stances” approach to epistemology this approach to evaluating knowledge is observable in the participants’ stances on the What primary test must knowledge pass in order to be true issue. Participants that evaluate the knowledge created by their research are moving away from a “correspondence” approach to truth to a more pragmatic position. Admittedly, the links between truth and usefulness to society are weak (when asked, most participants were somewhat confused by the distinction, because, as one participant said, “I can’t think of an example where something would be useful but not true”) but that does not lessen the significance of this epistemological stance. Acknowledging the role of societal processes in the evaluation of knowledge is a central part of civil engineering practice (indeed, it is what makes it “civil”), which suggests that this somewhat unique approach to “truth” may also be centrally characteristic of civil engineers.
Again, although the participants were largely postpositivist in their approach to research, on these issues they push more toward supposedly incommensurable paradigms, particularly constructivism. The description of *goodness or quality criteria* for constructivism is “trustworthiness and authenticity including catalyst for action” (Guba & Y. S. Lincoln, 2005). The participants quoted above describing “good research” apply very similar criteria of having an “impact” and being “practical for practicing engineers.” The participants’ emphasis on benefiting society also had implications for the *values* and *ethics* issues in Guba and Lincoln’s typology. The inclusion of values and ethics are often conflated with critical theory approaches to research (including in the description by Lincoln and Guba), and therefore emphasize how ethics of “revelation” shape research practices. These participants, however, implicitly (and in rare cases, explicitly) include different ethics and values within their approach to research. Civil engineers are explicitly bound by ethics in their practice, and this was forefront in the minds of some of the participants, as in the example of one participant who began his discussion of good research by saying bluntly, “If you can’t guarantee human safety, it won’t go. It doesn’t go.” As with the previous examples, this is another case where the participants’ clear, practical concerns actually correspond to unexpectedly complex epistemologies and research paradigms.

VI. Conclusion

The differences identified between the civil engineering faculty in this study and the assumed positionality of “scientific researchers” is important in two ways. First, it suggests some important features of an engineering epistemology which may have ramifications for the field of engineering education, and secondly, it highlights issues that need to be addressed in further steps in characterizing an “engineering epistemology.”
This preliminary study makes it clear that researchers cannot simply assume characteristics of an “engineering epistemology.” Even when those broad characterizations fit actual engineering faculty, their epistemological implications are unpredictable. For example, the engineering philosophers cited earlier were correct in their reasoning that engineering was unique for its emphasis on knowledge as a “tool,” and their close interaction with societally defined goals or benefits. In this study those features were shown to be related to unexpected epistemological approaches to truth, justification and research in general. The assumed characteristics of engineering educators may also unnecessarily limit transdisciplinary efforts, such as the collaborations inherent in many engineering education research endeavors (Borrego, 2007; Borrego & Newswander, 2008). The ways in which the participants didn’t fit into neat epistemological categories or research paradigms suggest potentially surprising commonalities with approaches more traditionally associated with social sciences, including educational research and public policy.

Finally, the ways these differences can are all logically related to aspects of civil engineering research practices suggests strong links between the participants’ environments and their epistemologies. For example, consider how the participants’ characterization of tools as forms of knowledge can be logically linked to their use of models in communicating with stakeholders, or how the inclusion of ethical considerations in the design and implementation of research clearly match with the core ethical requirements of civil engineering practice. These links were not intentionally investigated in this study, but a better understanding of how environment affects
epistemology could make it more possible to identify the ways in which faculty epistemologies interact with student learning, recruitment and retention processes.
VII. References


Scientists Learning Policy: Four Case Studies Of Doctoral Students Learning Policy-Relevant Nitrogen Science

I. INTRODUCTION

One of the central factors limiting the role of science in policymaking is the “epistemological distances” between scientists, policy makers and the general public (Garvin, 2001; Holmes & Clark, 2008). Because epistemology is the branch of philosophy dealing with knowledge and knowing, the phrase “epistemological distances” refers to the sometimes drastically different ways people conceptualize the role of scientific knowledge in policymaking. Recent debates about the role of evidence (Herrick, 2004; Oreskes, 2004) and uncertainty (see for examples Guo, Hepburn, Tol, & Anthoff, 2006; Gupta, 2003; Heath, 2000; Hoffmann, Trautmann, & Schneider, 2008; Janssen, Krol, Schielen, & Hoekstra, 2010; Rypdal, 2001) are examples of how epistemological differences can interfere with communication (Hovelynck, Dewulf, Francois, & Taillieu, 2010). Studies of successful integrations of science and policy, however, suggest ways in which those distances can be bridged (see for example Corburn, 2007; Glicken, 2000). Often, the approach to this problem involves changing the way new scientists are trained, particularly through involvement with interdisciplinary collaborations (Pohl, 2008). Through in-depth, longitudinal case studies of PhD students as they personally integrate science and policy, this paper builds on individual cases to propose a new way of looking at these “bridging” or “integration” processes.

II. BACKGROUND TO THE CASE STUDIES

Longitudinal data on students involved in an Integrative Graduate Education and Research Traineeship (IGERT) was collected through participant observation, semi-structured interviews
and document analysis. The “Nitrogen Systems: Policy-oriented Integrated Research and Education” (NSIPRE) IGERT program was explicitly focused on training doctoral students from scientific disciplines to “…seamlessly integrate N-cycle science for effective communication with public policy makers.” This was accomplished through a combination of interdisciplinary coursework including a seminar on public policy, and experiential learning through interdisciplinary research and a policy-oriented internship. Four students were studied throughout their first year of the NSPIRE program through participant observation of courses, study groups, and fieldtrips, as well as bi-monthly interviews, and the collection of primary documents such as course work, research writings and personal reflection journals. Observations and interviews focused on how students conceptualized the nitrogen cycle, their approaches to the interface between science and policy, and their beliefs about epistemological issues such as certainty or the structure of knowledge. In all, these case studies depend on approximately 300 hours of research-relevant interactions augmented with more than 100 pages of primary documents for each individual.

The research approach taken was based on the concept of participant observation (Preissle & Grant, 2004), in which the researcher is involved in the activities being studied. In this instance, this meant the primary author of this paper engaged in the same coursework, meetings and activities as the participants in the study, and indeed was undergoing the same learning and development as the other participants. There is a tension in this methodology between being actively engaged in the ongoing experience, and being able to objectively observe trends and data unfolding (Emerson, Fretz, & Shaw, 1995; Wolcott, 2008). The approach used here tended toward full engagement, coupled with after-the-fact fieldnotes and jottings (Emerson et al.,
1995). This research had the benefit of fully engaged and helpful participants, however, which further alleviated some the fears of “missing something” due to being too engaged in the activities being observed. Bi-monthly interviews included an unstructured “check-in” portion (Spradley, 1979), which acted as a kind of distillery for the observations and fieldnotes made between interviews because the participants themselves would often highlight experiences or insights they had had about their learning, or approach to policy and science. In these ways, this research project represents an important part of the participants’ case studies.

II. THEORETICAL APPROACH

In this research and in this paper epistemology is defined across a set of dimensions. The three dimensions relate (1) how knowledge is structured and whether it is more a cohesive whole or a particularistic collection of facts; (2) how knowledge is justified in terms of sources and processes of justification, and how certainty is obtained; and (3) the role of social interactions in the creation, utilization and manifestation of knowledge. These dimensions are interrelated, so the ways people address them tend to cluster into a small number of distinct epistemological stances. Table 1 presents four of these stances in terms of how they approach the three dimensions of epistemology. The dimensions and stances in this research are based on the author’s interpretation of the literature, although they rely most heavily on the work of Cunningham and Fitzgerald (J. Cunningham & Fitzgerald, 1996; Fitzgerald & J. Cunningham, 2002), Hofer (2000; 2004; Hofer & Pintrich, 1997), Sandoval (2005), and Hammer (1994).

<table>
<thead>
<tr>
<th>Stance</th>
<th>Structure of Knowledge</th>
<th>Nature of Justification and Certainty</th>
<th>Social Processes in Knowing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positivist</td>
<td>Highly</td>
<td>High levels of certainty</td>
<td>Knowing is an</td>
</tr>
</tbody>
</table>

Table 1 – Epistemological Stances
<table>
<thead>
<tr>
<th>Epistemological Perspective</th>
<th>Characteristics</th>
<th>Knowledge Acquisitional Processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relativist</td>
<td>Highly variable</td>
<td>Highly variable, based on individual schema</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Knowing is an individual process</td>
</tr>
<tr>
<td>Pragmatist</td>
<td>Low structure, particularistic combinations of sense data</td>
<td>Usefulness, or effect of knowledge is primary.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“Uses” and “effects” of knowledge are effected in a society</td>
</tr>
<tr>
<td>Postmodernist</td>
<td>Highly variable</td>
<td>Certainty is not a meaningful criteria, focus is on characteristics of knowledge as a narrative</td>
</tr>
<tr>
<td></td>
<td></td>
<td>All knowledge is enacted in social groups and is affected by them more than by its ostensible content</td>
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</tbody>
</table>

In addition to using these three dimensions to more fully characterize epistemological distances, this study applied the theories of conceptual change to distinguish epistemological distances from related conceptual distances or simple misunderstandings. Figure 1 presents the theory of conceptual change as it will be applied to this study. The basic point is that thinking, and therefore learning, can occur at various levels (Chi & Roscoe, 2002; Vosniadou, 1994). We are most comfortable dealing with the “Belief” level shown at the bottom of Figure 1, which involves facts or propositions (Chi, 2008). The point of the conceptual change approach, however, is to describe the ways in which these beliefs are in fact based on much broader understandings, so that, in some cases, changing a belief might require a person to fundamentally change the way they approach the world. Conceptual change research often aims to identify cases where individual beliefs are hard to change because they are based on more fundamental beliefs that need to change. It is this aspect of the field that applies most directly to these case studies; changing higher (i.e. more abstract or broadly applicable) cognitive structures is more difficult than changing lower (i.e. more concrete and specific) ones.
Figure 1. Model of learning and cognition in conceptual change research.

The process shown in Figure 1 is one of the most important implications of the conceptual change process: new information is processed in terms of people’s existing understandings of the world (Chase & Simon, 1973; Halloun & Hestenes, 1985; Hennessey, 2003). The figure shows how a new observation (“anoxic zones near river outlets” in the example”) is successively interpreted through more specific categorizations until it is linked at the belief level to a causal proposition.

IV. CASE STUDIES OF SCIENCE AND POLICY INTEGRATION

The genesis of this paper lies in a finding that is auxiliary to a broader investigation of PhD students’ learning processes. In investigating students’ learning it became apparent that the students had achieved admirable integration of natural-ecological and socio-political features of their understanding of the nitrogen cycle. The extensive data available for each case allowed for
further investigation into each student's process of developing this integration, with particular emphasis on the roles of their epistemologies.

The descriptions of the case studies are structured to include as much of the participants’ own words as possible, which tends to bias the reported data to being drawn from the interviews because these interactions are transcribed and it is therefore more possible to faithfully represent the participants’ voices. Additionally, as explained above, participants often reevaluated key experiences or thoughts during the check-in portion of interviews. Each finding, however, is supported by multiple streams of the broad data collection procedures referenced above. Each participant’s case description will be preceded by a table summarizing the key points of their case (Tables 2 through 5).

A. Case 1

<table>
<thead>
<tr>
<th></th>
<th>Table 2 – Case 1 Summary</th>
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</thead>
<tbody>
<tr>
<td><strong>Form of Integration:</strong></td>
<td>Full integration of public policy as essentially similar and closely-related processes</td>
</tr>
<tr>
<td><strong>Understanding of Policy:</strong></td>
<td>Conceptual change – policy-as-negative to policy-and-science-as-necessary-human-processes</td>
</tr>
<tr>
<td><strong>Epistemology Structure:</strong></td>
<td>Highly individualized, although individuals’ epistemological structures are likely to be coherent within themselves</td>
</tr>
<tr>
<td><strong>Justification:</strong></td>
<td>Objective justification of knowledge is not possible because it is not possible to apply to certain knowledge that is not the product of human interpretation</td>
</tr>
<tr>
<td><strong>Social:</strong></td>
<td>Social processes define knowledge, truth and reality</td>
</tr>
</tbody>
</table>

Case 1’s initial understanding of the policy process emphasized negative aspects. When asked how policies were formed, the immediate response was “backdoor agreements and compromise,” and although more discussion emphasized the ways in which the policy process was effective, this description of it, at core, remained one of distanced people making morally ambiguous deal
made by people with a “personal interest in having power.” Even when describing interactions between public interest and policy, Case 1 maintained distance from it by describing it in terms of “pressure and media outlets” and “emotionalizing an issue.” Case 1’s final definition of policy was “a manifestation of a belief by a group.” Building on this definition Case 1 gave examples and described the policy process without any reference to politicians or the government – instead the emphasis was entirely on the complex process of how a group of people (of which politicians and government are constituent parts) act on shared beliefs.

Somewhat surprisingly given initially negative view of the policy process, Case 1 eventually integrated understandings of the nitrogen cycle and policy to such a degree that in later interviews Case 1 discussed them interchangeably. In discussing the relationship between methods and findings Case 1 said, “And so to some degree, I see science and policy as being very parallel, as far as their biases.” Later, when discussing the challenges of interdisciplinary communication, Case 1 said “I think there’s a flaw in the fact that information can’t…be understood unless you’re wise enough to know what you’re reading. But it’s not just science. I mean that’s public policy! I can’t read a law and understand exactly what it means or what the ramifications are.” Case 1’s integration of science and policy allowed seamless crossing between the two systems of reference when answering questions about either public policy or the nitrogen cycle. As an example, the following quote shows an ability to reinterpret scientific findings into policy framework. When asked where policy impacts the nitrogen cycle, Case 1 said, “Even ‘natural’ things can be bad for us. Anywhere we’re creating an impact that’s greater then what may be considered a normal risk is an opportunity for public policy, or for any kind of policy. So I’d say everywhere on there [referring to her drawing of the nitrogen cycle], if we’re
impacting any of those systems beyond what we would consider normal.” This quote shows an explicit awareness of the distinct frames of reference of science and policy, as well as ability to speak in both simultaneously. Case 1’s explanation combines politically relevant features (i.e. “risks” or “things that can be bad for us”) with a technical, scientific description of the same processes (i.e. as “beyond what we would consider normal”).

In a second surprising feature this case, Case 1 expressed soundly relativistic epistemological stances. This is surprising because relativism is typically described in terms of a spectrum on which it is the polar opposite of scientific approaches, particularly in the Justification dimension of epistemology. Case 1 firmly denied the accessibility or knowability of an objective reality, which left the justification of knowledge to rely on social processes such as consensus, or a kind of triangulation in which observations made by many people with different individual biases can be combined to establish some degree of certainty. Case 1’s most characteristic quotes “I think facts are kind of relative,” and “Well, I mean [scientific] rules are something that we give to something,” emphasize the roles of individuals in creating and justifying knowledge. In a telling example, Case 1 once explained the differences between physics and soil science in a study session for a midterm exam. The study session was getting frustrating because the exam was made up primarily of open-ended questions, and it was difficult to establish any kind of consensus on how best to answer them. The other participants attributed these difficulties to the particular content of soil science, which involves a great deal of uncertainty at both the microscopic and landscape scales. Case 1, in agreeing with this assessment, tellingly revealed a subtle different in approach however. Case 1’s description focuses instead on the math underlying the two fields: instead of saying that physics is more certain, or more obviously based
on observable reality, Case 1 argued that studying physics is easier because there are more direct links to math, which provides the learner with an alternate means to explain or understand key concepts. Like most of Case 1’s epistemological stances, this approach neatly sidesteps common assumptions of the scientific method without assuming any kind of objective reality separate from the knower.

**Interpretation of Case 1**

Case 1’s fluid integration of policy and science involved the reconceptualization of policy from a negative kind of social practice to a more acceptable kind of social practice comparable to science. The idea of an “acceptable” social practice is firmly rooted in Case 1’s epistemological approach to science: because Case 1 denies reference to reality as an arbiter of truth, science becomes a social process of interpreting and reinterpreting individual experiences. In this case, the epistemological features of the integration are more apparent than the conceptual ones. It is not clear, for example, exactly what the differences are between “good” social practices like science, and “bad” social practices such as Case 1’s initial characterization of politics. The fact that Case 1 continued to view “politics” negatively however, suggests that the change in understanding of “policy” was a kind of recategorization. Initially “policy” was in a category along with “politics,” but was later moved to a less negative category.

**B. Case 2**

<p>| Table 3 – Case 2 Summary |</p>
<table>
<thead>
<tr>
<th>Form of Integration:</th>
<th>Addition of policy-relevant and policy-mediated processes into a complex, layered understanding of the nitrogen cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Understanding of Policy:</td>
<td>Conceptual change – policy-as-an-objective-system to policy-as-a-dynamic-human-process</td>
</tr>
<tr>
<td>Epistemology Structure:</td>
<td>Cohesive and organized, but ultimately too complex to be understood as a single coherent system</td>
</tr>
<tr>
<td>Justification:</td>
<td>Accumulation of unbiased observations lead to increasing certainty that observations reflect objective reality and are therefore true</td>
</tr>
<tr>
<td>Social:</td>
<td>Specialists often have to interact in order to develop more useful understandings of field-scale ecological processes</td>
</tr>
</tbody>
</table>

Case 2 integrated science and policy by adding political and social considerations to an understanding of the nitrogen cycle. In early descriptions of the nitrogen cycle, Case 2 was, in the participants’ own later judgment, “plant-centric.” This was referring primarily to the scope of the explanation which focused on a single plant and explained the movement of nitrogen through and around that plant. Case 2’s understanding was further divorced by policy, however, by the theoretical ways in which “nitrogen” was discussed as a series of measurable forms and known transformation mechanisms. This is in high contrast to Case 2’s later depictions which included human-scale and anthropogenic processes and pools such as “industrial discharge” or “automobile emissions.” These later descriptions of the nitrogen cycle were, again in Case 2’s own words, “a mess,” because they included detailed descriptions of the cycle at both scales – the human-centric view did not replace the plant-centric one, but was added to it. This is an example of beneficial integration of science and policy because it shows that Case 2, without too much additional effort, can place basic science questions in the broader context of human activities and observable entities.

Case 2’s understanding of public policy was also significantly enriched during the course of the year. In Case 2’s first description, policy was defined as “governments that regulate different
aspects of business and of personal life-- not personal life so much but just the way society is regulated.” He went on to list examples of legislation that limit or encourage behavior based on the government’s goals. This view of policy deemphasized the role of individuals in the policy process, and, by attributing it primarily to the role of the government, distances it from Case 2’s experiences. His later definition was “A policy is-- I mean, it's a social construct that we all agree to follow because we all agree it's in our best interest, or a majority of the people agree it's in our best interest…whether it be the Clean Air Act or whether it be like, you know, waiting in line for the water fountain is better than a random chaotic mob trying to fight over the water fountain.” This understanding is significantly different in that it now includes individuals like Case 2 (in that “we all agree it’s in our best interest”), and places more emphasis on policy as the outcome of a group process. Case 2’s first definition described policy purely as a thing that existed, a “system of regulation,” with little reference to how such things come to exist or could be expected to change. This later definition includes explicit reference to the complex social processes that lead to the creation of policies.

Epistemologically, Case 2 is most clearly characterized by a strong belief in the authority of science to represent reality. Primarily, this relates to the Justification dimension of epistemology, in that Case 2 strong believed that knowledge could best be justified through the use of the scientific method, which is a proven means of ensuring that observations and explanations best match reality. Of all the participants, Case 2 was by far the most likely to “look something up” during a discussion, or to refer to published or authoritative accounts when faced with challenges during research. These behaviors further provide further evidence of Case 2’s emphasis on scientific processes (i.e. reviewing and citing literature), and the existence of
one answer that was ultimately correct because it best reflected reality. This seeming “faith” in science, however, was offset by a characterization of scientific knowledge as highly particularized. Case 2 frequently referred to the complexity of natural systems in terms of how they shaped scientific and research endeavors by limiting grand theories or large increases in anyone’s understanding of an ecological system. Case 2’s characteristic approach to knowledge was most clearly expressed in a discussion about whether everything follows rules (the particular example was thunderstorms, as taken from the Epistemological Beliefs About Physics Survey).

The problem is that we just don’t have the ability to understand the full mechanics of that particular storm at that time. Or it’s happening between the molecules in the air. But it all follows a logical pattern. And if you somehow had the ability to see that, it would make sense. It’s not just like a random occurrence. That follows a set of rules, but the problem is that the rules are so- like it happens so quickly that, I don’t know, it’s so unavailable to us that we can’t- at a practical level, it’s random. But in reality, they’re following a set of rules of reactions.

In this single line of reasoning, Case 2 clearly expresses beliefs in the inherent power of science to describe reality (“if you had the ability to see that, it would make sense,”) as well as the stipulation that the inherent complexity of the natural world sometimes limits the application of science.

This emphasis on specialization means that Case 2 included some social processes in his description of scientific knowledge. In Case 2’s view, the inherent complexity of the natural world limits the potential for any single person to fully understand a system, and therefore better
representations of reality are achieved through collaborations. While it may seem trivial to acknowledge that collaboration can increase one’s understanding, the key feature for understanding Case 2 epistemologically is the way in which the collaborative understanding of a system is privileged over any individual specialists’ approach.

*Interpretation of Case 2*

Case 2 accomplished the integration of science and policy through two learning processes. First, Case 2 began to think of policy as a fundamentally different kind of thing. In the terminology of conceptual change, this is referred to as an “ontological shift” which occurs at a very high cognitive level. The second process of learning was the integration of this new understanding of policy with an existing understanding of the nitrogen cycle. For Case 2, this integration was achieved through a mental model revision. The addition of significantly new and different perspectives to his existing conceptualization of nitrogen cycling is more complicated than a simple belief revision, but it is not as a conceptually basic. It is notable how Case 2’s epistemology, which allows for multiple perspectives insofar as they contribute to a richer scientific understanding of reality, accords with this form of integration. Although Case 2 went through a surprisingly broad conceptual change in terms of understanding of policy, the effect of this change on Case 2’s understanding of policy-relevant nitrogen cycling was limited to additions to mental models.

C. Case 3

<table>
<thead>
<tr>
<th>Table 4 – Case 3 Summary</th>
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</thead>
<tbody>
<tr>
<td>Form of Integration:</td>
</tr>
<tr>
<td>Understanding of</td>
</tr>
<tr>
<td>Epistemology</td>
</tr>
<tr>
<td>-------------</td>
</tr>
<tr>
<td>Structure:</td>
</tr>
<tr>
<td>Social:</td>
</tr>
</tbody>
</table>

Case 3 stands out particularly for the broad physical scale of the given explanations of the nitrogen cycle. When generally describing the nitrogen cycle, Case 3 said,

I guess because the biggest human perturbations are our nitrogen cycle has been increasing the amount of biologically available nitrogen, and so a lot of research has sort of been directed at understanding what those effects are on natural systems that we can’t help influencing, like nitrogen depositing in, like, forests, far away from the nitrogen source. And also more direct certain impacts like agricultural fields right up against rivers and then all of this runoff and what's going on there. And then how much it’s impacted marine life. We’ve heard of, like, the dead zone in the Gulf of Mexico, and there's problems in the Colombia.

This explanation flows back and forth between multiple physical scales (a single farm to the Gulf of Mexico), and is also notable for the integration of scientific and political frames of reference. Case 3 approaches the nitrogen cycle as a societal problem (the “increasing amount of biologically available nitrogen) that is being partially addressed through science by “understanding what those effects are.” The science is even further framed in terms of policy because Case 3 notes the emphasis is on “natural systems that we can’t help influencing.” Case 3 does not mean that it is technically impossible, or even objectively undesirable to not influence
those systems (for example by depositing nitrogen in otherwise pristine forests), but that it is,
especially, a political reality that must be addressed. In the last explanation of the nitrogen cycle, Case 3 chose to depict it at the global scale as a kind of mental exercise, and because “I hadn’t seen one like that before.” Case 3 was the only person (including faculty that were interviewed as part of the broader study) to draw a global nitrogen scale that emphasized human-scale processes (like the transportation of synthetic fertilizer from where it is produced to where it is applied to the ground) more than those of a technical scale attached to a particular field of science (for example, the biologically mediated chemical reactions which transform applied fertilizer into microbial biomass). This can be seen as an increase in Case 3’s ability to integrate science and policy because this new approach to old material immediately and accurately. This flexibility in scale enhances the integration of science and policy because it better matches the science to the multiple layers of policy (intergovernmental, federal, regional, local) that operate on any given environmental problem. Case 3 is able to address problems not only in a broader scientific context, but in the broader political context that defined the situation as a “problem” in the first place.

Case 3’s early understanding of public policy focused on governmental regulation, but included more aspects of a more nuanced understanding that were notably absent from the other participants’ initial views of policy. For example, when asked how policy was created, Case 3 said, “I think, well, the ease of creating policy would obviously vary depending on how many people care about its outcome. So at a national level, I imagine it to be a lot trickier and more complicated than maybe at a city level.” Case 3 later added,
That’s just part of it: lots of different people want to be appeased and there should be ways of dealing with that. I don’t know if you should really call it a utilitarian approach, but like a way to address everyone’s needs without ignoring people due to socioeconomic issues or how loud they shout. It’s just like a part of making policies, that people want different things.

This initial view of policy was that it was fundamentally a group decision-making process, but that nuances of scale and other social features complicated it beyond a simple definition. Case 3’s understanding of policy did develop throughout this year, however, at least in terms of an ability to connect the various aspects of it. Case 3’s final definition of policy was “Political will translated into legislation, and its associated interpretation…and implementation.” This is a significantly more complex approach that the previous definitions, and includes terminology not previously used in order to combine the ideas that were expressed somewhat disjointedly in the earlier interviews.

Case 3’s approach to epistemological issues is best presented in Case 3’s own words: “It’s not uninteresting or unimportant. I feel like I just-- it’s sort of like auxiliary to what I'm doing…Sometimes I open the box, sometimes I don’t.” This statement came at the end of a somewhat unsuccessful line of questioning intended to encourage Case 3 to address the epistemological dimension of Structure. Case 3’s approach is characterized by a general lack of interest in the “truth” or “reality” of knowledge, and is instead focused more on its usefulness as an explanatory tool (the Justification dimension). When asked about “truth” as a potential goal of science, Case 3 said, “It just sounds so scary and definitive. I don’t know. Just like interpreting my
experiences and like how it’s going to be, so we’re just trying to explain things to ourselves you’ve been experiencing, I guess.” The interviewer asked, “So what is science trying to do then, if not trying to answer to truth?” and Case 3 replied, definitively, “Explain the world satisfactorily to us and hopefully to understand things better. [Then] we can make things that we’d like and the predictions that are helpful.” Case 3’s characteristic use of pronouns is revealing of an epistemological stance. Case 3 believed that scientific knowledge was highly structured, but only on an individual basis. *Structure* was addressed in the first person and focused on a personal approach to learning, which was described as a process of fitting new knowledge into an existing “jungle gym” of concepts. In addressing *Justification*, however, Case 3 shifted to the pronoun “we,” matching the emphasis on the social process of explanation. For Case 3, the social manifestations of knowledge (explanations or consensus) are more real than any internal cognitive structures or “jungle gyms” that people might use in generating those explanations. In explaining the frustration with some abstract epistemological questions, Case 3 said, “And this table is not here? I don’t care because I can see it. Like, you know what I mean? We established there is a real table. <laughs> I think it’s just about explaining our world to us, and so whether or not it’s real doesn’t matter. It [science] is just a way to find out about, like, explain what we’re experiencing.”

*Interpretation of Case 3*

Case 3’s initial understanding of science and policy were already closely combined. Although learning occurred, it is of a fundamentally different sort than that described for the previous cases because it did not require changes to mental models or framework theories: Case 3 maintained the same basic approach to policy and nitrogen cycle, but elaborated on it. Epistemologically,
Case 3’s disinterest in the objective reality of any finding in favor of its utility in explaining the world naturally encourages the integration of science and policy.

D. Case 4

<table>
<thead>
<tr>
<th>Table 5 – Case 4 Summary</th>
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<tbody>
<tr>
<td><strong>Form of Integration:</strong></td>
</tr>
<tr>
<td><strong>Understanding of Policy:</strong></td>
</tr>
<tr>
<td><strong>Epistemology</strong></td>
</tr>
<tr>
<td><strong>Structure:</strong></td>
</tr>
<tr>
<td><strong>Justification:</strong></td>
</tr>
</tbody>
</table>

Case 4 included reference to political processes in the earliest discussions of the nitrogen cycle, and this approach did not change noticeably from the beginning to the end of the year. Case 4 described policy and political processes as a kind of final check on solutions to scientific problems. Case 4 emphasized the ways political processes can limit the viability of otherwise sound scientific solutions to problems. In one course, for example, there was an extended discussion of how flooding effects the nitrogen cycle, and a general conclusion was that more flooding could decrease the negative effects of reactive nitrogen in water bodies. Case 4, however, was surprised that anyone would even hypothetically consider flooding as a management solution, because “I think there's going to be a lot of farmers that aren’t going to see eye to eye with you on that. It would be creating a huge problem.” In response to questions about the “big ideas” behind the nitrogen cycle, Case 4 noted, “I think that probably even bigger than, you know, ‘humans in their environment’ is like…not pissing everyone off.” This type of integration is distinct from that expressed by other cases (particularly Case 1 and 3) in that...
science and policy are still largely distinct. Whereas Case 1 and Case 3 seemed to meld science and policy into a single way of approaching the nitrogen cycle, Case 4 applied politics as an additional consideration to scientific thinking. For example, in the final explanation of the nitrogen cycle, under the same prompting that led Case 3 to draw a global scale cycle, Case 4 focused on a single experimental set-up. When asked, Case 4 was able to indicate how this small-scale explanation related to human-scale processes (e.g. industry and agriculture), but for Case 4, this explanation was separate from his explanation of the nitrogen cycle.

Case 4’s approach to public policy did not change significantly over the course of the year. Each explanation of policy represented it as a way of doing things. Case 4 defined policy at the beginning of the year as “a little bit more loose than a law or a regulation. Just kind of like, ‘Okay, here’s what we’re going to do for a while,’” and at the end of the year as, “the way some system is going to work, like an operating procedure about how things would be done.” Case 4 most often placed it in the context of governmental bodies, particularly regional and state-scale environmental regulatory agencies. While the other participants had to change their understanding of policy in order to incorporate concepts of “group decision-making,” Case 4’s initial approach was already consonant with these ideas. In another of his definitions of policy as a way of doing things, Case 4 said “but it’s also when an action is taken as someone’s policy to add organization, security, liberty, equity to whatever structure that the policy is set within.” This acknowledges values (e.g. security or equity) as part of the policy process.

In terms of the three dimensions of epistemology, Case 4 stood out as believing the most strongly in the coherence and structure of scientific knowledge. In some cases, the highly
structured organization of scientific knowledge was frustrating, because Case 4 did not consider knowledge “learned” until it was fully integrated with all related knowledge and understanding. This was evident in the questions Case 4 asked in courses, which almost exclusively compared course content with other findings, as well as in Case 4’s often surprising ability to connect bits of seemingly unrelated knowledge. A favorite example occurred when Case 4 answered a question about late-stage primary succession by saying, “it’s what killed Socrates.” The logical link (imminently more obvious to Case 4 than anyone else involved in the conversation) is that late-stage primary succession is dominated by hemlock forests, and Socrates is said to have killed himself with hemlock poison. When asked about it later, Case 4 explained that it was mostly a joke, but that it was also intended to be helpful because “that’s just how I remember it.”

In some ways Case 4’s firm belief in the coherence of scientific knowledge related to the belief that it was based on an objective reality. In other words, in the Justification dimension Case 4 believed strongly in evaluating knowledge based on its approximation of truth. Case 4 was the only participant to comfortably and frequently use works like “truth,” “right” or “wrong” when discussion knowledge or understanding. Finally, Case 4’s emphasis on a coherent, objectively true form of knowledge also affects the Social dimension of epistemology. Highly structured knowledge based on an objective reality implies that truth is independent of the individual. For Case 4 this means that while other people may be an important resource in developing understanding (or, at a larger scale, political processes may be an important reference for shaping science outcomes), these social processes are only one among many potential resources.
Interpretation of Case 4

Case 4’s epistemology supported a particular understanding of the relation of science to policy, and constrained changes in this relationship. Case 4’s epistemological conviction in the essential organized structure of reality (and, consequently, the essential coherence of scientific knowledge) characterizes scientific progress as a process of gradually identifying human misconceptions and eliminating them so that the correct conception can be fitted into the overall structure. For Case 4, policymaking and indeed any essentially social practice is incommensurable with science because it would interfere with that process. It makes sense then, that Case 4’s approach to integrating science and policy is a sequential one, in which policy considerations are attached to the end of a scientific problem-solving process.

V. IMPLICATIONS OF CASE STUDIES

This section will describe the four primary implications of these case studies for the broader context of trying to increase the interaction between science and policy.

A. A More Specific Characterization of “Epistemological Distances”

While it is tempting to try to identify the single epistemological dimension that has the most effect on the interaction of science and policy (for example, different stances on the Social Processes of Knowing seemed to correspond to different understandings of policy), these cases show that individuals’ means of relating their stances to the three epistemological dimensions are as important as their stance on any given one. For example, both Case 2 and Case 4 expressed strong beliefs in the primacy of scientific methods in the justification of knowledge. Their differences in stances on the Structure of Knowledge, however, related to drastically different stances on the Social Processes of Knowing, which, in turn, constrained the ways in which
science and policy could be integrated. No one aspect of their epistemologies could explain their different approaches, but instead they each must be taken as an interacting system.

In addition to the potential tensions between scientists and policymakers caused by different epistemological stances, these case studies highlight the potential for tensions arising from different conceptions of policy itself. A great deal of attention has been paid to increasing “scientific literacy” (for example see National Academy of Sciences, 2007), but political literacy has not been emphasized in the same way. The initial understandings of policy expressed by Cases 1 and 2, for example, could lead to the same kinds communication challenges or contradictory goals associated with epistemological differences. Additionally, the conceptual change framework provides a means for comparing the effort necessary, or the general probability of different types of change. Case 2, for example, was able to recategorize policymaking as a legitimate kind of social practice because the category of “legitimate social practice” already existed (due to Case 2’s epistemological refusal to classify science as anything other than a social practice). Conceptual change theories show that this recategorization process, while difficult, is not as difficult as it would be if the category did not exist (i.e. if a person’s epistemology did not allow for social practices that were valid) (Chi, 1992; Chi & Roscoe, 2002). The potentially different kinds of learning and the importance of the interactions between the dimensions of epistemology suggest that there could be a typology of different challenges in integrating science and policy. Very abstract conceptual changes that were epistemological disfavored may not be possible to accomplish in efforts to incorporate more science into policy, but other types of conceptual change within epistemologically favorable conditions may actually be easier to encourage than commonly supposed.
B. A More Complicated Picture of “Scientists”

The epistemological differences among the cases discussed here were significant. In the broader debate about the interface of policy and science, however, scientists are often assumed to be epistemologically homogenous, at least compared to the scale of differences between scientists and policymakers. Although there is no absolute scale of epistemological differences, contemporary research on individuals’ epistemologies is based on models (King & Kitchener, 2004; Kuhn, Cheney, & Weinstock, 2000; Perry, 1970) that would place Case 1 and Case 4 at opposites ends of a spectrum. In other words, within the scope of epistemology as it is currently understood, it is difficult to imagine an epistemological difference between scientists and policymakers that is greater than the differences between these two scientists. An important step in moving forward in addressing these epistemological distances is to stop attributing them to monolithic communities of like-minded peers.

C. A Potential Explanation of the Benefits of Transdisciplinary Research

Case 1 and Case 3 suggested potential epistemological implications of engagement with transdisciplinary research. Both of these Cases incorporated the sharing of specialized knowledge in their stance on the Social Processes of Knowing dimension. This type of sharing between equally valued but divergent knowledge bases may not be unique to transdisciplinary research endeavors, but it is definitely more common in that context than in traditional academic science. This sharing is fundamentally different from common definitions of teaching (which is common in traditional academic settings) because the understanding of everyone involved is equally valued. Different explanations or approaches to the same phenomena cannot be dismissed in this context (as they can in “teaching” contexts where students’ understandings are expected to be different from experts’, and to the extent that they are different are dismissed as
“wrong”) and therefore they must be epistemologically accommodated. These epistemological accommodations could remove or alleviate some of the barriers to the integration of science and policy.

VI. POTENTIAL FOR FUTURE RESEARCH

These cases studies raise a number of new and interesting questions. First, although it can be assumed the doctoral students in science programs associate themselves with “scientists” to some degree, these kinds of identities were not investigated here. This could be important because the participants identities with regards to “scientists” and “policymakers” would shape their response to the perceived epistemological mismatch between them. In the simplest case, someone who strongly identified as a scientists may be more inclined to reject challenges to what they perceive as the scientific approach. Similarly, differing degrees of identification as a political entity may be an important factor determining how individuals attempt to integrate science and policy.

Secondly, the participants described in these case studies were all in different doctoral programs, and had different scientific training and backgrounds. Little is known about how environment and life experience contribute to epistemological stances, but it seems likely that disciplinary differences could lead to epistemological differences. Case 1, for example made frequent references to the ubiquitous uncertainty and variability characteristic of their core research topic, and explicitly linked these experiences with a relativist epistemology. It is likely a complex interaction between the epistemological stances that are drawn to a particular field and the ways in which training in a field can affect epistemological development. The affects of disciplinary
training on epistemology remains a complicated and open question, but it could be vital part in future plans to address epistemological distances that limit the interaction of science and policy.
VII. REFERENCES


Comparison of Diffusion of Innovations Theory and Concerns-Based Adoption Model in Engineering Education

I. INTRODUCTION

Engineering educators are often in the position of evaluating new curricular innovations due to constant efforts to improve engineering education. Curricular innovations can take many forms, from concrete and reliable assessments to abstract philosophical approaches to pedagogy. Understanding how engineering educators come to understand new innovations and how they make decisions about their use is important for the developers of these curricular advancements because it can help them to better market their innovations or to encourage broader adoption. More importantly, however, understanding the adoption of curricular innovations is also important to engineering educators who see themselves primarily as consumers of these advancements. In order for most innovations to achieve their desired effects on the enterprise of engineering education, they must be widely adopted. Understanding the adoption process is a step toward comprehending how complex social systems (for example, engineering departments) change, and is a key part of encouraging positive changes. This study begins this process by examining two different theoretical approaches to such changes in terms of how they describe the adoption of the same innovation.

II. BACKGROUND

A. The Innovation

The innovation in this study is the Team Citizenship Assessment Instrument (TCAI); one part of a suite of assessment instruments currently being developed for widespread use in capstone design courses. The various evaluation tools were developed to help engineering
educators achieve important educational outcomes such as teamwork, communication and design skills (ABET Accreditation Commission, 2010). These assessment tools were developed by a group of diverse and experienced engineering faculty at various institutions.

At the time of this study, the assessment developers were in the process of piloting their first assessment instrument, the TCAI which consists of a questionnaire to be given to each student in a capstone design team. Each team member rates the others’ contributions to the team, communication skills and team effectiveness. The TCAI was designed to be flexible and to fit within as broad a range of course designs as possible. For example, the TCAI could be implemented verbally by a faculty advisor with one small team in an effort to promote more productive attitudes toward teamwork, or could be used in written form by a course instructor to evaluate the quality of students’ feedback at the beginning and end of the course. Although the TCAI was designed primarily to serve as one of a suite of assessments intended to cover the full range and content of capstone courses, it can also be used as a stand-alone instrument.

The sharing and adoption process of the TCAI described in this study involved three very different and internally diverse groups: (1) the developers, (2) colleagues of the developers who have agreed to use it in their capstone courses and, (3) people who have attended workshops about the capstone assessment instruments. The workshop participants, faculty users and developers all have significantly different interactions with the TCAI, and therefore would be expected to have significantly different adoption perspectives and experiences. In both theoretical frameworks applied in this study, interaction with an innovation is the primary force driving the adoption processes. These three groups, then, represent theoretically and practically important and distinct adoption processes.

B. Theoretical Frameworks
There are a variety of approaches to studying adoption and institutional change, but two approaches – The Concerns Based Adoption Model (CBAM) and Diffusion of Innovations theory (DI theory) – are clearly more established and prominent than the others. These frameworks have significant overlap, but their approaches are subtly and fundamentally different. Both approaches are explicitly framed to guide interventions intended to increase the adoption of an innovation, and have been proven to be effective in this role. There is less empirical evidence, however, supporting their underlying explanations of the adoption process. There is no direct evidence supporting the choice of one framework over the other for any new context under study. Two studies have begun to address the applicability of these frameworks to engineering education (Turns et al., 2007; Borrego, Froyd and Hall, 2010), but neither has been investigated with respect to a single innovation with a focus on the respective benefits of each approach in the context of engineering education. This study will contribute to both CBAM and DI theory with the ultimate goal of contributing to the development of a model of adoption specific to engineering education.

C. Literature Review

1) CBAM and DI in Engineering Education. Both Borrego, Froyd & Hall’s (2010) paper utilizing the Diffusion of Innovations Theory (DI) and Turns et al.’s (2007) paper utilizing the Concerns Based Adoption Model (CBAM) emphasized the need for more detailed information on the interactions between faculty and administrators and the multiple roles they play. Borrego, Froyd & Hall (2010) surveyed engineering education administrators in order to understand their awareness and adoption of a set of well-established pedagogical innovations. They found that awareness of innovations far exceeds adoption of them, and proposed that interventions that were personalized to each department might close this gap. Personalization, however, requires further
research into how each department’s context and needs affect its adoption process. Most administrators surveyed were far more likely to become aware of an innovation through word of mouth or a presentation they attended than through publications. They recognized that not all adoption decisions are made by administrators, but noted, “Administrators claim that teaching changes are faculty-level decisions; on the other hand, faculty members…emphasized the important role of administrators” (Borrego et al., 2010, p. 203). They call for future research to investigate the actual interactions between faculty and administrator decision-making processes, specifically calling for “… at least one line of future research [that] should focus more deeply on a smaller number of organizations…” (Borrego et al., 2010, p. 203).

Turns et al. (2007) investigated the “teaching concerns” of engineering educators by analyzing consultation sessions with an instructional specialist. They found a variety of teaching concerns that did not easily fit within the framework of the Concerns Based Adoption Model. One major finding was that engineering educators’ teaching concerns are inseparably affected by the multiple roles they play in a university as mentors, instructors and researchers.

2) **Summary of Literature and Rationale for this Study.** Although the Concerns Based Adoption Model and the Diffusion of Innovations Theory have been applied in engineering education and have successfully identified elements of key importance, authors have concluded that more detail is needed to better understand the interactions between those key elements (Turns et al., 2007; Borrego et al., 2010). These conclusions match calls among adoption researchers using both frameworks for more “actor-centered” studies (Haggman, 2009) that include enough detail to describe individuals’ processes of adoption (Damanpour, 1996; Wejnert, 2002). Furthermore, there is very little direct evidence to support the choice of CBAM over DI Theory, or vice versa. This study is closely focused on a single innovation in the early stages of
adoption. This naturally limited scale made it possible to attempt to collect data from every person who is aware of the TCAI, and to interpret that data within each framework.

III. PURPOSE AND RESEARCH QUESTIONS

The purpose of this study is to examine the applicability of existing models of adoption and diffusion to engineering education by investigating the early adoption of one innovation. To achieve this purpose the following research questions will be addressed:

1. How do the factors identified in CBAM and DI Theory interact with and affect the TCAI’s adoption?

2. How do the descriptions of the adoption process generated by CBAM and DI Theory compare, contrast and complement each other?

IV. METHODS

A. Research Approach

This study is based on the phenomenographic approach to research. Phenomenographic research deals with collecting and describing individuals’ experiences (Marton, 1981), or, more generally, their experiences of a particular “conception” (Svensson, 1997). This type of research is contrasted with more positivist attempts to define and capture data about a universal, objective reality (Svensson, 1997). Phenomenography is particularly well suited for this study because (1) as the TCAI develops and is used by numerous people, there is no one definition of it on which to base research into its adoption; (2) people’s perceptions and beliefs about the TCAI are much more important in their adoption behavior than the description of it generated by an outside researcher, and; (3) as in phenomenography, the analysis in this study relies on collecting and comparing many people’s interpretations of the conception of interest (in this case the TCAI) in order to draw meaningful conclusions (Marton, 1981; Marton, 1986).

B. Participant Selection
All of the workshop participants, faculty users and developers of the TCAI were invited to participate in this study. In total, 23 people were potential adopters of the TCAI, of which 16 agreed to participate. Throughout the rest of this paper participants will be identified in terms of their participant group. W1 through W6, for example, refer to the six workshop participants who were interviewed.

1) Workshop participants (6 Participants): This study was performed approximately five months after a workshop was held at a national engineering education conference that introduced attendees to the TCAI. Of the eleven workshop participants, six were interviewed, two did not respond to attempts to contact them, two declined to be interviewed due to time constraints and one agreed to be interviewed but responded too late to be included in the study. During the five months between the workshop and the interviews the participants had all started a new semester or quarter of capstone courses. At this time they had an opportunity to choose to adopt the TCAI, or to continue to seek out information about it.

2) Faculty users (5 Participants): Through interaction with the project development team, some faculty members at each university had already adopted the assessment instrument. As reported by the developers, these five participants are the only people other than the developers themselves who had used the TCAI at the time of the study.

3) Developers (5 Participants): Interviews were conducted with five of the seven members of the development team. The other two developers cited busy schedules and time constraints when declining the invitation to participate.

C. Data Collection

Data was collected in two ways for this study. The primary method was through semi-structured interviews with the participants, described below. Additionally, the workshop
introducing the TCAI was audio recorded, and the two-day developers’ meeting focusing on its final revisions was observed and audio recorded.

1) Interview Methods: Semi-structured interviews were conducted over the phone with follow-up and clarification questions through e-mail when needed. An interview guide was used to ensure comparable coverage of the participants’ use and impressions of the TCAI while maintaining the flexibility needed to understand each individual’s responses to the standard questions (Ginsburg, 1997; Seidman, 2007). Table 1 shows a simplified version of the interview guide edited for clarity. As shown in Table 1, the interview questions were formulated in language that addressed the constructs of both theoretical frameworks with wording appropriate for both users and non-users. Because the frameworks are based on the adoption process as it happens, questions that explicitly focus on the process (but are not biased towards any particular theoretical framework) are required. This allowed responses to be relevant to both theoretical frameworks guiding the research, as well as making it possible for participants to describe their experiences in their own preferred terms. Participants were also asked demographic questions about their employment, teaching and design experience, capstone experience and questions specific to their participant group. The developers were asked if anyone else at their university was using the TCAI, and how they encouraged others to use it.
<table>
<thead>
<tr>
<th>Example Questions for Users</th>
<th>Example Questions for Non-Users</th>
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<tbody>
<tr>
<td>Any troubles so far?</td>
<td></td>
</tr>
<tr>
<td>What’s your favorite part about using it?</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Are you planning on changing anything before your next use?</td>
<td>What more would you want to know about it?</td>
</tr>
<tr>
<td>How does it compare to previous tools?</td>
<td>What do you currently use and how does it compare?</td>
</tr>
<tr>
<td>How can you tell if it’s working or not?</td>
<td>What interested you in the workshop?</td>
</tr>
<tr>
<td>Have you made changes to suit your class?</td>
<td>What interested you in the workshop?</td>
</tr>
<tr>
<td>How has the implementation gone?</td>
<td>Does it seem sufficiently robust to accomplish your goals?</td>
</tr>
<tr>
<td>Did you try it out first? How was the first implementation?</td>
<td>Would you be interested in trying it?</td>
</tr>
<tr>
<td>What do your colleagues think of it?</td>
<td>What do you think your colleagues would think of it?</td>
</tr>
</tbody>
</table>

Table 1. Interview guide with prompt questions.

The first interviews ranged from 20 to 40 minutes. This length of interview reflected the range of experience the participants had with the TCAI. A faculty user who had used it once because they were asked to, for example, wouldn’t be expected to have as much to say as a developer who had been involved with it over the course of years. Attempts to prolong the interviews resulted in a form of data saturation where participants would repeat themselves, or refer to earlier statements by saying, for example, “It’s pretty much like I said before.” Participants were asked multiple forms of the same general questions in order to allow for triangulation within the interviews. For example, each participant was asked, “What was your first impression of the instrument?” as well as, “What stands out to you about the instrument?” and, “What do you like and dislike about the TCAI?” The interview guide was refined after the first two interviews to rephrase questions that participants found too repetitive, and to clarify others to ensure that they referred to the constructs of interest.
It is also important to note that these interviews were not intended to allow the researchers to completely describe each participant’s context. Instead, the purpose of this research relies on identifying which aspects of the participants’ contexts were most important to them in describing their adoption process.

D. Analysis Procedures

Following the general outline of what Braun and Clarke (2006) call inductive thematic analysis, the analysis progressed in four iterated phases. The first phase of coding was entirely inductive, meaning that it was “…a process of coding the data without trying to fit it into a pre-existing coding frame, or the researchers’ analytic preconceptions” (Braun and Clarke, 2006, p. 83). This inductive phase increases a study’s credibility and trustworthiness by providing a descriptive touchstone against which to test all the later interpretations and conclusions (Lincoln and Guba, 1985; Patton, 2002; Creswell, 2007).

The second phase involved constructing a description of each participant from the perspective of the two theoretical frameworks. In this phase the codes were all predefined based on the theoretical frameworks and then applied to statements in the transcripts of the interviews and meetings. Separate from its role in preparing for the third phase of analysis, this phase provided the means to compare the relative strengths of and prevalence of participants’ perceptions. For example, the participants’ “key concerns” will be presented in the CBAM results sections below. The identification of such “key” elements relied on the results of this phase of analysis. The relative importance of an element (such as the participants’ concerns) was based both on how frequently it was repeated or referred to, and how strongly it was stated.

The third phase is described by Braun and Clarke (2006) as the construction of themes, and is very closely related to the second phase through iteration. In this phase the previously
generated themes were investigated for interactions and relationships. The iteration occurs because this phase requires constant comparisons between the researchers’ accumulated inferences and the actual, raw data.

The purpose of the final phase was to bridge the two theoretical frameworks in order to draw out comparisons and general findings. This stage made extensive use of what Miles and Huberman (1994) call “matrices,” which are basically means of reducing and visualizing qualitative data. For example, several tables were created that grouped participants in rows according to different characteristics. These tables could then be compared in order to investigate the co-occurrence of characteristics with themes and other attributes. It is important to note that even at this stage each new finding was checked against actual participant statements. This is what makes the process iterative, and is sometimes referred to as the “constant comparative method” of qualitative analysis (Maykut, 1994). The themes are combinations of the previously interpreted codes, and therefore must be frequently checked against the participants’ actual statements in order to avoid successive approximation or other forms of bias (Maykut, 1994; Miles and Huberman, 1994).

E. Limitations

The data collection methods used limits the potential implications of this research. The participant selection is not representative of a larger population of interest, and therefore limits the generalizability of the findings. Therefore, the purpose of this study is limited to identifying interactions and relations that are important in the cases of the particular participants involved, and thereby providing guidance for future, potentially generalizable research. In other words, although the data collection limits the generalizability of the results, it does not diminish the
veracity or importance of the relationships revealed in this study, and therefore can still contribute to future research by providing a basis for hypothesizing about larger-scale patterns.

V. CBAM BACKGROUND

For purposes of clarity and ease of understanding, the background, results and discussion section for each framework will be presented separately. After both frameworks are presented, a synthesis section will draw conclusions from their combination.

The Concerns-Based Adoption Model (CBAM) was developed to describe the process of “teacher change,” using three analytical tools: Levels of Use, Stages of Concern and Innovation Configurations (Hall, 1974). Later developments in the model have increasingly emphasized context as a fourth construct of importance (Hall and Hord, 2006).

A. Levels of Use and Stages of Concern

The Levels of Use describe how adopters behave in relation to the innovation, and how that behavior develops over time (Table 2). Stages of Concern are organized around a developmental chain similar to the Levels of Use, and describe adopters’ attitudes toward a change (Table 3). They are generally considered to be developmental, with all adopters proceeding through the same stages.

<table>
<thead>
<tr>
<th>Level of Use</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>L0 – Non-Use</td>
<td>Not yet using or seeking to use the innovation</td>
</tr>
<tr>
<td>L1 – Orientation</td>
<td>Working to understand the innovation</td>
</tr>
<tr>
<td>L2 - Preparation</td>
<td>Working toward first implementation</td>
</tr>
<tr>
<td>L3 - Mechanical Use</td>
<td>Working to implement the innovation</td>
</tr>
<tr>
<td>L4 A – Routine</td>
<td>Use is comfortable and unchanging</td>
</tr>
<tr>
<td>L4 B - Refinement</td>
<td>Use is changing to increase effectiveness</td>
</tr>
<tr>
<td>L5 – Integration</td>
<td>User is collaborating with other users</td>
</tr>
<tr>
<td>L6 – Renewal</td>
<td>Efforts have moved to new innovations</td>
</tr>
</tbody>
</table>

Table 2. Description of CBAM's Levels of Use. Adapted from (Hall and Hord, 2006).
Concerns and Levels of Use, however, do not necessarily develop together. Note that while Turns et al. (2007) identified concerns that did not fit within CBAM’s seven stages, the context of their study was “teaching concerns” in general, while the research reported here is focused on one particular innovation. Additionally, as Turns et al. (2007) did not propose revisions to the CBAM Stages of Concern, the originally proposed seven stages were used to test their applicability to engineering education. The seven stages proposed by Hall and Hord (1987) are summarized below in Table 3.

<table>
<thead>
<tr>
<th>Stage of Concern</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>S0 - Awareness</td>
<td>Low concerns due to lack of experience</td>
</tr>
<tr>
<td>S1 - Informational</td>
<td>General interest in learning more about the innovation</td>
</tr>
<tr>
<td>S2 – Personal</td>
<td>Concerns related to how adoption will affect the adopter</td>
</tr>
<tr>
<td>S3 - Management</td>
<td>Concerns regarding using innovation efficiently</td>
</tr>
<tr>
<td>S4 - Consequence</td>
<td>Concerns related to how implementation is affecting students</td>
</tr>
<tr>
<td>S5 - Collaboration</td>
<td>Concerns regarding coordinating with other users</td>
</tr>
<tr>
<td>S6 - Refocusing</td>
<td>Concerns have moved beyond individual innovation to broader contexts or new innovations</td>
</tr>
</tbody>
</table>

Table 3. Description of CBAM's Stages of Concern (Hall and Hord, 2006).

B. Innovation Configurations

The concept of an innovation’s various configurations is used to describe how innovations tend to change as they are being adopted. Every user of an innovation utilizes it in a certain configuration, leaving out, adding or modifying aspects of the innovation and related practices. For example, a curricular innovation might involve a textbook, class assignments and lecture notes intended to be used in a certain time frame with a certain pedagogical approach. Potential Innovation Configurations could make use of any or all of these elements. One Configuration would be to use only the textbook, while another would be to use all of the other elements with a different textbook. In this study participants are said to “have” a particular Innovation Configuration. This refers to how they define and use or visualize use of the TCAI.
C. Contextual Features

Originally, CBAM studies focused on educational settings, primarily in the public K-12 school system. The developers of CBAM have attempted to broaden the model’s applicability beyond educational systems by including ways to describe different contexts (Hall and Hord, 2006). They divide context into two components: “physical features, such as the size and arrangement of the facility, and the resources, policies, structures and schedules that shape the staff’s work” and “people factors, which include the attitudes, beliefs and values of the individuals involved as well as the relationships and norms that guide behavior” (Hall and Hord, 2006, p. 14). More specifically, the developers’ use the concept of Professional Learning Communities to identify five features of contexts that promote change: “(1) shared values and vision, (2) collective learning and application, (3) supportive and shared leadership, (4) supportive conditions, and (5) shared personal practice…” (Hall and Hord, 2006, p. 26). In this use “supportive” means providing means and motivation to make changes in order to better achieve the shared values and goals of the community. These five characteristics were used as dimensions along which to measure the participants’ descriptions of their contexts.

VI. CBAM RESULTS AND DISCUSSION

A. Results

1) Levels of Use: Figure 1 displays the participants’ Levels of Use. The Developers (D1-D5) generally had the highest Levels of Use, followed by the Faculty Users (F1-F5) and then the Workshop Participants (W1-W6).
Figure 1. Participants’ Levels of Use.

Participants W1, W2 and W3 exemplified the Non-Use Level because they had all decided not to use the TCAI and were no longer interested in learning about it. W6, in the Orientation Level, was differentiated from Non-Use because she had not yet reached a decision, and was actively pursuing answers to questions about the TCAI. W4 represented the best example of the Preparation Level because although she had not yet used TCAI, she was thinking about how she would use it in the future, saying, “…if I felt like it [a particular instructor’s course objectives] was a good match for this instrument, I would definitely recommend it [the TCAI].” As examples of the Mechanical Level, F1–F4 typically talked about what they were “supposed to do,” or would comment on their own decisions with remarks such as, “I didn’t know what I could do with that [the students’ responses to the TCAI].” D3, in the Routine Level, used the TCAI comfortably without much variation between uses, speaking mostly about what he “usually did” and not referring to any particular use. Finally, the Refinement Level was most clearly exemplified by D4 and D5 who frequently referred to “tweaks” (in D4’s words) they made between each implementation in order to best suit the TCAI to their particular purposes.

2) Stage of Concern Profiles: Table 4 summarizes the concerns of all participants. Each participant expressed multiple concerns, but in each case one or two concerns were clearly dominant. These dominant concerns have been collected into profiles. In order to clearly
differentiate these profiles, which are specific to this implementation and analysis, they will be denoted with quotation marks. (This convention of noting constructs unique to this study with quotation marks will hold for the rest of this paper as a way to maintain clarity among the many theoretically specific words and concepts.) Similar to the Levels of Use, the Developers generally had later Stages of Concern than the Faculty Users who generally had later Stages of Concern than the Workshop participants.

<table>
<thead>
<tr>
<th>Profile Name</th>
<th>Key Concerns</th>
<th>Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. “Awareness and Management”</td>
<td>High Awareness and High Management</td>
<td>W1-W4</td>
</tr>
<tr>
<td>2. “Personal”</td>
<td>High Personal</td>
<td>F1</td>
</tr>
<tr>
<td>3. “Management”</td>
<td>High Management</td>
<td>F2 D1, D2</td>
</tr>
<tr>
<td>5. “Management and Consequence”</td>
<td>High Management and High Consequence</td>
<td>F5 D3</td>
</tr>
<tr>
<td>6. “Consequence”</td>
<td>High Consequence</td>
<td>D4, D5</td>
</tr>
</tbody>
</table>

Table 4. Profiles of participants’ strongest and most frequently cited concerns.

Awareness concerns are not really “concerns” in the same way as the other Stages of Concern. In this use they instead reflect the fact the participants remembered generally what the TCAI was, but did not have strong impressions of its strengths or weaknesses. As examples of the Awareness profile W1-W4 generally did not express concerns about the TCAI, and if so they were Management concerns. W3, for example, said he hadn’t really thought about the TCAI since the workshop, and, “…the main thing I remember was that there was a lot of information gathering, it would be cumbersome, I think, to implement it with my faculty.” Other common Management concerns included worry about having to “nag” students to complete the survey and how to ensure their responses were honest. F1 was unique in expressing Personal concerns. For example, both F1 and F4 expressed concern that students didn’t understand some of the TCAI’s questions, but F4 attributed that to the TCAI itself and recommended adding clearer instructions,
while F1 said, “I didn’t do a good job explaining to them what they should have done. I think [they needed] a little more of a primer for me.”

Consequence concerns took a number of forms in the interviews. In some cases they were enmeshed with Management concerns, for example when D3 said, “…sometimes I’ll grab different pieces of what people have done [referring to students’ comments about their teammates], but it, you know it requires me to re-key stuff. I just haven’t done it as extensively as I might have liked to, just because of the overhead of transcription.” In this statement D3 is revealing Consequence concerns in his intentions because he had previously explained that he liked to share students’ feedback with the team in order to help the students develop their “metacognition” about teamwork and the design process. The expression of these Consequence concerns, however, is hindered by Management concerns about how long the process takes. W6 simultaneously expressed both Management and Consequence concerns in a slightly different way. She was concerned about how the instrument would affect students if one team-member was singled out as not performing, saying, “Do I destroy that group now totally, or not? If I tell them this, what will they think of each other?” In this statement the Management concerns (about whether or not to share a specific type of feedback with students) arose because of ongoing Consequence concerns about the purpose of the TCAI and sharing feedback, and what the desired effects would be for students. It’s as if W6 is simultaneously asking, “Is this the right way to go?” and “Where do I want to go.” Finally, Consequence concerns were also expressed more directly by an explicit interest in how the TCAI would affect students. For example W5 said he would be more comfortable recommending the TCAI if he had used it himself because then, “…I would know better where students struggle using [it], or where faculty have trouble
explaining [it], to the students,” and F5 evaluated the TCAI’s usefulness based on how well it “…helped them [the students] realize a few things.”

2) Innovation Configurations: In this study, the participants’ configurations of the TCAI varied along three main dimensions: how it was to be used, what its purpose was and its relationship to the other capstone assessments in development as part of the same project. Table 5 shows these dimensions and provides the intended definition, as well as the primary alternative definition. Table 5 also lists the participants who expressed alternative definitions in each dimension.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Intended Definition</th>
<th>Alternative Definition</th>
<th>Participants Expressing Alternative Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Use”</td>
<td>To be used by the adopter with students in his/her course</td>
<td>To be recommended to others for use in their courses</td>
<td>W4, W5</td>
</tr>
<tr>
<td>“Purpose”</td>
<td>To help students develop teamwork skills by guiding and promoting constructive feedback</td>
<td>To guide instructor interventions for poorly functioning teams</td>
<td>W1-W4, W6</td>
</tr>
<tr>
<td>“Relation to Other Assessments”</td>
<td>A flexible, removable part of a larger suite of assessments</td>
<td>A stand-alone assessment</td>
<td>W1-W4, W6</td>
</tr>
</tbody>
</table>

Table 5. The ways in which participants’ perceptions of the TCAI’s configuration varied and definitions representing the range of those variations.

W4 and W5 provided particularly good examples of both the “Use” and “Relation to Other Assessments” dimensions. In the “Use” dimension the key difference was that W4 and W5 viewed the TCAI as something to be recommended to others, while the rest of the workshop participants were considering it only for use in their own courses with students they were responsible for mentoring. In terms of the “Relation to Other Assessments” dimension, W5 knew the developers of the TCAI, and was more familiar with the other assessments they were
developing. W5 therefore defined the TCAI as part of “... a set of tools that you can use for various aspects of teamwork and engineering design that you can use to help students improve their skills...you can pick and choose what you wanna use out of this suite of assessment tools.” The other participants viewed it as a stand-alone instrument, and when they were aware of the other instruments in development, treated the TCAI as a completely separate entity. This difference is particularly notable in the case of W4, who said, “I consider teamwork to be just one aspect of engineering design. So I thought there might be other things that were in that instrument...I was looking for a little bit more than that.” This dimension was particularly important to the developers of the TCAI. For example, D3 expressed the underlying commonality between all of the capstone assessment instruments, saying, “They’re all sort of similar in that their goal is to promote dialog between instructors and mentors and students.” This quote represents the way the Developers viewed the TCAI as one piece of a larger effort to achieve explicit goals (in this case, dialog between instructors and students).

The primary difference along the “Purpose” dimension was how the participants viewed the role of providing students with the feedback from the TCAI. Recall that a large part of the TCAI instrument involved students assessing their teammates’ teamwork skills and contributions. The “Purpose” dimension captures the differences in how the participants’ used these peer evaluations once they were gathered. D3 most clearly exemplified the intended definition of this dimension when he summarized the TCAI as a means of “collecting 360 degree feedback around the team and playing that back to the team.” Other participants, however, viewed the purpose of the TCAI as identifying potential problems within teams, and providing some guidance to the instructors on how to remedy them. For example, all of F2’s concerns about the TCAI centered on his use of the data generated. He suggested changes to the user
interface to allow more flexible and powerful ways of interpreting it, and remarked that while he found some patterns in the data interesting, he “…didn’t know what [he] could do with that.”

The authors grouped the participants’ definitions of the TCAI into four Innovation Configurations, as shown in Table 6. W6 is a special case: her definitions of the TCAI matched the “Alternative” grouping, except in the “Purpose” dimension. As shown in Table 6, the “Purpose” and “Relation to Other Assessments” dimensions tended to group together: if a participant had an alternative definition of one dimension, he or she almost always had an alternative definition of the other. The “Use,” dimension, however, varied independently of the other dimensions.

<table>
<thead>
<tr>
<th>Innovation Configuration Name</th>
<th>Characteristic Definitions</th>
<th>Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Alternative”</td>
<td>Use: To be used by the adopter</td>
<td>W1, W3, F1, F3, F4</td>
</tr>
<tr>
<td></td>
<td>Purpose: To guide instructor interventions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Relation: A stand-alone assessment</td>
<td></td>
</tr>
<tr>
<td>“Alternative (Rec. To Others)”</td>
<td>Use: To be recommended to others</td>
<td>W4, W6*</td>
</tr>
<tr>
<td></td>
<td>Purpose: Same as “Alternative”</td>
<td>F2</td>
</tr>
<tr>
<td></td>
<td>Relation: Same as “Alternative”</td>
<td></td>
</tr>
<tr>
<td>“As Intended (Rec. To Others)”</td>
<td>Use: To be recommended to others</td>
<td>W5</td>
</tr>
<tr>
<td></td>
<td>Purpose: Same as “As Intended”</td>
<td>D2</td>
</tr>
<tr>
<td></td>
<td>Relation: Same as “As Intended”</td>
<td></td>
</tr>
<tr>
<td>“As Intended”</td>
<td>Use: To be used by the adopter</td>
<td>F5</td>
</tr>
<tr>
<td></td>
<td>Purpose: To help students</td>
<td>D1, D3-D5</td>
</tr>
<tr>
<td></td>
<td>Relation: A removable part of a larger suite</td>
<td></td>
</tr>
</tbody>
</table>

Table 6. The Innovation Configurations expressed by participants.

3) **Contextual Features:** Table 7 lists important physical features of each participant’s context. The participants range from young faculty with no design experience to administrators with more than ten years of design experience. Similarly their home universities ranged from small, private teaching colleges to large, public research-focused institutions.
<table>
<thead>
<tr>
<th>Participant</th>
<th>Uses of Instrument</th>
<th>Position</th>
<th>Teaching Experience (Capstone Experience)</th>
<th>Design Experience</th>
<th>University Description*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Development Team</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D1</td>
<td>2</td>
<td>Faculty</td>
<td>4 yrs (4)</td>
<td>12 yrs</td>
<td>Large, Public, Research</td>
</tr>
<tr>
<td>D2</td>
<td>3</td>
<td>Administrato   r</td>
<td>11 yrs (5)</td>
<td>8 yrs</td>
<td>Medium, Private</td>
</tr>
<tr>
<td>D3</td>
<td>5</td>
<td>Faculty</td>
<td>20 yrs (10)</td>
<td>1 yr</td>
<td>Medium, Public, Research</td>
</tr>
<tr>
<td>D4</td>
<td>2</td>
<td>Faculty</td>
<td>15 yrs (15)</td>
<td>6 yrs</td>
<td>Small, Private, Technical, Teaching</td>
</tr>
<tr>
<td>D5</td>
<td>2</td>
<td>Faculty</td>
<td>8 yrs (5)</td>
<td>0 yrs</td>
<td>Small, Private, Teaching</td>
</tr>
<tr>
<td>Faculty Users</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F1</td>
<td>2</td>
<td>Faculty</td>
<td>2 yrs (2)</td>
<td>0 yrs</td>
<td>Medium, Private</td>
</tr>
<tr>
<td>F2</td>
<td>2</td>
<td>Administrato   r</td>
<td>10 yrs (10)</td>
<td>20 yrs</td>
<td>Medium, Private</td>
</tr>
<tr>
<td>F3</td>
<td>2</td>
<td>Faculty</td>
<td>4 yrs (4)</td>
<td>2 yrs</td>
<td>Medium, Private</td>
</tr>
<tr>
<td>F4</td>
<td>2</td>
<td>Faculty</td>
<td>2 yrs (2)</td>
<td>8 yrs</td>
<td>Medium, Private</td>
</tr>
<tr>
<td>F5</td>
<td>2</td>
<td>Faculty</td>
<td>18 yrs (4)</td>
<td>10 yrs</td>
<td>Medium, Public, Research</td>
</tr>
<tr>
<td>Workshop Participants</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W1</td>
<td>0</td>
<td>Administrato   r/Faculty</td>
<td>6 yrs (6)</td>
<td>25 yrs</td>
<td>Medium, Public, Research</td>
</tr>
<tr>
<td>W2</td>
<td>0</td>
<td>Administrato   r /Faculty</td>
<td>8 yrs (2)</td>
<td>2 yrs</td>
<td>Large, Private, Research</td>
</tr>
<tr>
<td>W3</td>
<td>0</td>
<td>Faculty</td>
<td>19 yrs (7)</td>
<td>15 yrs</td>
<td>Medium, Public Research</td>
</tr>
<tr>
<td>W4</td>
<td>0</td>
<td>Administrato   r</td>
<td>4 yrs (0)</td>
<td>0 yrs</td>
<td>Very Large, Public, Research</td>
</tr>
<tr>
<td>W5</td>
<td>0</td>
<td>Administrato   r</td>
<td>8 yrs (5)</td>
<td>0 yrs</td>
<td>Large, Public, Technical, Research</td>
</tr>
<tr>
<td>W6</td>
<td>0</td>
<td>Administrato   r/Faculty</td>
<td>8 yrs (3)</td>
<td>0 yrs</td>
<td>Large, Public, Research</td>
</tr>
</tbody>
</table>

Table 7. Participants’ physical context. *University descriptions taken from Carnegie Foundation for the Advancement of Teaching university classifications, with the addition of Small referring to universities with less than 5,000 undergraduate students, Medium for those with between 5,000 and 15,000, Large for those with between 15,000 and 30,000 and Very Large for those with more than 30,000 students.
In order to simplify and best represent the wide variation in contexts as well as the broad diversity in ways of reflecting on their own contexts, the five features of a Professional Learning Community have been broken down into two groupings: “Sharing” and “Support,” where “Sharing” encompasses any discussion of collaborating with colleagues on practices or efforts to improve the capstone program, and “Support” includes any help participants described in understanding, achieving or improving the goals of the capstone program and their own personal goals. Table 8, below, summarizes each participant’s discussion of their context in terms of these two characteristics of a Professional Learning Community. A “+” indicates that the participant described their context as sharing or supportive, while a “–” marks when contexts were described as limiting sharing and lacking in support. An empty space means that the participant did not describe his or her context in those terms. D4’s context is a special case in which she expressed disappointment in the lack of sharing at her institution, but noted that this was due to her being the only capstone instructor.

<table>
<thead>
<tr>
<th>Participant</th>
<th>“Sharing”</th>
<th>“Supportive”</th>
</tr>
</thead>
<tbody>
<tr>
<td>W1</td>
<td>+</td>
<td>–</td>
</tr>
<tr>
<td>W2</td>
<td>+</td>
<td>–</td>
</tr>
<tr>
<td>W3</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>W4</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>W5</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>W6</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>F1</td>
<td>+</td>
<td>–</td>
</tr>
<tr>
<td>F2</td>
<td>+</td>
<td>–</td>
</tr>
<tr>
<td>F3</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>F4</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>F5</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>D1</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>D2</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>D3</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>D4</td>
<td>–*</td>
<td>+</td>
</tr>
<tr>
<td>D5</td>
<td>–</td>
<td></td>
</tr>
</tbody>
</table>
Table 8. Participants’ perceptions of how their context compares to a Professional Learning Community. *D4 was the only capstone instructor at her institution, and it may not have been possible for her to have a “sharing” context.

W4 and W5, as assessment consultants, described their capstone program as both sharing and supportive. W4 summarized her perceptions, saying, “I think I’ve come into a college where assessment has already been a focus, and the faculty that I’ve been working with do understand the importance of assessment.” F5 described his context as both sharing and supportive in a slightly different way, instead focusing on a relatively small group of close associates. For example, when asked why he decided to use it, he said, “We all just decided that it was probably a good thing to do.” He strongly differentiated this small group from the rest of his university, saying, “So I don’t know that [at my university] there’s much going on in the way of assessment mindset, except in, you know, this small group of people that work together in capstone.”

Contexts that didn’t involve sharing were characterized by a general lack of involvement with other capstone faculty. For example, when asked how other faculty are involved in grading, W6 said,

W6: Uhm…they should be? But most of the time that doesn’t work out.

Interviewer: Okay. Kind of a time commitment thing?

W6: It’s a time commitment thing yes, mainly. For some of them it’s time commitment thing… But there are also one or two professors who kind of…they would like to have the project because they have these big projects going on. But they don’t want to be involved in any grading or anything. So I have to hunt them down way more than I do have to hunt down my students.
Contexts lacking in supportiveness were similarly described in terms of the other capstone faculty. W2, for example, said, “I just know my faculty and know that they’ll resist that [implementing the TCAI].”

The physical factors did not align with people factors as might be expected. For example, although they both came from small, private, teaching-focused universities, D4 said, “…the environment here and the culture here focuses on that [teamwork skills] a lot as well. There’s a big emphasis on community, community-building and collaboration.” While D5 said, “The other guy that I teach with [has] been doing it a certain way for years and he’s not gonna change. I just haven’t talked to them about it, you know, it’s just like one of those things.”

B. Discussion

The most important and logical grouping of these individuals is based on their interaction with the TCAI. This grouping coincides with the participant groups discussed above. Figure 2 is a schematic depiction of how the interactions between the workshop participants’ contexts, perceptions of the TCAI’s innovation configurations and Stages of Concern. These pathway figures will be used throughout the paper to visually represent the patterns in participants’ adoption statuses. They show arrows moving left-to-right, but this is not meant to imply that columns to the right are caused by columns to the left. These figures are meant more as a map of how the different theoretical components of CBAM tended to coincide with one another.

1) Workshop Participants: The points of divergence in Figure 2 are particularly interesting. For example, W4 and W5 differed from the other workshop participants because of their definition of the TCAI and their contexts. These differences can be linked to W4 and W5’s role as assessment consultants rather than capstone instructors. Their “use” of the TCAI consisted of recommending it to a capstone professor and helping them implement it effectively.
Also, the existence of their positions indicates some level of acceptance and interest in developing assessment skills.

W6 diverged from the other workshop participants in terms of her concerns and Level of Use, but it is unclear from these interviews why this is the case. Although W6 described her context very similarly to the other workshop participants (particularly W3), it is important to note that similar perceptions can arise from dissimilar circumstances.

![Figure 2. Workshop participants’ pathways to their Levels of Use.](image)

2) Faculty Users: The similarity of F1-F4’s Level of Use, despite small but significant differences in their concerns and Innovation Configurations, seems to indicate that their context was centrally important in determining their Level of Use. The differences are “small but significant” because of the theoretical importance of the shift from Management concerns that focus on the self (Stage of Concern profile 2 and 3) to Consequence concerns that focus on students (Stage of Concern profile 4). Fuller’s (1969) work identifying the importance of the
movement from self-focused concerns to external, student-centered concerns is one of the foundational inspirations for the development of CBAM (Hall and Hord, 2006). Figure 3 emphasizes this by highlighting that the only Faculty User with a different context, F5, was also the only one who achieved a Level of Use other than Mechanical Use. This analysis cannot pinpoint the different contexts as the cause of the differences in Levels of Use, but can highlight the importance of particular interactions. This is discussed in more detail below in the context of F5’s somewhat unique case.

Figure 3. Faculty Users’ pathways to their Levels of Use.

Although F1-F4 discussed their contexts very similarly, they developed different concerns. The dominance of management concerns in F2’s case may be attributed to his joint role as an instructor and an administrator in his capstone program (which is also connected with his Innovation Configuration), but there are no similarly simple explanations for the others’
contexts. It is unclear what lead F1 to develop such strong personal concerns when the others did not.

The case of F5 raises some key questions in the study of adoption in general because he expressed a high Level of Use and corresponding concerns. These seem strongly related to the people factors of his context in the capstone program, which emphasized Consequence concerns and a focus on student outcomes. These people factors were closely aligned with the goals of the TCAI. A possible counter-explanation for F5’s Level of Use is that he was introduced to the TCAI in a different way from the other faculty users, and had different interactions with the person encouraging its use (D3, in this case). This case study, however, emphasizes the fact that a person’s introduction to an innovation and their interactions with people encouraging its use are determined in part by their contexts. F5’s interactions with the group of like-minded capstone instructors would likely change the way he would react to interventions designed to encourage his adoption of an innovation. The presence of this group is only half of its importance, however. F5’s group of capstone instructors has norms that promote positive student outcomes (Consequence concerns) as the goal of their instruction, and are therefore more likely to spend time discussing a new intervention because such discussions of pedagogy and practices are already a part of their normal interactions. A different group, while similarly close-knit and influential on its members’ adoption decisions, may have different norms that would not be compatible with pedagogy-based arguments for adoption.

F1-F4 provide a counter-case to add support to this trend. In their case the change agent (D2) was also an administrator. This role is often assumed to be central in promoting adoption and change in departments. In these cases, however, D2 was less effective as a change agent
than D3, despite his role as an administrator. These differences can be attributed to the context in which the adoption is taking place.

3) Developers: Somewhat surprisingly, the central distinguishing feature of the Developers’ pathways was their physical context. Recall that, in CBAM, the physical context refers to observable features of the adopters’ institution, such as structure and policies, and is contrasted with the people factors of context such as an institution’s norms and values. As shown above in Table 8, the Developers reported mostly supportive and sharing contexts at their home institutions, but only D4 and D5 expressed Refinement Levels of Use and primarily Consequence concerns. This is reflected in the Context column of Figure 4, which, unlike the Workshop Participants’ and Faculty Users’ pathway figures, shows features of the Developers’ universities. The Developers at large, public universities with an explicit research focus tended to have lower Levels of Use and Concerns than those at small, private universities emphasizing teaching. Although it may seem like an unrelated coincidence that D1 had not had the opportunity to use the TCAI in a capstone course, his role as “involved” with the capstone course while not actually interacting with students is a direct consequence of the size of his departments’ capstone program, which is directly related to the size of his home institution.

Equally surprising in the Developers’ cases is the lack of Collaboration concerns or Integration Levels of Use. Despite actively working to promote future broad use of the TCAI and related assessments, none of the Developers expressed Collaboration concerns or Integration Level of Use. This is especially interesting in the cases of D2 and D3 who have actually asked colleagues to use the TCAI. When asked what they did to promote TCAI use among their colleagues most of the developers said something similar to D4, who said, “No I haven’t mentioned it to any of them yet. I’m kind of waiting to see how it works on this end first, and if
it seems particularly great then I’ll be able to say, ‘hey this is a neat tool, I wonder if this would work in [your course].’” Although this is a valid reason not to emphasize sharing the TCAI, it is also just a restatement of her Level of Use and concerns: her focus is on developing the TCAI, and less on working to use it in conjunction with other faculty members. These cases may reveal an area where CBAM needs to be adjusted when applied to university systems as opposed to K-12 schools. Because the many roles of a university professor, and the different ways in which university courses relate to each other may make it less likely that they will progress to the Integration Level of Use (Turns et al., 2007).

![Figure 4. Developers’ pathways to their Levels of Use.](image)

C. CBAM Conclusions

In comparing the trends observed within each participant group, the most prominent conclusion is that the CBAM framework is most useful when fully applied and interactions
between its elements are considered. For example, the “Use” dimension of the Innovation Configurations stands out in this analysis because it corresponds with W4 and W5’s relatively high Levels of Use and D2’s relatively low Level of Use. Additionally, D2 had the same Level of Use as F2, who also shared the same alternative definition in the “Use” dimension. These coincidences are not very meaningful until they are considered in light of the participants’ contexts. When considering the Workshop Participants it appeared that W4 and W5’s roles as assessment consultants encouraged them to adopt the TCAI: their Innovation Configuration meant that “adopting” the TCAI didn’t involve a great deal of work or commitment on their parts. However, D2 and F2 were in a different context as administrators in engineering departments. They therefore viewed the TCAI as something to recommend to others just as W4 and W5 did, but, as administrators they were much more involved in the day-to-day implementation of the TCAI. Organizing the use of the instrument among faculty naturally leads to Management Concerns (does everyone have the materials and time they need to learn about and effectively use this instrument?). In the same way, recommending it to others based on their needs would naturally lead to Consequence concerns (is this instrument helping address student and instructor needs?). The participants’ contexts effected their interactions with the TCAI, and therefore effected the development of their Concerns and Levels of Use. In W4 and W5’s contexts the “Recommend to Others” Innovation Configuration may promote adoption, while it may hinder it in contexts similar to F2 and D2’s.

Comparisons between the participant groups highlight the complexity and elusiveness of “context” as a subject of research. First, it can be very difficult to collect data on such an ambiguous concept. Consider the cases of F5 and D2, whose adoption statuses were both strongly affected by their involvement with a small group of like-minded capstone instructors.
This group wasn’t defined by department and didn’t include all capstone professors. This informality is likely what made the group so important to F5 and D2, but would also make the group extremely difficult to describe or even reveal using surveys or less qualitative methods. Secondly, the same context (or, perhaps more surprisingly, the same self-reported experience of a context) does not always lead to the same adoption status. Most of the Workshop Participants directly attributed their lack of interest in the TCAI to their perceptions of their colleagues’ reactions to it (i.e. the people factors of their context). W6 described her context as similarly opposed to adopting the TCAI, but unlike W1-W3, this didn’t lead her to Non-Use. Finally, even the importance of people factors, such as the norms and values of the institutions, does not hold for all cases. In the cases of the Developers, the size and emphasis of their home institution was more closely related to their Levels of Use than its norms and values. For example, despite sharing goals in line with the purpose of the TCAI, D4’s context was not conducive to change because she reported no shared goals or practices in her capstone program. It may seem trivial that this lack of sharing was caused by the simple lack of any other capstone instructors at her university, but the underlying implication is that not only the interactions themselves, but even the types of interactions a potential adopter has with their context can be different in different universities.

VII. DI BACKGROUND

Diffusion of Innovations (DI) Theory describes the process of how an innovation is broadly adopted. This theory is most clearly and comprehensively described by Rogers in his book, *Diffusion of Innovations*, currently in its fifth edition after being published originally in 1962 (Rogers, 2003). Rogers defines diffusion by breaking it into four components: communication, channels, time and social systems. He writes, “Diffusion is the process by
which (1) an innovation (2) is communicated through certain channels (3) over time (4) among the members of a social system” (2003, p. 11). These four constructs form the background and framing for all DI studies (see Bennett and Bennett, 2003; Sahin, 2006 for broad reviews), and therefore have guided this analysis. Because this study involved a one-time data collection the “time” component of DI Theory was not fully incorporated. Instead, as described in the subsection “Stages of the Adoption Decision,” the focus was identifying which stage of adoption the participants were in and the factors that influenced their adoption.

A. Communication Channels

Because innovations are defined as a type of information and diffusion is defined as a type of communication, the pathways through which innovations diffuse are called “communication channels.” Rogers cites extensive research indicating that innovations are diffused more rapidly and effectively through interpersonal communications rather than mass media approaches.

B. Innovation Characteristics

Rogers identified the five characteristics of an innovation that have the largest effects on its adoption. Importantly, these categories are defined and utilized in terms of the potential adopter’s perspective rather than any inherent characteristic of the innovation itself. The actual attributes of the innovation are not discussed; Rogers states only that the way potential adopters perceive an innovation has a strong influence on their decision to adopt. The five perceived characteristics that have been shown to have the largest effect on how quickly an innovation is adopted are relative advantage, observability, trialability, compatibility and complexity. Relative advantage describes how potential adopters expect the innovation to improve their lives as compared to the existing tool, system or idea. Observability describes the degree to which an
innovation’s benefits are visible to potential adopters. *Trialability* describes how conveniently an innovation could be partially adopted. *Compatibility* describes how well an innovation’s purpose and use are integrated with a society’s values and norms. An innovation’s *complexity* is defined as its perceived difficulty of use.

C. Social Systems

Rogers has identified key characteristics of a social system that affect diffusion: (1) the structure in terms of roles and communication channels; (2) the norms, including attitudes and values; (3) the roles of opinion leaders and change agents; (4) the dispersion of authority in decision-making (i.e. authoritative versus individualistic); and (5) the consequences of potential adoption. As with the innovation characteristics described above, these categories are intended to guide research, but not necessarily to capture all the important interactions in every case.

An adopter’s social system affects their adoption by determining the type of adoption decision available to them. According to Rogers (2003), the three types of adoption decision are (1) authoritative, in which the decision is made by a person or group in power over the actual users; (2) collective, in which a group of users decides together to adopt an innovation and; (3) optional, in which an individual’s adoption decision is made separately from their colleagues’.

D. Stages of the Adoption Decision

The actual decision to adopt is broken into five progressive stages, as shown in Table 9. These stages are always iterated, but a particularly important loop exists between Implementation and Persuasion. Rogers (2003) argued that the adoption decision isn’t actually made until after Implementation has lead back to Persuasion. Although the perceived attributes of the innovation affect all stages of adoption as well as an adopters’ progress through them, they
are formed (and therefore are centrally important to researchers and promoters of adoption) during the Persuasion stage.

<table>
<thead>
<tr>
<th>Stage of the Adoption Decision</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge</td>
<td>Becoming aware</td>
</tr>
<tr>
<td>Persuasion</td>
<td>Forming an opinion</td>
</tr>
<tr>
<td>Decision</td>
<td>Deciding to adopt or not</td>
</tr>
<tr>
<td>Implementation</td>
<td>Using the innovation</td>
</tr>
<tr>
<td>Confirmation</td>
<td>Evaluating the adoption decision based on experience of use</td>
</tr>
</tbody>
</table>

Table 9. DI theory’s stages of the adoption decision.

VIII. DI RESULTS AND DISCUSSION

A. Overview and Guide to Results

To address the four characteristics of diffusion as defined by Rogers (2003), results are broken into four subsections: (1) communication channels through which participants heard of the TCAI; (2) their perceptions of the TCAI’s innovation characteristics; (3) social system in which it may be adopted; and (4) their adoption decision. Just as the Level of Use was presented in the CBAM section as the feature of primary interest to those promoting and studying adoption, the participants’ adoption decision will be presented as if it were the result of the other three items mentioned above.

1) Communication Channels: The channel through which each participant learned about the TCAI is determined by their participant group. For example, although they would both be classified as “interpersonal” communication channels in the DI framework, learning about the TCAI in a workshop designed to encourage adoption is clearly different from being informally
introduced to it by a departmental peer. The developers are actively involved in communicating the TCAI, and in crafting it to be more easily and effectively communicated. The Workshop Participants, however, are more like the passive recipients of a mass media message in that they are being encouraged to adopt an innovation by people they do not know very well. The Faculty Users’ were similarly encouraged to use the TCAI, but in this case it was by a closer associate with a more localized message within a single department instead of a national conference.

2) Perceptions of the TCAI’s Innovation Characteristics: Table 10 shows each participant’s perceptions of the TCAI in terms of the five characteristics proposed by DI Theory. Not every statement revealing a participants’ perception is the same strength or directness. In Table 10 plusses and minuses show positive and negative perceptions, respectively. The perceptions that were most strongly expressed are bolded and placed in brackets.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Relative Advantage</th>
<th>Complexity</th>
<th>Compatibility</th>
<th>Observability</th>
<th>Trialability</th>
</tr>
</thead>
<tbody>
<tr>
<td>W1</td>
<td>[-]</td>
<td>[-]</td>
<td>[-]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W2</td>
<td>+</td>
<td>[-]</td>
<td>[-]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W3</td>
<td>-</td>
<td>-</td>
<td>[-]</td>
<td>-</td>
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<tr>
<td>W4</td>
<td>-</td>
<td>-</td>
<td>+</td>
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<tr>
<td>W5</td>
<td>-</td>
<td>-</td>
<td>[+</td>
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<td></td>
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<tr>
<td>W6</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F1</td>
<td>+</td>
<td>[+</td>
<td></td>
<td>+</td>
<td></td>
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<tr>
<td>F2</td>
<td>[+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
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<tr>
<td>F3</td>
<td>+</td>
<td>-</td>
<td>[-]</td>
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<tr>
<td>F4</td>
<td>-</td>
<td>[-]</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F5</td>
<td>+</td>
<td>+</td>
<td>[+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D1</td>
<td>+</td>
<td>+</td>
<td>[+</td>
<td></td>
<td></td>
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<tr>
<td>D2</td>
<td>[+</td>
<td>+</td>
<td>+</td>
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<td></td>
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<tr>
<td>D3</td>
<td>[+</td>
<td></td>
<td>+</td>
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<tr>
<td>D4</td>
<td>[+</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D5</td>
<td>-</td>
<td>+</td>
<td>[+</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

Table 10. Participants’ positive and negative perceptions of the TCAI.

No two participants’ perceptions of the TCAI’s characteristics were exactly the same, even in the cases where participants shared the same generally negative or positive impressions.
The interpretation of the results as presented in Table 10 is further complicated by strong interactions between perceived characteristics and aspects of the participants’ social structures (the dashed boxes Figure 5 below). However, these interactions were not as varied among the participants as the perceptions themselves, and tended to occur in the same general forms, or constellations. Four distinct constellations describe the perceptions of most participants, as shown schematically in Figure 5. Note that not every participant exactly conforms to one of the perception constellations. F1, for example, is described in a constellation of perceptions that includes positive perceptions of the TCAI’s Complexity. He expressed both positive and negative perceptions of the TCAI’s complexity, however, and therefore his overall perception cannot be clearly identified as either negative or positive. The participants that do not exactly fit into a constellation (W3, F1, D1 and D3) are all of the same nature: not contrary to the description of the constellation, but not clearly matching it in terms of one perception.
The first constellation, “Instructor Perspective,” involved positive perceptions of Relative Advantage that emphasized the instructors’ roles in using the TCAI. This focus corresponded with negative perceptions of the TCAI’s Compatibility and Complexity, because the benefits to
students were not considered. For example, W2 said, “I thought that what they were asking faculty to do was too invasive, or too time-consuming for any faculty to agree to. So mostly my impression was something I can’t ask my faculty…to do. They’ll just kind of balk at me, because it’s more than they’re willing to do for ABET.” W2’s focus on the use of the TCAI for ABET accreditation lead to her positive perceptions of the TCAI’s Relative Advantage, but, as shown in the quote, these positives were outweighed by the negative perceptions of Complexity (“…it’s more than they’re willing to do…”) and a lack of Compatibility demonstrated by W2’s belief that the TCAI’s potential benefits aren’t important enough to warrant its implementation.

In the second constellation, “Too Much,” the participants perceived the TCAI’s goals as being incompatible with those of their capstone colleagues, and therefore also perceived it as being too complex and having low Relative Advantage. These perceptions reinforce each other such that any perception could be seen as the cause of the other two. W1 exemplified the “Too Much” constellation’s typical lack of perceived value in the TCAI, saying,

Although I saw some things in it that appealed to me, we uh, basically had trouble in our capstone course with the amount of writing material that we’re asking from students… So there was no point in asking them an artificial, academic kind of question, you know, ‘what are you getting out of the course’ or anything like this. It just didn’t fly.

In his characterization of the TCAI as “artificial” and “academic,” W1 seemed to view the TCAI as work without benefit, or Complexity without Relative Advantage.

The third constellation, “Valuable Information,” has the same cyclical self-reinforcing form as the “Too Much” constellation, but this time the self-reinforcing perceptions are positive. Participants who viewed the purpose of the TCAI as revealing valuable information in the form
of how students are interacting often had positive perceptions of the TCAI’s Complexity and Compatibility. F1 expressed the clearest example of this constellation, saying,

…that’s [having the students evaluate each other] always interesting because it gives you - but I don’t think you can ever know this real well, but it gives you as an advisor an idea of how little you know about what you think you know about going on in the group. [laughs] So I think we, you know it’s hard to really know what’s going on, but we probably know even less than we think we know. So, it does a good job of proving that to us, maybe.

F1’s perceptions of value (Relative Advantage) are directly tied to his beliefs that assessing teamwork processes is important, and therefore the TCAI’s complexity is warranted by the inherent difficulty of what its intending to assess.

In the last constellation, “Do Something Similar,” participants expressed high perceptions of Compatibility, and had often already developed their own teamwork assessments. This balanced the positive Compatibility perceptions with negative perceptions of the Relative Advantage. D5 expressed the combination of perceptions characteristic of this constellation particularly clearly, saying, “The bottom line is I’m gonna do something regarding peer evaluation. At least twice a year in my class… So there are a number of different evaluations that could work reasonably well.” She clearly values goals of the TCAI, but is not convinced that the TCAI is the best route to achieving these goals, and is therefore somewhat ambivalent about its “Relative Advantage.”

3) Social Systems: Of the five components of a social system described by Rogers (2003), three were prominent in the interviews: social structure, norms, and type of adoption
decision. Nearly all interview participants described the social and communication structure of their capstone program when asked questions like, “How does capstone work at your university?” Participants often drew on institutional norms to explain aspects of their approach to using the TCAI or their thoughts about adopting it. The most consistently mentioned norms were those reflecting the value of assessment in capstone, which seemed to vary along a continuum ranging from solid opposition to passionate activism. Like the participant perceptions, the features of their social systems that were prominent can conveniently be grouped into four sets of similarly interacting features. Table 11 summarizes these sets of features.

The “Coordination” set of social system features is best captured by F1-F4’s description of their capstone program. They described it as being organized and focused on completion of student projects and successful collaboration with industry. F1, F3 and F4 frequently referred to meetings involving capstone advisors, and in fact cited one of these meetings as their primary source of knowledge about the TCAI. F1 and F3 also implied that these sessions didn’t always meet their needs. For example, F1 requested another short meeting with D2 (who had introduced the TCAI to him in one of the large-group meetings), and said that it had “probably helped.” In contrast, F5’s small group of like-minded capstone professors is the clearest example of a “Collaborative” social system in which goals are formulated and shared by the group, with an emphasis on student learning and outcomes.

The “Alone” social system describes circumstances like W6’s, who said, “I basically do all of capstone, because no one else is interested.” Similarly, when asked to elaborate on why he thought the TCAI would be too much work his colleague, W3 said, “we have a big problem getting people motivated about the capstone design course in the first place.” D4 described a
slightly less extreme version of this situation. When asked if she thought the other capstone faculty were aware of how she taught her capstone course she said, “probably not.”

The “Advisors” social system is exemplified by W4 and W5’s role as assessment advisors. Their system is unique among the participants because there is automatically a focus on assessment in capstone. W4 aptly emphasized this point, noting that the faculty “that have sought me out … already know that assessment is important.”

Finally it is worth noting that some of the participants were in the same capstone programs. In the case of D2, who was at the same university as F1-F4, their descriptions of their social systems matched fairly closely and emphasized the same points. D3, however, who was in the same group of capstone instructors as F5, expressed a very different social system. Compared to F5’s detailed explanation of how the group came together, D3 mentioned other capstone instructors once, saying only that there were a group of them who “all taught capstone.”

<table>
<thead>
<tr>
<th>Group Name</th>
<th>Social Structure</th>
<th>Norms</th>
<th>Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Coordination”</td>
<td>--</td>
<td>Focus on project coordination over assessment</td>
<td>F1-F4, D1-D3</td>
</tr>
<tr>
<td>“Collaborative”</td>
<td>Small, distributed capstone program</td>
<td>Committed to assessment and student outcomes</td>
<td>F5, D5</td>
</tr>
<tr>
<td>“Advisors”</td>
<td>Large institution</td>
<td>Assessment valued</td>
<td>W2, W4, W5</td>
</tr>
<tr>
<td>“Alone”</td>
<td>Large, hierarchical capstone program</td>
<td>Assessment in capstone not valued</td>
<td>W1, W3, W6, D4</td>
</tr>
</tbody>
</table>

Table 11. Common collections of participants’ social system features.

4) Adoption Decision Type: DI Theory proposes three distinct types of adoption decision: authoritative, collective or optional (Rogers, 2003). As shown in Table 12, all three types were expressed by at least two participants, but the most common by far were collective type decisions. However, these types of decisions were talked about in two very distinct ways
among the participants. In the first and rarer case, the participants described an equitable group decision-making process based on explicit, shared goals. In the much more common case the goals and decision-making processes were tacit or operated at multiple levels simultaneously. This more complex type of Collective decision is denoted with an asterisk in Table 12 and future figures to emphasize its position as a special case of Collective-type adoption decisions.

<table>
<thead>
<tr>
<th>Type of Adoption Decision</th>
<th>Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Authority</td>
<td>W1, F1-F4, D2</td>
</tr>
<tr>
<td>Optional</td>
<td>W4, W5</td>
</tr>
<tr>
<td>Collective</td>
<td>F5, D5</td>
</tr>
<tr>
<td>Collective*</td>
<td>W2, W3, W6, D1, D3, D4</td>
</tr>
</tbody>
</table>

Table 12. Participants’ types of adoption decision

D2 made an Authority-type decision as the authority. He described himself as, “I’m just more or less the, the conduit, sort of the bad guy that goes around telling people they need to assess stuff.” He later joked, “So they kinda have to, like, do what I say.” Although F1-F4 clearly described this as voluntary, the decision type is still closer to the Authority type rather than Collective or Optional because the Faculty Users – the actual users of the innovation – were not involved in the early decision-making process. They did not engage in the problem that was being solved, or in the choice of which solution to use, but were only asked to agree to the solution once it was decided upon. The case of F5 provides a contrasting case in which a group made a Collective-type decision in order to achieve a shared goal of improving student teamwork skills.

W4 and W5 exemplified the Optional-type decision in which they could decide to adopt the TCAI or not based on their own needs and judgments. D4 and D5 similarly implied that they had adopted the TCAI based almost entirely on their own judgments, but that these judgments
were in part determined by their understanding of their institutions’ goals for the capstone program, and were therefore a Collective*-type decision. D4, for example, referred to the “trade-offs” between time-management and getting “real information” from the students. In follow up questions about this balance, she clearly referred to how her decisions are determined in part by the larger context of her program, saying, “I think that the majority of design faculty [at my institution] are interested in monitoring the design process and getting good feedback and helping students and improving how students learn. And I see this as being a way to help students learn.”

5) Stages of the Adoption Decision: The participants’ stage of adoption decision can be collected into six groups based on the theoretical stages of adoption in DI Theory. The groups and the participants who fell into each stage are shown in Table 13. It was difficult in this data to distinguish between the Persuasion and Decision stages of the Adoption Decision, because each stage involves information-seeking and perception-forming (Sahin, 2006). Therefore, these two theoretical stages are presented as one in this research. Similarly, the difference between participants who had Confirmed adoption of the TCAI and those who had decided to discontinue its use was significant and interesting, despite the fact that all those participants would be in the Confirmation stage.

<table>
<thead>
<tr>
<th>Stage of Adoption</th>
<th>Theoretical Stages of Adoption</th>
<th>Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) “Knowledge Acquisition”</td>
<td>1</td>
<td>W6</td>
</tr>
<tr>
<td>(2) “Passive Rejection”</td>
<td>2</td>
<td>W1-W3</td>
</tr>
<tr>
<td>(3) “Confirmation-Discontinuance”</td>
<td>2, 3, 5</td>
<td>F2-F4</td>
</tr>
<tr>
<td>(4) “Persuasion-Decision”</td>
<td>2, 3</td>
<td>W4, W5, D1</td>
</tr>
</tbody>
</table>
Table 13. Groups defined by participants’ expressed stages of the adoption decision.

| (5) “Implementing” | 4 | F1 | D2 |
| (6) “Confirmation” | 5 | F5 | D3-D5 |

The groups in Table 13 progress in degree of adoption. Those at the “Knowledge Acquisition” stage haven’t yet decided whether or not they will use the TCAI, while those in the “Passive Rejection” stage have decided not to adopt the TCAI and not to seek out any more information on it. As an example of the differences between these two stages, W2 and W3 described their “first impression” of the TCAI in terms of their colleagues’ rejection of it, but W6’s first impression was subtly different: “you will never be able to do this on your own.” This indicates that her desire to “get real information” wasn’t completely overwhelmed by the expected rejection of the TCAI by her colleagues. Throughout the interview, W6 (in the “Knowledge Acquisition” stage) referred to lingering questions she had, while W1-W3 (in the “Passive Rejection” stage) were generally satisfied with their current level of knowledge.

The “Persuasion-Decision” stage refers to those participants who had decided to use the TCAI, but had not actually used it yet. As an example of the “Implementation” stage, D2 did not reflect much on his future use of the TCAI, but was instead focused on the ongoing administration of it at his university. He discussed ongoing feedback he was receiving from capstone instructors who had used it, and referred to a report he was in the process of preparing. Although all of this activity is reflective and actually occurred after the implementation, at this point D2 had not yet reached a decision on the relative success or failure of this implementation.

The “Confirmation-Discontinuance” stage is represented by those participants who had used the TCAI in the past, but might not use it again. This stage is contrasted with the “Confirmation” stage most clearly by comparing F2, who said he “might use something like this”
in the future, with D4 and D5 who saw their latest use of the TCAI as only one instance in ongoing implementation, and frequently referred to small changes they would make in the future.

B. Discussion

In the same way the participants’ groups framed the discussion of the CBAM framework, they will guide the following discussion section. This grouping is significant within the DI framework because it coincides with the three types of communication channels through which the participants became aware of the TCAI.

1) Workshop Participants: Figure 6 presents a simplified summary how the workshop participants are described in terms of DI Theory. As shown in the figure, each perception constellation corresponds to only one adoption decision stage, except in the case of W6. It is unclear why the same negative perceptions lead some participants to passively reject the TCAI, but did not discourage W6’s adoption in the same way.
W5 and W4 provided a particularly clear example of how the interactions of different elements can control adoption. Like W1-W3, W5 thought that his colleagues would probably view the TCAI and related instruments as “overwhelming.” While these expected perceptions prevented W1-W3 from adopting the TCAI, W5’s role as an assessment consultant caused him to react differently. He and W4 did not assume that their colleague’s perceptions of the TCAI would overwhelm their own in the same way that W1-W3 did. W2’s role as ABET advisor further highlights the subtleties of defining a social structure: she was an “advisor,” but operated within a different set of norms. The most obvious differences are that the faculty who worked with W4 and W5 did so voluntarily, although with the tacit support and encouragement of the system that was visibly prioritizing assessment (by making assessment consultants available, for example). W2’s interactions with faculty were more focused on requirements external to the faculty, and ultimately even external to the department as ABET is, by definition, an external review process.

2) Faculty Users: As shown in Figure 7, the Faculty Users almost all share the same type of adoption decision, social system and constellation of perceptions, and 60% of them are considering discontinuance of the TCAI. It is difficult to draw any simple lessons from these cases of discontinuance, however, because the potential reasons are all interconnected. For example, F2-F4’s negative perceptions are the likely cause of their disinterest in continued use of the TCAI, but those perceptions are all closely linked with their general belief that this type of assessment isn’t valuable in capstone courses, which is almost certainly affected by their institutional norms. These relationships are further interwoven by the fact that these participants all chose to use the TCAI through an Authority type decision. Because they did not seek it out themselves to meet a perceived need of their own (as they would in a Collective or Optional type
of adoption decision), they are considerably less likely to find value in its intended purpose. The general finding, then, seems to be that it was the interactions of the entire system that lead to or at least encouraged F2-F4 to consider discontinuing use.

Figure 7. Faculty user’s pathways to their stage of the adoption decision.

The case of F1 provides an interesting counter-example. The only differences between he and the other Faculty Users at his institution were that his perceptions of the TCAI were largely positive, and that he was at the “Implementing” stage of adoption. These are logically linked because someone who views the TCAI more favorably will be less likely to consider discontinuing its use, but the question arises as to why his perceptions were different.

F1’s perceptions of the TCAI’s value, despite sharing the same social system as F2-F4 is revealing of a key underlying issue controlling participants’ perceptions of the TCAI. F1 clearly thought that revealing and understanding a team’s interactions was difficult, and it might not even be possible to “ever know this real well.” In view of the complexity of the task, the challenge of using the TCAI as acceptable and probably even required. Because F1 valued “real
information” about his teams’ interactions, he perceived it as more valuable than his previous efforts which he described as “more, you know, as you go if you can get an impression of whether you think things are working or not working.”

In the DI framework F5’s social system would be described as an interpersonal group that enacts norms and values that prioritize student outcomes and development. The difference between F5’s description of his interaction with his capstone colleagues and F1-F4’s can be explained using the DI concept of homophily. Rogers defines homophily as “… the degree to which pairs of individuals who interact are similar with respect to certain attributes, such as beliefs, values, education, social status, etc.” (Rogers and Bhowmik, 1970, p. 526). Increased homophily increases the effectiveness of communication and, therefore, diffusion. As quoted above, F5’s interactions with his colleagues are marked by a shared purpose developed “through years with this course.”

3) Developers: The diversity of the Developers’ adoption statuses (as highlighted in the relative complexity and multiple crossing arrows of Figure 8) reveals some of the underlying complexity in applying the DI framework to the university setting, and particularly capstone programs. For example, comparing D5’s “Do Something Similar” with D3’s “Valuable Information” perceptions shows that, in this case, some people have an alternative to compare the TCAI to, and some don’t. This complicates the construct of Relative Advantage by making it more difficult to compare perceptions between individuals. This insight, combined with the fact that the Developers’ shaped the TCAI to suit their own needs, suggests that D1 and D5’s negative perceptions of Relative Advantage weren’t actually negative, but were instead expressed differently than the other Developers’ because of their previous exposure to alternative teamwork assessments.
Despite diversity in every other aspect, the Developer’s almost all reported a complicated Collective-type adoption decision. It is particularly interesting that three different types of social systems coincided with this type of adoption decision. The differences between the capstone programs described by D3 and D4, for example, might be expected to result in comparable differences in how those programs make decisions. However, both systems are classified as a Collective*-type adoption decision.

![Figure 8. The Developers’ pathways to their stage of the adoption decision.](image)

**C. DI Conclusions**

Perceptions of the TCAI’s Compatibility were centrally important in affecting participants’ adoption, but their importance depends on interactions with other types of perceptions and social systems. Perceptions of the TCAI’s purpose (and therefore its compatibility with their purposes), for example, were closely related to participants’ perceptions of the TCAI’s Relative Advantage and Complexity. As shown in the case of F1, participants who didn’t highly value assessment of team interactions didn’t perceive any advantage to the
TCAI, which was also perceived as an overly Complex tool for a relatively simple and unimportant task.

Although not as central as the perceptions of its Compatibility, Complexity was an important aspect of the TCAI’s diffusion processes. It was seen as a hindrance to the TCAI’s wide appeal and subsequent adoption. Most of the Faculty Users and Workshop Participants expressed the feeling that there was simply too much to learn about the TCAI and its related assessment instruments. The Faculty Users received some guidance on how to use the TCAI, but still perceived it as highly complex. Both F1 and F3, for example, suggested that more guidance on how to use the TCAI might lead to it being more useful. This is interesting because of the differences in their other perceptions. Recall that F1 found value in the TCAI’s ability to show instructors how little they actually know about students’ team interactions, but F3 felt it was just something he should know if he was paying attention. F3 said, “… and so if anything that I gain [from the TCAI]…becomes extremely useful I’m probably not doing my job right.” The fact that, despite very different views of the purpose of the TCAI, capstone programs, and assessment in general, both F1 and F3 perceived its Complexity as limiting suggests that this is a robust finding that could transfer to future adopters.

F1 and F3’s perceptions contrast sharply with the Developers perspective that “ease of use” is the TCAI’s “strongest selling point,” (in the words of D1). D4 even suggested adding more complexity in the form of more customization options. This disconnect can be explained in terms of two distinct types of knowledge that facilitate adoption: “how-to knowledge” which is the knowledge required to properly use an innovation and “principles knowledge,” which is knowledge related to “the functioning principles underlying how the innovation works” (Rogers, 2003, p. 166). Principles knowledge is the framework in which the innovation makes sense:
Rogers (2003) uses germ theory as an example of principles knowledge underlying the practice of boiling drinking water. Without recourse to the assumptions and tenants of germ theory, water boiling is unlikely to diffuse because it is not seen as necessary, or related to the problems it intends to solve. The Faculty Users’ introduction to the TCAI focused on how-to knowledge, but what they lacked may have been principles knowledge. They were not able to fully grasp its benefits, and therefore were overwhelmed by its costs in time and understanding.

IX. SYNTHESIS AND CONCLUSIONS

The following is a list of the main findings from within the CBAM framework: (1) each theoretical component of CBAM (e.g. Concerns and Innovation Configurations) gained explanatory power when combined with the other components, and (2) the participants’ contexts greatly affected their perceptions about the adoption processes, but the variety and scope of these contexts presented methodological challenges. In DI Theory, there were two major findings: (1) perceptions of “Compatibility and Complexity” were centrally important to the adoption of the TCAI, and (2) principles knowledge about the purpose of capstone courses and assessment seemed to be limiting diffusion.

The rest of this section will draw broader lessons from the specific findings of each framework. First the important features, as identified from both CBAM and DI Theory, will be presented, followed by a section comparing the two frameworks. The paper concludes with future research directions building on the findings of this study.

A. Summary of Features Found to Affect Adoption

The findings of this study lay the groundwork for the development of an engineering-education-specific model of the adoption process, but do so through the concept of transferability as opposed to generalizability. Although it is unlikely that all of the participants of this study are
very different from the population of engineering educators, it is not the purpose of this study to argue that their cases are representative. Instead, the goal is to build toward a representative model by identifying key features of adoption that would need to be addressed if the model hopes to explain similar cases.

These findings highlight three such key features: pre-existing beliefs, small group contexts and costs. Figure 9, below, displays how these three features are related to main findings identified within the CBAM and DI frameworks.

![Figure 9. Relationship of synthesized findings to previous conclusions drawn from each framework.](image)

In this study, participants’ pre-existing beliefs about assessment and capstone courses were fundamental to their adoption or non-adoPTION of the TCAI. This was apparent in CBAM through the range of Innovation Configurations and the people features of the participants’ contexts. It is most clearly present, however, in DI Theory’s “principles knowledge” and
Complexity perceptions. The value of the TCAI was limited unless participants agreed with the Developers that (a) assessment is not a trivial task, neither in terms of importance nor ease of implementation, and (b) teamwork should be assessed in capstone courses. Participants accepted these propositions (“principles knowledge” in DI parlance) to varying degrees. Some participants’ Innovation Configurations, for example, emphasized instructor-oriented perceptions of value (i.e. that the purpose of the TCAI is to collect information for accreditation and that feedback to students is not necessary), which contrasts strongly with the Developers’ vision of a student- and learning-oriented assessment tool. For many of the Faculty Users, these variations in Innovation Configurations were supported by the norms and values of their institution which relied on highly structured organization in order to manage the details and challenges of student projects closely tied to engineering practice in real time. These specifics probably will not apply to different innovations outside of capstone programs, but the principle holds: adoption, particularly in engineering education, relies on potential adopters’ related underlying beliefs. This is particularly true in engineering education contexts because of its position at the intersection of so many diverse pedagogical and practical approaches. Consider, for example, that adoption of the TCAI at some institutions in this study would rely on a consensus among assessment specialists (like W4), professional engineers who now teach design (like D1 and W1), administrators (like D2 and F2), experienced teachers (like D4 and F5) and people who fall in multiple categories (like W5 and W3). Differences in training, experience and approach to education lie at the core of these categories.

The second key feature identified in this study was most clearly revealed by D3 and F5’s “small group of capstone instructors.” Once the importance of this localized, informal group is recognized, it can help explain the adoption processes of other participants. The workshop
participants were all actively seeking such a group, for example. This is evidenced by their attendance of the workshop (W6, for example said she attended because “I hope to get more a grasp of what other universities do in terms of senior design classes.”), but more meaningfully in their reports of looking for shared approaches to capstone in research literature or among old colleagues in their less immediate social network. The Faculty Users similarly lacked such a group. Although they spoke of interactions and meetings, they still referred to their decisions and practices as individual preferences. F1 even seemed uncomfortable making these decisions in isolation. At the very least, this study underscores the potential importance of such small, informal groups in controlling the adoption processes. The Developers themselves provide an interesting case in that they were not localized, but instead leveraged a grant and a shared project in order to meet regularly in person and discuss capstone courses.

There is a possible connection between the two important features of adoption identified in the previous paragraphs. Those small group interactions seem to be a natural way to acquire “principles knowledge” or change underlying beliefs. The level of transparency and trust in such relationships allows for the kind of layered, repeated explanations that can effect such changes (Bruner, 1960).

Finally, this study found that the innovation’s cost in terms of time and energy is centrally important in engineering education. In this particular case this is apparent in the prevalence of Management concerns and perceptions of high complexity which both emphasized the costs of using the TCAI in terms of time and learning. This finding is well supported by previous investigations of adoption in engineering education. Turns et al. (2007) found, for example, that the balancing of multiple roles and commitments featured prominently in the teaching concerns of engineering educators, who also often had to evaluate all changes and
decisions in terms of how they would affect their prospects for tenure. Borrego et al. (2010) similarly found that cost was explicitly one of the primary considerations of departmental chairs when evaluating new innovations.

B. Limited Comparison of the Two Frameworks

The differences between the frameworks’ explanatory power was somewhat less than the variations of that power within each framework. Although their definitions and emphases were different, the descriptions of the participants’ adoption from within CBAM and DI both seemed to catch the same general trends. W4 and W5, for example, are differentiated in both frameworks due to their roles as assessment consultants.

Two specific cases suggest that combining both frameworks can provide enhanced explanatory benefits. The first case is that of F1, who was the Faculty User who expressed high levels of Personal concerns. This was inexplicable in CBAM because none of the other Faculty Users who shared his general context and Level of Use developed the same concerns. F1’s perceptions of the TCAI, however, explain this. He was described in the “Valuable Information” perception constellation, which was defined by perceptions that the TCAI was appropriately complex because it was so compatible with the participants’ goals and values. While F2-F4 viewed the complexity as a negative characteristic of the TCAI itself, F1 viewed it more as a necessary component in a difficult task. This view means that the challenge of using the TCAI is related to an individuals’ preparedness in dealing with the requisite complexity. In other words, F1’s perceptions of the TCAI meant that his uncertainty in using it resulted in Personal concerns about his abilities, and F2-F4’s perceptions meant the same uncertainties resulted in Management concerns about the TCAI’s inherent ease of use.
The second case is that of W6, the workshop participant who generally shared characteristics with W1-W3, but unlike them, was still interested in the TCAI. Although, like W1-W3, W6 perceived the TCAI as requiring “Too Much” for her colleagues to use it, unlike them she did not see this as precluding her from adopting it. This difference can be explained with reference to her concerns about the TCAI as revealed within CBAM. Unlike W1-W3, W6 expressed significant Consequence concerns about how the TCAI would affect her students and their learning. W6’s Consequence concerns meant that she was aware of a potential source of value (or Relative Advantage) in the TCAI that W1-W3 weren’t aware of: its effects on students. It is important to note that W6 still had the same negative perceptions of how difficult it would be to implement the TCAI in her institution. However, the result of these perceptions is different because she is considering the potential benefit of the TCAI (Consequence concerns) as well as the difficulty of implementation (Management concerns).

W6’s case highlights the most important difference between CBAM and DI as revealed in these cases. Although CBAM places W1-W3 in the Non-Use Level of Use, and W6 in the ostensibly more developed “Orientation” category, DI posits that “Passive Rejection” is actually a later stage of adoption than “Knowledge Acquisition.” In other words, W6 is considered to be in a later stage of the adoption process in the CBAM framework, but earlier in the process in DI. This is significant because such distinctions control what is expected, and what would be considered unusual and therefore worthy of research. It is unclear between DI and CBAM, for example, whether W6 is the special case because of her lack of decision about the TCAI, or W1-W3 are unusual for their quick rejection of it.

C. Future Research Directions
This study, and others like it, could guide future research utilizing both the CBAM and DI frameworks to develop an engineering-education-specific model of adoption. Next steps could involve broadening the research to investigate how general such findings are, or deepening it to gain more understanding of the key interactions involved. As an example of broadening the research, future researchers could build on the relationship between DI perceptions and CBAM concerns suggested by the cases of F1 and W6 by developing surveys focused on the co-occurrence of certain perceptions and concerns.

Central questions for future research involve understanding what this study called “Collective*-type adoption decisions” and “small capstone groups.” Recall that the asterisk was appended to the Collective-type decision processes because most participants’ experiences of the adoption decision were confusingly multi-layered and complex. The study of these decisions may be aided by reference to the field of public policy, particularly theoretical approaches to the study of collective action (see for example Stone, 2002; Kingdon, 2003), and Haas’ (1992a; 1992b) work investigating policy change among communities as diverse as engineering education. Investigations of the importance and role of small, informal, peer groups would really be a subset of future investigations into the role of context in the adoption process. As an object of investigation, the construct of “context” can appear somewhat like a fractal: observable and seemingly important features appear at any level of specificity or generality. Case study enthusiasts could delve deeply into the daily social interactions of a potential adopter in an effort to record and describe the full range of norms and values affecting his or her adoption decision. Similarly, surveyors could harness mountains of demographic and psychographic information in order to correlate certain contextual features with adoption behavior. The point is that both extremes are made inefficient by the sheer volume of potential data to be collected, and that both
methods could be more sagely guided by the other. This difficulty is exacerbated by the relative newness of the application of these frameworks to the context of engineering education. It is unclear what underlying assumptions, if any, will prove to be unjustified in this new context. The existing quantitative research has developed a list of potential interactions to be investigated in more detail by qualitative methods, but both approaches still have much to offer the study of adoption in engineering education.


Hall, G. (1974). The Concerns-Based Adoption Model: A developmental conceptualization of the adoption process within educational institutions. The Research and Development Center for Teacher Education. Available at


What is Cyberlearning: Practitioners’ and Experts’ Perspectives

Introduction

“Cyberlearning” is a term that has recently risen to prominence and reflects an important shift in approaches to educational technology. The National Science Foundation (NSF) Taskforce on Cyberlearning published a report in 2008 that is often described as the origin of the term, and provides an insightful and thorough meta-analysis of the literature and general movements in educational technology that have led to their adoption of the term (NSF Task Force on Cyberlearning 2008). The Taskforce defined cyberlearning as “…the use of networked computing and communications technologies to support learning” (pg. 5). The authors go on to explain that although the prefix “cyber” has come to be associated with computer technology, they also intend it to be used in its original sense, which was “…built etymologically on the Greek term for ‘steering’.” Although the focus is clearly on the networking technologies that are defining the Information Age (e.g. cloud computing and social media), the report authors intentionally left the term open to refer to any form of technology that mediates the human interactions that are at the heart of education. It is this inclusiveness that marks the important difference inherent in the term. Instead of attempting to name the newest technologically driven advances in education, the Taskforce aimed to create a term that would encapsulate the way technology and education interact, without specific reference to a particular innovation or even era. Changes in education and learning due to technological/cultural shifts are unavoidable, the report argues, but careful planning can ensure that those changes are positive. A newly released Request for Proposals in NSF’s “Cyberlearning: Transforming Education” program builds on this definition of the term and calls for “cyberlearning research [that] will marry what is known
about how people learn with advances in information and communications technologies” in order to “cultivate a citizenry” more able to address current societal needs.

Most definitive reports (Committee on Improving Learning with Information Technology 2003; Steering Committee on Improving Learning with Information Technology 2002; Atkins et al. 2003) approach educational technology in basically the same way by focusing on the unrealized potential of existing technology to change the nation’s fundamental approach to education. The background for these reports focuses on national problems, such as the United States’ ability to stay competitive in a global economy, and places education in the context of a possible solution to these problems. The U.S. Department of Education’s (DOE) National Education Technology plan for 2010, however, takes education as intrinsically valuable, and therefore approaches educational technology with a different emphasis (Office of Educational Technology 2010). The focus is on how technology – particularly the networked computer and communications technologies emphasized in the original definition of “cyberlearning” – could provide more equitable educational opportunities for all learners.

The differences in emphasis between the NSF report and the DOE’s report suggest that differences in experts’ and practitioners’ opinions about the purpose of cyberlearning need to be addressed in order to meaningfully interpret their recommendations and what they consider to be “effective” cyberlearning. Taken together, these reports show that the central questions concerning cyberlearning are how to define it, evaluate it and improve it without limiting it in ways that would decrease its effectiveness. The definition, for example, needs to be inclusive and responsive to unforeseeable changes in technology while at the same time maintaining its
usefulness as a category. The purpose of this study is to begin this process in a formal way by synthesizing current practitioners’ and experts’ views of what cyberlearning is and how to best implement and evaluate it.

**Purpose and Research Questions**

This study is intended to characterize the current understanding of the term “cyberlearning” and to further the discussion about how to best evaluate and practice it. This purpose leads to the following research questions:

1. How do current practitioners and experts in cyberlearning implement it?
2. How do current practitioners and experts understand cyberlearning?
3. What do current practitioners and experts see as the purpose of cyberlearning?
4. What do current practitioners and experts recommend to make it more effective?

**Methods**

Data was collected through two means: a survey of current practitioners, and interviews with experts. The combination of these methods allowed for both the breadth and depth necessary to achieve the purpose of this research. The general intent of the survey was to include as many diverse people as possible in answering the three research questions (see Table 2 for a summary of how each survey question contributed to answering the research questions). In order to maximize the comparability of responses while still maintaining the openness needed to address the research questions a combination of closed and open-ended questions was used. The open-ended questions were necessary to capture the range of possible responses, and also served to clarify or support responses to the closed questions. The survey design drew from the national
reports cited previously, and was pilot tested. Even open-ended questions in surveys, however, could not provide the depth necessary to characterize the participants’ understanding of cyberlearning. The interviews gave this required depth, as well as providing a means of triangulation with survey results to check the survey content validity (Patton 2002). The interview questions were designed parallel to the survey questions and drew from the same sources.

**Participant Identification**

*Survey Sample Selection*

Information was downloaded on all active and recently expired CCLI grants through NSF’s Award Search Utility. Of these projects (nearly 1,600), 298 were identified as involving cyberlearning through the content of their abstracts and titles. Based on the national reports cited above, cyberlearning was taken in this study to refer to any form of learning mediated by technology in a way that changed the learners’ access to and interaction with information.

The 298 awards identified reflected a broad range of start dates (1995 to December 2010), sizes (single institution Type I grants to Type III’s), content areas, and organizing institutions. Additionally, 42 projects in various award programs were identified through the Award Search utility that included the term “cyberlearning” in the title or description. The total sample included 340 projects. This sample was designed primarily for diversity in what Patton calls maximum variation sampling (Patton 2002). The goal is to include participants in the sample that are expected to be very different in terms of the research purpose. Due to the popularity and
centrality of the CCLI program, this sample is also a fairly broad cross-section of those involved in post-secondary science, technology, engineering and mathematics education. Note that this selection does not include the Transforming Undergraduate Education in Science, Technology, Engineering and Mathematics (TUES) which replaced the CCLI in 2010.

All of the 340 project Principal Investigators (PI’s) were invited to participate in an online survey. Following Dillman’s (Dillman 2007) methodology to increase survey response rate, each PI was contacted three times: a first invitation, a second reminder, and a final notification of the survey’s ending date. Each contact with the PI’s was personalized with the inclusion of their name, as well as a direct reference to the title of their project. Finally, each invitation explained that the survey was designed to take less than 15 minutes to complete. The combination of these practices is expected to have increased the survey response rate by 15 to 40 percentage points (Dillman 2007; Schaefer and Dillman 1998).

Of the 340 people invited to participate in the survey, 198 (58%) eventually responded. The respondents reflected the same diversity as the 340 projects identified in terms of project scope, start date (including completed projects and projects that had not yet started), geographical location and type of grantee (including single researchers, multi-institution collaborations, non-university institutions, and collaborations with K-12 public schools). The largest difference between the respondent pool and the total population is that a slightly lower proportion of PI’s from CCLI Type 3 projects responded. Seven of the 19 CCLI Type 3 PI’s (38%) eventually completed a survey.
This is a low overall response rate, but is within the expected range of unsolicited email surveys (Schaefer and Dillman 1998). A possible reason for the low response rate is the intentionally open inclusion criteria. A PI involved with a project utilizing scientific modeling in the classroom, for example, may not be sufficiently interested in cyberlearning or educational technology to volunteer time. Dillman proposes up to 30 repeated requests to each participant or the use of financial incentives to increase the response rate above the typical 60% (Dillman 2007), but such a campaign was deemed inappropriate for this project with this population.

**Interview Sample Selection**

Potential interviewees were identified through three channels. First, the abstracts of the 340 CCLI projects previously identified as including cyberlearning were reviewed and the PI’s of projects directly investigating cyberlearning processes, implementation or outcomes were included. This resulted in 54 potential interviewees, of which 20 agreed to be interviewed. The second source of interviewees was the contributors to the national reports described in the Literature Review section. Of the 33 listed contributors, 16 were unavailable or were not currently involved in work relating to cyberlearning. Six of the remaining 17 contributors agreed to be interviewed. Finally, each interviewee was asked to recommend other potential interviewees. Although references to local collaborators (for example the IT consultant in their department) were frequent, these were not pursued because they would increase the scope of the project without adding significant new information. Of the remaining references 20 were recognized experts, and 5 were general recommendations (to talk to university administrators, for example). Six of the experts referred had already been interviewed, as well as representatives of
4 of the 5 general recommendations, so the recommendation process resulted in 20 potential interviewees of whom seven responded, leading to four interviews.

Table 1 summarizes the response rates of invited interviewees. Although 28% is a low response rate, it is important to note that the group of people interviewed was still able to provide important perspectives. The interviewees included governmental and non-governmental policymakers; widely published and recognized researchers in the fields of education and educational technology; and dedicated, experienced practitioners of cyberlearning.

<table>
<thead>
<tr>
<th>Source</th>
<th>Total Potential Interviewees</th>
<th>Unreachable / Non-responsive</th>
<th>Interviews Declined</th>
<th>Interviewed</th>
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<td>8</td>
<td>20</td>
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<tr>
<td>Experts in Literature</td>
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<td>24</td>
<td>3</td>
<td>6</td>
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<tr>
<td>Recommendations</td>
<td>20</td>
<td>13</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>107</strong></td>
<td><strong>63 (59%)</strong></td>
<td><strong>14 (13%)</strong></td>
<td><strong>30 (28%)</strong></td>
</tr>
</tbody>
</table>

Table 1 Summary of sample selection and participation.

**Survey Development**

The survey consisted of 13 questions designed to collect information about the respondents’ experience with cyberlearning, and their definition and understanding of the term. Participants were encouraged to express their definition of cyberlearning in open-ended questions, as well as respond to others’ definitions. The responses to others’ definitions of cyberlearning were obtained by asking the participants to rank components of cyberlearning in terms of the
importance to them. The components of cyberlearning were taken from the definitions of cyberlearning put forth in the national reports cited previously. For example, survey items 4 and 5 asked participants to rank the importance of "flexibility in assessment" as a potential component of cyberlearning because the potential of cyberlearning to enhance assessment was a frequent theme NSF’s Taskforce on Cyberlearning Report (NSF Task Force on Cyberlearning 2008) and Blue-Ribbon Committee on Cyberinfrastructure (Atkins et al. 2003). The following potential components of cyberlearning were included in the survey: “connecting educators”; “flexibility in assessment”; “high quantity, quality and diversity of data available to learners”; “personalization of how, when and where learning occurs”; “inclusion and motivation of diverse students”; and an “Other” category. Further questions were included to clarify what participants took each of the components to mean. The follow up questions about “flexibility in assessment,” for example, asked participants to rank the following potential sub-components: “fast or real-time assessment feedback”; “archiving for program evaluation (e.g. accreditation, progress reports)”; and “archiving for formative, student-centered feedback.” These sub-components were also based on the differing definitions of cyberlearning included in the national reports. The sub-components of “flexibility in assessment,” for example, were based on statements like the following one taken from DOE’s National Plan summarized Assessment in the 21st century: “The model of 21st century learning requires new and better ways to measure what matters, diagnose strengths and weaknesses in the course of learning when there is still time to improve student performance, and involve multiple stakeholders in the process of designing, conducting, and using assessment” (Office of Educational Technology 2010). The structure of the survey and the wording of each question were piloted within a focus group of three typical engineering
faculty members to improve clarity and ease of implementation. The survey questions are summarized in Table 2, and reproduced in full in an appendix.

<table>
<thead>
<tr>
<th>Prompt</th>
<th>Response Type</th>
<th>Research Question Addressed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Do you prefer terms other than “cyberlearning” to refer to learning that is affected by computers, networked computers, the Internet, or web-based platforms or applications? If yes, what terms do you prefer?</td>
<td>Yes or No, with comment box</td>
<td>1</td>
</tr>
<tr>
<td>2. Please mark the forms of cyberlearning you have utilized as an instructor or designed for use by other instructors.</td>
<td>Multiple choice, with “Other” comment box</td>
<td>2</td>
</tr>
<tr>
<td>3. What are the benefits of cyberlearning?</td>
<td>Short answer</td>
<td>1</td>
</tr>
<tr>
<td>4. Given the following potential components of cyberlearning, please choose which is the most important in determining the effectiveness in achieving your goals for cyberlearning.</td>
<td>Forced choice, with “Other” comment box</td>
<td>1</td>
</tr>
<tr>
<td>5 – 12. Please rank the following potential components of cyberlearning in terms of their importance in achieving your goals for cyberlearning. Any additional comments on your ranking? (e.g. ties or large differences between sequentially ranked items)</td>
<td>Forced choice ranking, with comment box</td>
<td>1, 2</td>
</tr>
<tr>
<td>13. What does it take to make cyberlearning successful?</td>
<td>Short answer</td>
<td>1, 3</td>
</tr>
<tr>
<td>14. What are some common mistakes or potential pitfalls you have discovered that may limit the effectiveness of cyberlearning?</td>
<td>Short answer</td>
<td>1, 3</td>
</tr>
</tbody>
</table>

Table 2 Summary of survey questions.

Item 1 was a necessary preface because “cyberlearning” is not a widely used term, and it was important to establish what participants were referring to in the following questions. Research Question 1 was addressed by items 2 and 4. These were both forced-choice questions because a wide diversity of uses and forms of cyberlearning was expected, and it was necessary to
encourage the participants to identify themselves within a group of comparable projects. Research Question 2 required the most survey items in order to provide multiple means of describing participants’ understandings of cyberlearning. Survey items 3-13 all contribute to this research question. Items 3 and 13 encourage participants to use their own words in discussing the consequences of cyberlearning. These items reveal how participants use the concept of cyberlearning, which is directly related to their understanding of it. Items 4-12 asked participants to rank the importance of various aspects of cyberlearning. Again, these were forced choice (participants could only choose one component for each ranking and ties were not allowed) because the purpose was to organize the responses into a manageable number of categories. Research Question 3 was directly addressed in survey items 3 and 14. The directness of the link between these survey items and the underlying research question is possible because the research question is phrased in terms of the participants’ statements and no interpretation is therefore needed.

The survey responses imply that the wording and predefined categories captured the majority of the participants’ perspectives. For each question, only approximately 10% of respondents (about 20 individuals) noted that they were unable to rank the items. In each case approximately half attributed their inability to rank them based on equal importance (writing for example, “I think these are all quite important, and the differences between my rankings are slight,” or “These are all equally highly ranked for me.”), and half ascribed it to poor question design (“I'm not really clear on the differences between some of these items,” or “These different components did not make sense to me. I'm not really sure how to rank them,”). Some of the participants who selected “Other” made comments that suggested that their projects would fit into one of the
predefined categories, but the respondents had been confused by the wording of the prompt. For example, one respondent wrote “fast feedback. But I would say that ‘flexibility in assessment’ [one of the predefined components] becomes more limited.” Comments in the “Other” responses that did not fit into existing categories are reported and described in the Results.

**Interview**

Similar to the design of the survey, a key requirement of the interview protocol was that it be short to encourage participation. Each interviewee was asked the following questions:

1. How would you explain the term “cyberlearning” to someone?
   a. Would you talk about it differently with different audiences?
2. Overall, what are the pros and cons of cyberlearning?
3. How have you been involved in cyberlearning?
   a. What personal goals or values encourage you to be involved?
   b. Do you encourage others to use it?
4. What have you found to be most important in designing successful cyberlearning, or achieving your goals with it?
5. What’s an example of something you’ve done very well in this area?
6. What are potential pitfalls you could advise others to avoid?
7. If you were trying to evaluate programs utilizing cyberlearning, what would you look for?
8. Is there anyone else you recommend I talk to?
9. Is there anything that you believe is central to discussions of this topic that wasn’t covered by these questions?
These interviews were semi-structured (Patton 2002), which means that although the nine questions listed were asked in the same form to every interviewee, the follow-up and clarifications questions were different in each interview. This combination of structure and flexibility is particularly well-suited to this study because of the emphasis on definitions and clarifications (Fontana and Frey 2003; Ginsburg 1997). The interviews were audio-recorded, and notes were taken summarizing the responses to each question (Emerson et al. 1995).

**Analysis**

The audio recordings, interview notes and survey responses were all collected in a qualitative analysis program. The interview and open-ended survey responses were categorized based on common or similar responses. This required a two-pass approach to coding in which the first pass described the data by simply labeling the responses, and the second pass collected the similar labels into categories (Braun and Clarke 2006; Miles and Huberman 1994). For example, the survey question about the benefits of cyberlearning and the interview question about its pros and cons shared the same general categories, some of which are listed in Table 3. Every response to each survey item and interview question was categorized in this way. The Results and Discussion arose from comparing the prevalence and content of the different categories.

<table>
<thead>
<tr>
<th>Category Name</th>
<th>Description (Responses emphasized…)</th>
<th>Characteristic Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assessment</td>
<td>Data collection, feedback, grading</td>
<td>“better ability to track student”</td>
</tr>
</tbody>
</table>
Table 3 Sample of categorization scheme for survey question 3 and interview question 2.

<table>
<thead>
<tr>
<th>Equity</th>
<th>Creating access to typically underserved groups</th>
<th>“democratizing education across different populations”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access to Information</td>
<td>Availability of data, resources or modules designed to increase access to data</td>
<td>“Access to data; variety of resources”</td>
</tr>
<tr>
<td>Personalization</td>
<td>Flexibility to better suit individual students’ needs</td>
<td>“24 hour access, students can choose their own pace, infinite attempts”</td>
</tr>
</tbody>
</table>

Results

How is cyberlearning implemented?

Most participants used multiple forms of cyberlearning. Generally, more complicated or resource-intensive forms of cyberlearning (e.g. remote access laboratories) were less popular than the simpler forms. The majority of respondents indicated that they used “online learning modules.” Because “online learning modules” is a very general phrase, it might appear that participants really are only using one form of cyberlearning, but included “online learning modules” because it constituted a part of their overall use. For example a participant might have only used cyberlearning in the form of a remote access laboratory, but included “online learning modules” because some of the lab reports and procedures were available online. The data, however, show that only 14 respondents (about 7%) checked “online learning modules” and only
one other form of cyberlearning. Table 4 summarizes the data from survey item 3 which asked participants to identify which forms of cyberlearning they had utilized. Respondents that marked “Other” were asked to “please specify” in a comment box. These responses resulted in two new categories noted with asterisks in Table 4: 6% of participants used cyberlearning in a form that emphasized collaboration between students and 3% used online course management systems. The remaining comments varied, including references to visualization, grading, games, access to scientific resources and specific proprietary programs or systems.

<table>
<thead>
<tr>
<th>Form of Cyberlearning</th>
<th>Respondents Indicating Use</th>
<th>Respondents Using Only This Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>Online learning modules</td>
<td>161 (87%)</td>
<td>10 (5%)</td>
</tr>
<tr>
<td>Supplemental reference materials (e.g. online textbooks)</td>
<td>109 (59%)</td>
<td>12 (6%)</td>
</tr>
<tr>
<td>Access to online databases or archives scientific data</td>
<td>99 (54%)</td>
<td>1 (&lt;1%)</td>
</tr>
<tr>
<td>Distance learning</td>
<td>78 (42%)</td>
<td>0</td>
</tr>
<tr>
<td>Virtual laboratories</td>
<td>75 (40%)</td>
<td>3 (2%)</td>
</tr>
<tr>
<td>Computerized scientific modeling</td>
<td>71 (38%)</td>
<td>1 (&lt;1%)</td>
</tr>
<tr>
<td>Personal response systems</td>
<td>69 (37%)</td>
<td>1 (&lt;1%)</td>
</tr>
<tr>
<td>Remote access laboratories</td>
<td>42 (23%)</td>
<td>1 (&lt;1%)</td>
</tr>
<tr>
<td>Other</td>
<td>36 (7%)</td>
<td>0</td>
</tr>
<tr>
<td>Foster student collaboration*</td>
<td>11 (6%)</td>
<td>0</td>
</tr>
<tr>
<td>Online course management systems*</td>
<td>6 (3%)</td>
<td>1 (&lt;1%)</td>
</tr>
</tbody>
</table>

Table 4 Summary of survey responses to “Please mark the forms of cyberlearning you have utilized as an instructor or designed for use by other instructors.” *These categories were not predefined options, but arose from the data.

How is cyberlearning understood?

There was very little agreement among the participants about the definition of cyberlearning. Primarily, participants disagreed about cyberlearning along two dimensions: what technologies are included in the term, and what the purpose of cyberlearning should be.
Thirty-six percent of the survey respondents said that they preferred to use terms involving “online” or “web” instead of cyberlearning, indicating that they believed the term to be limited to those technologies. Similarly, 30% of the interviewees limited “cyberlearning” to only involving networked or “online” technologies, and 53% included other computer-based technologies (the remaining interviewees either did not use the term, or were unwilling to define it so precisely). A small number of participants limited the term to one specific technology (for example the use of interactive visualizations), or used it as a synonym for distance learning.

As suggested by the different interpretations of cyberlearning included in the national reports cited previously, one of the ways peoples’ understandings of cyberlearning can differ is in their assumptions about its purpose. For many of the participants in this study, the purpose of cyberlearning was clearly focused on the delivery of content to students. When asked to pick the most important aspects of cyberlearning, for example, 75% chose options centered on students (the first three rows in Table 6), while only 15% chose components emphasizing the instructor’s role (the last two rows in Table 6). The emphasis on students is even more pronounced when the follow-up survey questions are considered. The student-centered sub-components of “Flexibility in assessment” were much higher-ranked than the administrative components, as shown in Table 7.
<table>
<thead>
<tr>
<th>Components of Cyberlearning</th>
<th>Survey Respondents Identifying it as Most Important</th>
<th>Interviewees Mentioning it as a Benefit of Cyberlearning*</th>
</tr>
</thead>
<tbody>
<tr>
<td>High quantity, quality and diversity of data available to learners</td>
<td>36%</td>
<td>43%</td>
</tr>
<tr>
<td>Personalization of how, when and where learning occurs</td>
<td>26%</td>
<td>37%</td>
</tr>
<tr>
<td>Inclusion and motivation of diverse students</td>
<td>13%</td>
<td>3%</td>
</tr>
<tr>
<td>Other (Please Explain Below)</td>
<td>10%</td>
<td>60%</td>
</tr>
<tr>
<td>Connecting educators</td>
<td>10%</td>
<td>0%</td>
</tr>
<tr>
<td>Flexibility in assessment</td>
<td>5%</td>
<td>13%</td>
</tr>
</tbody>
</table>

Table 6 Responses to “Given the following potential components of cyberlearning, which is the most important in determining the effectiveness in achieving your goals for cyberlearning.”

*Each interviewee mentioned more than one benefit, so the total of their responses is greater than 100%.
Table 7 Survey responses to “Please rank the following potential components of ‘flexibility in assessment’ in terms of their importance to you or your project.”

<table>
<thead>
<tr>
<th>Potential Component of “Flexibility in Assessment”</th>
<th>Respondents who Ranked it as “Most Important”</th>
<th>Respondents who Ranked it as “Least Important”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fast or real-time assessment feedback</td>
<td>57%</td>
<td>20%</td>
</tr>
<tr>
<td>Archiving for formative, student-centered feedback</td>
<td>30%</td>
<td>22%</td>
</tr>
<tr>
<td>Archiving for program evaluation (e.g. accreditation, progress reports)</td>
<td>15%</td>
<td>57%</td>
</tr>
</tbody>
</table>

In response to the open-ended question, “what are the benefits of cyberlearning?” 80% of the survey respondents emphasized the benefits of information access for students. Access to data also stood out among the interviewees’ responses to a similar question, although their more diverse responses meant that even though it was among the most common responses, only a third of the interviewees mentioned it.

The single most common understanding of cyberlearning among the participants is that it is the use of networked computer technology to change the way content is delivered to learners. There are three less common understandings revealed through the interviews, however. Although these particular understandings are not the only ones to diverge from the median (indeed there were nearly as many understandings of cyberlearning as their were participants), they are particularly important because of the relatively authoritative roles of the interviewees as recognized experts,
administrators or policy-makers and the reflection of these understandings in the existing literature.

First, three of the interviewees defined cyberlearning as the use of technology to allow students access to what was referred to in one interview as “authentic science.” This also appeared in the survey responses in respondent comments, although in very low numbers (one or two comments per question). This view is intellectually related to earlier movements in educational technology. As described in the 2008 Taskforce Report, one motivating force behind the interest in cyberlearning is the desire to leverage cyberinfrastructure investments in the sciences to also improve science education (NSF Task Force on Cyberlearning 2008). As described by one interviewee, the best way to achieve this policy goal is to use the same cyberinfrastructure resources in the classroom as scientists are using in their research.

The second alternative understanding emphasizes the potential power of cyberlearning in creating more equitable education in the United States. Similar to the DOE’s report (Office of Educational Technology 2010), these interviewees took education to have an inherent value based on their personal values and beliefs about society. They therefore described access to education as a national problem, instead of the solution to various challenges (for example the need for a more innovative and skilled workforce). Cyberlearning is seen as a way to change educational practice, perhaps even somewhat subversively. One interviewee gave the example of how smartphones with internet access have significantly weakened the “pretense of authority” inherent in traditional, lecture-based courses. For this small group, cyberlearning is a tool to be
used in encouraging paradigmatic changes in the practice of formal education toward a more
decentralized, equitable model.

Finally, a small number of the participants understood cyberlearning as the set of changes
educators must make “in response to societal changes.” Many interviewees cited the societal and
generational shifts accompanying new information technology, but these changes were central in
only a few interviews and survey responses. One interviewee, for example, expressed certainty
that physical textbooks will be replaced in the next decade by some form of online media. He
viewed this as an economic necessity similar to the music publishing industry’s struggles with
the online market. For him, cyberlearning refers to the practical necessity of educators to be
prepared to utilize resources that are unavoidably shifting to the online world. Another
interviewee said that “students who have been born into cyberspace” would be expected to bring
very different “motivations and skill sets to the classroom, and we [educators] need to capitalize
on it.”

Participants’ Recommendations

As emphasized by many participants, the underlying pedagogy is no different when it involves
computers than when it involves chalkboards, and cyberlearning does not necessarily have a
different set of pedagogical problems than traditional, face-to-face classroom learning. As one
interviewee put it, “To the extent that it [cyberlearning] is just an automated version of having
them read something and answer questions…it’s really not all that exciting.” However, there are
aspects of generally accepted pedagogical practice that come more sharply into focus in the
context of cyberlearning. The most commonly cited aspects were interdisciplinary expertise, knowing the target population, and careful design of implementation.

Include Interdisciplinary Expertise

Many fields of study bear on cyberlearning. This is a challenge because it means that, in this early stage, developers need either to be experts in multiple fields, or to be members of diverse teams. It is also an opportunity, however, because it means that there are large bodies of research that could be applied to cyberlearning to expedite its evolution. The most commonly referenced areas of expertise that might be lacking were educational research and technical expertise. For example, one survey respondent wrote that the greatest mistake someone could make in cyberlearning would be a “lack of using education research to inform practice,” while another wrote that educators need a “technology translator” to be successful in cyberlearning. A few of the expert interviewees also emphasized the importance of assessment expertise in cyberlearning projects. They referred to a general lack of evidence concerning the effects of cyberlearning practices, and emphasized that this created an even greater need for valid, reliable assessment of cyberlearning projects. A small number of survey respondents (6%) also stated that careful assessment was particularly necessary in the context of cyberlearning. In terms of technological expertise, many participants noted that the newness of the field and the speed with which technology and our relationship to it is changing requires effective projects to be “forward-looking.” Instead of developing one tool to meet a specific need, for example, one interviewee suggested focusing more on developing an “architecture” which would create the means to develop infinite tools to meet different needs. Building on the NSF Taskforce’s recommendation to be use a “platform approach to development,” many interviewees warned
against developing tools or approaches that were tied too closely to any specific platform, and would therefore be obsolete when newer platforms emerged.

**Know the Target Population**

Although not as frequently cited as the previous recommendation, this recommendation was the only one that applied across all of the various participants’ expressed purposes for cyberlearning. Participants mentioned a variety of dimensions that should affect how cyberlearning is applied, including learners’ language skills, preferred means of interaction, interests and access to resources outside of class. The most common specific recommendation was to find out what the learners know in order to better design the content of the materials to suit their needs. This refers to educational content (one respondent recommended, “Materials carefully matched to the diverse learners likely to encounter the materials,” as necessary for success), as well as technical content (another wrote, “I assumed students knew about blogging...and they don't. They need some coaching.”)

**Design the Implementation**

As noted by one interviewee, cyberlearning cannot succeed if developers of cyberlearning content adopt a “throw it over the wall” approach. His point, echoed explicitly by many participants, is that the implementation of cyberlearning materials is as important as their design in determining their effectiveness in achieving desired outcomes. The recommendation to invest resources and planning into the implementation phases could be seen as a specific application of the previous recommendations. When discussing the “target audience,” some respondents referred to the difficulty in defining the end-users for cyberlearning materials. In one sense, it is
obviously the learners themselves, but many respondents also pointed out the vital role instructors play in choosing content and practices to be made available to the learners. This was mostly referenced in the context of K-12 settings, but it was also an issue in universities. One survey respondent advised, “If you are engaging with technology solutions, while your institution in general does not, then it's harder to get the students excited about it. It's hard for them when [...] they have only one class which actively and creatively uses technology.” Similarly, many of the examples participants used to support their argument for interdisciplinary expertise focused on mistakes made during the implementation phase based on assumptions made outside of areas of expertise. The most common specific recommendation was to incorporate user feedback and pilot tests throughout the design process. One interviewee suggested that the optimum procedure needs to balance research with iteration.

Although cost did not come up very often in the surveys (only about 5% of respondents mentioned it), most people viewed decreased cost as a potential benefit of cyberlearning, saying, for example, “It’s cheap and easily replicable,” or “lower cost versus hardcopy textbooks or physical labs.” A few of the interviewees, however, were wary of this belief. One respondent wrote, “I think… that people who have never tried it think it is cheap,” and one interviewee said, “I would be very surprised if cyberlearning turned out to be cheaper than traditional pedagogy.” This debate perhaps brings the participants’ recommendations full circle by again emphasizing the importance of interdisciplinary expertise in the design and implementation of effective cyberlearning; while the true impact of any educational practice cannot be measured without rigorous assessment practices, technical engineering expertise is also required to avoid costs that are unlikely to improve the final outcome.
Discussion

The results are characterized by divisions among the participants in which a small group argues against the perspective expressed by a larger group. For example, although the majority of participants viewed cyberlearning primarily as a new form of content delivery, some interviewees argued that this view limits the transformative potential of the technology by tethering it to outmoded practices and pedagogies. The alternative understandings presented in the Results section all emphasize ways in which cyberlearning can and should change the content of learning, but the majority opinion deals only with its potential as a delivery media. These disagreements about cyberlearning and its purpose reveal groups of distinct perspectives among the participants. The data collected here suggests that there are least four such distinct perspectives on cyberlearning: a form of learning, a technical problem, a new practice to be promoted or a new practice to be evaluated. The following sub-sections will describe how each perspective was apparent in the data, will briefly describe the fields of expertise underlying each perspective, and will provide an example of how work in that field could contribute to cyberlearning.

As a Form of Learning

As described above, several of the interviewees argued strongly that knowledge of how people learn is the central factor determining the success or failure of cyberlearning efforts. While this study did not attempt to measure participants’ familiarity with educational research, a broad range of approaches to education were apparent in the responses. For example, many participants said that cyberlearning only works with unusually motivated students. Conversely,
about twice as many participants said that the effectiveness of cyberlearning depends on the instructors’ and materials’ abilities to motivate students. The questions underneath these opposing views are those of the learning sciences: is it effective to motivate students to guide their own learning, or does this approach lead to a detrimental lack of structure? From this perspective cyberlearning is understood as one form of learning among many, and is therefore firmly situated in a broad and dense network of existing research about how people learn. The most important challenge is how to apply existing knowledge to this new field. A potential starting point is the National Academies’ *How People Learn* series (Bransford et al. 2000; Donovan et al. 1999), which summarizes the current state of knowledge about learning, and how it applies to teaching practices. Similarly, descriptions of assessment practices (Angelo and Cross 1993; Wiggins and McTighe 2005) offer proven and effective means to characterize learners’ understandings, which is an essential step in getting to “know the target population.”

**As a Technical Problem**

Participants with more expertise in communication and information technology understandably focused on the technological challenges and opportunities inherent in cyberlearning. In particular, they referred to the problem of how to design cyberlearning systems that are stable but don’t rely too heavily on underlying infrastructure that is likely to change. One interview participant said, “it’s software, so as much as we try to make things platform-independent, it’s not, and things become obsolete.” Additionally, many participants referred to the problem of how to integrate non-technical end-user feedback into useful product specifications. From this perspective, cyberlearning is a new challenge to proven methods of design. The primary challenge is to design tools that meet the needs of the instructors and learners using them.
As a New Practice to be Promoted

Twenty-six of the 30 interviewees said that they actively promoted the use of cyberlearning. Many of the survey responses also placed the respondent in the role of a proponent of cyberlearning among others. For example, one respondent wrote, “We need to have enough user support so that teachers and students feel they can use the tools properly.” Some participants at universities focused on encouraging their colleagues to adopt cyberlearning practices, others focus on K-12 teachers, and still others have targeted school administrators. From this perspective cyberlearning represents a beneficial change that needs to be encouraged in educational institutions. The challenge becomes how to encourage that change, and ensure that the full potential of the innovation is achieved. There is extensive research describing these processes of change that offer specific recommendations on how best to encourage them (Hall and Hord 2006; Rogers 2003).

As a New Practice to be Evaluated

Four of the interviewees involved in this study were faced with the dilemma of establishing policies about cyberlearning either as administrators in their educational institution or as leaders of national agencies committed to supporting and improving science education. For these participants, cyberlearning presents a particularly difficult public policy problem – namely, how to manage the interaction between new technology and education. The problem is complicated by the inclusion of many diverse stakeholders with competing values (e.g. students, teachers, schools, universities, parents, the Department of Education, state school boards). The field of public policy offers means to understand conflicts of values in group decision-making processes
(Rittel and Webber 1973; Stone 2002), and the complex interactions of multiple stakeholder groups (Heclo 1978; Weible et al. 2009).

**Conclusion**

The current understanding of cyberlearning could be described as amorphous. Even among the practitioners and experts who agreed on what it *is*, there was disagreement about what it *is for*. Primarily, it is implemented as a tool within existing educational and pedagogical frameworks. However, a small but non-trivial group of educators are actively seeking ways to leverage seemingly small technological changes to effect broad-scale paradigmatic changes. The participants’ various perspectives on cyberlearning as well as their recommendations for others highlight the need for more information; practitioners need more information about what learners’ know, product designers need more information about how their tools are being used, and everybody needs to know more about how their carefully designed cyberlearning tools are actually being implemented. In what is both a challenge and an opportunity, there is a great deal of knowledge situated in different academic fields that could help those involved with cyberlearning.

Moving forward in cyberlearning will require some means to synthesize the various perspectives that bear on it. The question of how to promote effective cyberlearning is an important policy question that will be significant in the future of education, but it is based on questions from the learning sciences, organizational change and information technology. Explicit reference to the learning sciences provides a means to define “effectiveness”, and how to measure it. Similarly, both organizational learning and information technology offer frameworks to measure and
describe the implementation of cyberlearning, which is, at the most basic level, simultaneously a form of technology and a learning process.

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References


Appendix

Survey Question 1
Do you use or prefer terms other than “cyberlearning” to refer to learning that is affected by computers, networked computers, the Internet or web-based platforms or applications?

Checkboxes – Yes or No

If yes, what terms do you prefer?

Short-answer response field

Survey Question 2
Please mark the forms of cyberlearning you have utilized as an instructor or designed for use by other instructors.

Checkboxes – Online learning modules; Virtual laboratories; Remote access laboratories; computerized scientific modeling; Access to online databases or archived scientific data; Personal response systems; Distance learning; Supplemental reference materials (e.g. online textbooks)

Other – Please specify.

Short-answer response field

Survey Question 3
What are the benefits of cyberlearning?

Short-answer response field
Survey Question 4

Given the following potential components of cyberlearning, please choose which is the most important in determining the effectiveness in achieving your goals for cyberlearning? Note that you will have a chance to elaborate on what these terms mean to you in the following questions.

- Checkboxes – Connecting educators; Flexibility in assessment; High quantity, quality and diversity of data available to learners; Personalization of how, when and where learning occurs; Inclusion and motivation of diverse students; Other (please explain below)

Other

Short-answer response field

Survey Question 5

Please rank the following potential components of cyberlearning in terms of their importance in achieving your goals for cyberlearning.

- Ranking checkboxes – Connecting educators; Flexibility in assessment; High quantity, quality and diversity of data available to learners; Personalization of how, when and where learning occurs; Inclusion and motivation of diverse students

Any additional comments on your ranking? (e.g. ties or large differences between sequentially ranked items)

Short-answer response field
Survey Question 5 – Alternate (used if participants checked “other” in response to Question 4)

Please rank the following potential components of cyberlearning in terms of their importance in achieving your goals for cyberlearning.

- Ranking checkboxes – Connecting educators; Flexibility in assessment; High quantity, quality and diversity of data available to learners; Personalization of how, when and where learning occurs; Inclusion and motivation of diverse students; Other (as explained above)

Any additional comments on your ranking? (e.g. ties or large differences between sequentially ranked items)

Short-answer response field

Please describe an example of when the component you listed in the “Other” category was particularly important or successful.

The following 5 questions ask for more information about the options you were asked to rank in Question 5. Each question refers to one of the components of cyberlearning listed in that question.

Survey Question 6

“Connecting Educators”

Please rank the following potential components in terms of their importance to you or your project.
Ranking checkboxes – Sharing lesson plans and/or curricular materials; Instructor-to-instructor interaction and/or counseling; Instructor-to-student interaction or lesson delivery; Building educator communities; Instructor-to-instructor sharing about students

Any additional comments on your ranking? (e.g. ties or large differences between sequentially ranked items)

Short-answer response field

Survey Question 7

“Flexibility in Assessment”

Please rank the following potential components in terms of their importance to you or your project.

Ranking checkboxes – Fast or real-time assessment feedback; Archiving for program evaluation (e.g. accreditation, progress reports); Archiving for formative, student-centered feedback

Any additional comments on your ranking? (e.g. ties or large differences between sequentially ranked items)

Short-answer response field

Survey Question 8

“High quantity, quality and diversity of data available to learners”

Please rank the following potential components in terms of their importance to you or your project.
Ranking checkboxes – More information available to learners; More diverse information available to learners; More interaction between information and learners; More pertinent information available during tasks

Any additional comments on your ranking? (e.g. ties or large differences between sequentially ranked items)

Short-answer response field

Survey Question 9

“Personalization of how, when and where learning occurs”

Please rank the following potential components in terms of their importance to you or your project.

Ranking checkboxes – Availability of course materials outside of class time and/or place;
Self-paced tasks and information; Information provided only when it is needed

Any additional comments on your ranking? (e.g. ties or large differences between sequentially ranked items)

Short-answer response field

Survey Question 10

“Inclusion and motivation of diverse students”

Please rank the following potential components in terms of their importance to you or your project.
Ranking checkboxes – Access to information regardless of geographic location; Support for non-traditional (e.g. distance learning) curricula; Accommodation for multiple styles of learning; Support for diverse aptitudes and abilities within one course design

Any additional comments on your ranking? (e.g. ties or large differences between sequentially ranked items)

Short-answer response field

**Survey Question 11**

What does it take to make cyberlearning successful?

Short-answer response field

**Survey Question 12**

What are some common mistakes or potential pitfalls you have discovered that may limit the effectiveness of cyberlearning?

Short-answer response field
Conclusion

The purpose of this section is to synthesize the five body sections of this dissertation and highlight the ways in which they combine to be significant. The theoretical contributions made by this work will be discussed first, followed by the potential practical implications. Finally, the relevance of the work to the core question described in the Introduction will be discussed.

I. Theoretical Contributions

Primarily, this research serves as a beginning in mapping existing and useful research from other fields onto the content area of civil engineering. It is a significant finding that misconceptions related to emergent processes are apparent in the civil engineering students’ understanding of Mechanics of Materials. It is also significant that civil engineering faculty are, in some ways, epistemologically very distinct from previously studied populations.

The insights gained into how to better match the theoretical approaches to civil engineering also have broader theoretical implications for the fields being utilized. For example, the competing theories of conceptual change utilized in Section 2 did not contradict each other as much as would be expected from the literature. Indeed, Chi (2008) and Vosniadou’s approaches to cognitive structures were highly complimentary in the ways they allowed for the explanation of consistent misconceptions as evidence of Chi’s ontological miscategorizations (1992), as well as the ways in which students’ reasoning often failed to apply available resources, including the students’ own previous reasoning. Furthermore, even the highly contentious “pieces versus coherence” debate appeared less fundamental when applied to the data. In the absence of strong conceptual structures, or, more likely, in the presence of competing or parallel structures (for example, if students are able to conceptualize stress as both a substance and a process), the
highly context-dependent processes preferred by knowledge-in-pieces theorists match the data well (Posner, Strike, Hewson, & Gertzog, 1982; Strike & Posner, 1985; 1992). In cases where students’ conceptual structures are more closely linked to the context being investigated, the regularities of persistent cognitive structures is more appropriate.

The integration of educational research dialogs, philosophical debates and a framework for describing personal epistemology is a theoretical contribution to the field of personal epistemology research. At the core of this integration is the concept of “epistemological stances.” As discussed in Section 3, personal epistemology theorists disagree on how to characterize personal epistemology. The construct of “stances” is a dialogic response to those theoretical disagreements. The metaphor of a “stance” acknowledges the fluidity and performativity of epistemological positions without denying the usefulness and reality of empirical links between personal epistemology and other constructs of interest. An epistemological stance, as opposed to a “belief” or metacognitive process, applies equally well to Guba and Lincoln’s research paradigms (1994). Because research is a conscious activity and the ties to epistemological issues are slightly more obvious, descriptions of personal epistemology that assume tacit or deeply held beliefs fall short of being able to describe the fluidity with which researchers communicate about knowledge and knowing.

A) Contribution of Studies of Adoption

A surprising parallelism between theories of adoption and the theoretical frameworks of conceptual change and personal epistemology was suggested. The findings of Sections 5 and 6 emphasized the ways in which individuals’ underlying beliefs effected the way they reacted to new pedagogical innovations or approaches. This is basically a restatement of the fundamental theories of conceptual change and personal epistemology. For example, in Section 5 it was
argued that participants’ pre-existing beliefs about assessment and capstone courses were fundamental to their adoption or non-adoption of the TCAI. These undifferentiated “pre-existing beliefs” seem to be a combination of epistemological beliefs which constrain the potential role of education in society, or the importance of assessment and the conceptual structures built upon those beliefs. Participants who did not find value in the TCAI’s approach to assessment sometimes implied that assessment wasn’t necessary. Compared to the developers’ beliefs about assessment, in which it is a definitional cornerstone of the educational process, this conceptualization is vastly different. One aspect of that difference are the underlying epistemological assumptions about certainty, and how easy it is to find out about students’ knowledge and experiences.

Similarly, Section 6 argued that a vital step in moving forward in NSF’s goal to promote and manage cyberlearning in the future was to recognize distinct perspectives of the same basic phenomena. The perspectives given as examples (for example “as a form of learning” or “as a technical problem”) are really framework theories (Vosniadou, Vamvakoussi, & Skopeliti, 2008) in the sense that they represent broad theories of how the world works in this context. Identifying them in this way gives a sense of the scope of the task of trying to integrate these frameworks, and also creates an opportunity for another research tradition to inform that process. Vosniadou and others have been working for years on the problem of how to help learners adjust their frameworks (Vosniadou, 1994; 2003; Vosniadou, Ioannides, Dimitrakopoulou, & Papademetriou, 2001), and their findings should be applicable to the problem of increasing understanding of cyberlearning.
II. Practical Implications

Each paper in this project has a number of practical implications of importance for the general practice of engineering education. The purpose of this section is to highlight the aspects of this research that would be of importance to those involved in engineering education who are not otherwise interested in the theoretical underpinnings of the work.

A) Implications for Instructional Strategies

In the simplest case, this research has highlighted important content in engineering courses that may not otherwise be sufficiently covered. In Mechanics of Materials, it appears that despite frequent remonstrations to ignore localized stress effects, students’ reasoning is still strongly affected by these concerns. Spending more class time explaining the reasoning, calculations and theory behind the instruction to “ignore localized effects” could help students reason more clearly about normal stress in bending beams, shear stress in axially loaded members, stress elements and failure processes. Similarly, class-time spend explaining why certain stresses develop and the mechanisms behind their behavior could alleviate significant conceptual challenges facings students as they try to learn about stresses in various contexts. Even though this discussion may concern more “material science” than “mechanics of materials,” this research suggests that students’ reasoning ignores such disciplinary differences in that misconceptions of materials concepts can affect reasoning in mechanics of materials.

Epistemologically, this research suggests that students’ stances toward socially defined aspects of engineering, such as policymaking and the enacting of common values, could interfere with achieving important learning objectives. As explained in Section 4 of this dissertation, distinguishing between policymaking and “science,” tends to limit the effectiveness of efforts to
integrate the two. Because civil engineers are ethically required to practice scientific methods in service to society, this integration is an essential part of the curriculum.

**B) Policy Implications**

There are two avenues of implication for public policy. First, the theoretical descriptions of learning as a process of change could inform the field of public policy, particularly in the arena of policy learning, but more generally in its interest in collective changes of action. Secondly, the findings themselves have implications for educational policy as it attempts to change the ways in which civil engineering students are prepared.

As exemplified in Sections 4, 5 and 6 of this study, conceptual and epistemological processes can be seen to affect processes of change in a variety of contexts, including contexts of political relevance. The analysis of Sections 5 and 6 provided in this Conclusions section suggest that potential barriers to policy change, or policy learning (Casey, 2009; Dunlop, 2009; Eising, 2002), should include conceptual and epistemological changes required to support a policy. One approach to policy change, the “epistemic communities” approach, has already begun to integrate aspects of personal epistemology research in to the description of why and how public policies can change (see for examples Haas, 1989; 1992a; 1992b). As shown in these sections even a preliminary analysis based on these frameworks can provide insights into potential barriers to policy change, and ways to encourage desired changes. Additionally, these analyses, which do not privilege one understanding over another and explicitly recognize the role of values in the debates, are well-suited to approaches to public policy that define it in terms of dialogs of group action (for example Stone, 2002)

Changing university education to better support conceptual and epistemological changes is one such example of a policy change. The first step in promoting such policy changes would
be to characterize conceptual and epistemological structures that support current policies. As suggested by this and other research (Turns, Eliot, Neal, & Linse, 2007) the multiple roles of academics (as teacher, mentor, researcher, department-member, etc) shape the way they view pedagogical innovations. With the various demands on academics, pedagogical innovations are seen as a potential investment of their scarce time. In public policy terminology, in this context academics are rational actors in that they make decisions based on maximizing their own benefits (Smith & Larimer, 2009; Weimer & Vining, 1992). This view suggests that one approach to this policy change would therefore be to incentivize the adoption of effective pedagogical practices.

There is, however, the broader question of whether increase conceptual understanding is desirable or necessary for civil engineering students. Findings that most graduates of science programs do not develop conceptual understanding do not change the fact that most systems designed by civil engineers work: bridges and buildings do not often collapse, and delivery of good and removal of waste are so reliable as to be taken for granted. One potentially important barrier to enacting such policy changes in the engineering education system is that there currently is no viable means of discussing the potential value of specific polices (such as changing practices to promote conceptual and epistemological change) among stakeholders. This discussion is vital to the progress of any such reform efforts.

III. RELATIONSHIP TO THE CORE QUESTION

In the Introduction to this research, the core question posed was why some forms of learning are harder than others. The answer proposed here is that some types of learning require students to change ways of thinking that are more fundamental to basic approach to the world. Part of the difficulty, therefore, is simply that it takes more effort to change, but another challenge is one of tractability. When learners are undergoing ontological shifts, or changing
their epistemological stances, they are attempting to change the cognitive structures that they rely on. In effect, they are attempting to fix the engine while it is running. As theoretical approaches to conceptual change and personal epistemology develop, researchers and instructors will be increasingly able to identify and distinguish which structures or concepts should change. In keeping with the constructivist theory of learning, the direction of progress is toward increasing learner control by informing them of effective practices to achieve their own goals.
IV. REFERENCES


