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Epistemic Cognition During Problem Solving

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EPISTEMIC COGNITION DURING PROBLEM SOLVING

A Dissertation
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by
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Abstract

Students' beliefs about knowledge and knowing (personal epistemologies) have been shown to influence various aspects of learning including, self-regulated learning, metacognition, and problem solving achievement (Bromme, Pieschl, & Stahl, 2009; Muis & Franco, 2009b, 2009a). Additionally, these beliefs have been shown to be discipline and context specific (Hofer, 2006; Hofer & Pintrich, 1997; Liu, 2011; Chinn, Buckland, & Samarapungavan, 2011). Multiple studies have investigated students' personal epistemologies across disciplines and how these beliefs influence aspects of learning; however, little work has investigated the connections between students' personal epistemologies and the processes they utilize during problem solving.

Through a three phase study, this work sought to answer the overall research question, "How do undergraduate engineering students' epistemic beliefs and need for cognitive closure relate to their activation of components of epistemic cognition during problem solving?" This study investigated epistemic cognition in two unique problem solving contexts, the classroom and research environment. Throughout this work, engineering epistemic beliefs are defined based on Hofer and Pintrich's (1997) conceptualization and include students' beliefs about the source, structure, and certainty of knowledge. Epistemic cognition is defined based on Chinn and colleagues' (2011; 2014) proposed framework that brings work from philosophy and psychology together. This framework suggests considering the nature of students' aims when approaching a task to determine if they are epistemic (related to gaining knowledge or understanding), as well as the processes students use to accomplish these goals.

Phase I (Chapter 2) of the study focused on assessing the reliability and validity of a survey instrument designed to measure students' engineering epistemic beliefs and need for cognitive closure. During this phase, the internal consistency reliability of each construct was assessed and students' open-ended responses to items were analyzed to further understand their beliefs. Phase II (Chapter 3) aimed to understand the connections between students' engineering epistemic beliefs, need for cognitive closure, and activation of

components of epistemic cognition when solving an open-ended homework problem using a mixed methods approach. This phase revealed similar epistemic cognitions among students in clusters based on their epistemic beliefs and need for closure. Additionally, it revealed aspects within the classroom that influence how students approach assigned problems. Phase III (Chapter 4) sought to understand students' epistemic cognitions when making decisions in their undergraduate research experiences. The results of this phase revealed how students chose a research topic and the processes students use when making research decisions.

The outcomes of these three phases provide a more complete understanding of students' epistemic cognitions and beliefs related to problem solving in the classroom and research environment. Many of the findings presented in this work have direct implications for both practice and research. Future work will seek to understand how these results translate to other disciplines and students at other institutions in order to push theory and practice further.

Dedication

This work is dedicated to my family and friends who have always encouraged and supported me in the pursuit of my dreams. I appreciate everything you all have done and will do as I continue to pursue my passions.

Acknowledgments

I would like to first thank my advisor, Lisa Benson, for introducing me to the field of engineering education and for her support during my time at Clemson University. I would also like to thank Julie Martin, Sandy Linder, and Pennie Vargas for being on my committee and providing valuable feedback about my work. I am extremely grateful for all of the members of the Engineering and Science Education Department that I had the pleasure of working with. They were wonderful resources who were always willing to lend a helping hand. Additionally, I want the thank the National Science Foundation for funding my Graduate Research Fellowship (GRFP) and Dr. Benson's CAREER Award "Student Motivation and Learning in Engineering" (EEC-1055950) that provided the funding for my research.

Table of Contents

List of Tables

List of Figures

Chapter 1

Introduction

1.1 Background

1.1.1 Personal Epistemology

Personal epistemology, an individual's beliefs about how knowledge and knowing, has been studied using a number of approaches in educational psychology. This area of research has been referred to by researchers using different terminology, including epistemic beliefs (Muis, 2007), epistemic cognition (Chinn et al., 2011, 2014), epistemological reflection (Baxter Magolda, 2004), and personal epistemology (Hofer & Pintrich, 1997). Personal epistemology has been studied qualitatively and quantitatively and beliefs about knowledge have been conceptualized as both discipline specific and discipline general. Trends in recent work suggest studying personal epistemology from a qualitative perspective and considering beliefs to be discipline and task specific.

Throughout this dissertation the term personal epistemology will be used to refer to the general field and area of research. When referring to a particular researcher's work, the terminology that the researcher uses will be adopted. It is important to keep in mind that while researchers in the field use different language to describe their work, they all seek to further understand individual's beliefs about knowledge and knowing in different domains and how this impacts aspects of learning.

The first model that emerged from research exploring personal epistemology was a developmental model that viewed epistemic beliefs as progressing through set stages. The first study to investigate the personal epistemology of college students examined how the beliefs of male students at Harvard and Radcliffe

developed (Perry, 1968). Through this longitudinal, qualitative study, a framework with nine positions ranging from simple to complex was developed. Since Perry's (1968) study, other developmental models have emerged, suggesting that epistemic beliefs develop overtime through set stages during college.

More recent models take a multi-dimensional look at personal epistemology, viewing it as a collection of individual beliefs. Schommer's (1990) initial research conceptualized epistemic beliefs around five dimensions: the extent that students believe 1) knowledge is complex, 2) knowledge is certain, 3) learning is quick, 4) the ability to learn is innate, and 5) knowledge is handed down by authority. An instrument was developed in parallel to Schommer's (1990) initial study and received widespread use. Recent work has brought attention to this instruments lack of reliability and validity and the nature of the five constructs resulting in the adoption of other models (DeBacker, Crowson, Beesley, Thoma, & Hestevold, 2008). Hofer and Pintrich added to the multi-dimensional models by considering how epistemology has been studied in philosophy and conceptualized epistemology as "an area of philosophy concerned with the nature and justification of human knowledge" (Hofer & Pintrich, 1997, p.88). Based on this definition, Schommer's (1990) quick learning and innate ability dimensions are not considered to be epistemic in nature. Hofer and Pintrich (1997) suggest that personal epistemologies consist of beliefs about the nature of knowledge and the processes of knowing. The nature of knowledge is conceptualized by two dimensions: the simplicity of knowledge and the certainty of knowledge. Likewise, the process of knowing is composed of two components: the sources of knowing and justification. This framework has been adopted by a number of researchers and multiple instruments exist that strive to measure both discipline specific and domain general epistemic beliefs of students based on Hofer and Pintrich's (1997) conceptualization.

Other emerging models seek to further bring the research in philosophy and educational psychology together to create a more robust framework. One such framework is the AIR model of epistemic cognition proposed by Chinn et al. (2014). This framework expands Hofer and Pintrich's (1997) work by clarifying and expanding the constructs based on philosophical and psychological considerations. Epistemic cognition is conceptualized as a network of interconnected cognitions that cluster into five separate constructs: 1) epistemic aims and epistemic value, 2) structure of epistemic achievements, 3) source and justification of knowledge and epistemic stances, 4) epistemic virtues and vices (motivations), and 5) processes for achieving epistemic aims. *Epistemic aims*, such as knowledge, understanding, and true beliefs, are defined as a subset of goals that people adopt related to their desire to figure things out. These goals become *epistemic accomplishments* once they have been reached and have different *epistemic values* based on their worth to an individual. An individual may choose to believe knowledge claims to different extents, taking various *epistemic stances*.

Structure, source, and justification of knowledge have all been expanded in Chinn and colleagues' (2011, 2014) model to account for the situation specific nature of epistemic cognition. These constructs are analogous to Hofer and Pintrich's (1997) conceptualization of an individual's epistemic beliefs, which has been the primary focus of previous studies conducted in the field of personal epistemology. *Epistemic motivations* are motivations that are directed at and specifically impact the acquisition of epistemic aims and include two categories: epistemic virtues, which assist in the acquisition of knowledge and understanding, and epistemic vices, which impede the attainment of knowledge and understanding. Two components of Need for Cognitive Closure have been identified as epistemic vices, closed-mindedness and discomfort with ambiguity (Chinn et al., 2011; Kruglanski, 1990). Need for cognitive closure is defined by Kruglanski and Webster (1996, p.264) as, "an individual's desire for a firm answer to a question and aversion toward ambiguity." It has been suggested to influence an individuals' actions, motivations, and choices based on whether closure is threatened or facilitated (Kruglanski & Webster, 1996). It is also suggested that an individual's perceptions about the processes that produce valuable and reliable data be investigated as this may help explain the learning processes of individuals as they engage in inquiry and evaluation tasks. Additionally, Chinn and colleagues (2011) suggest that epistemic cognition is situation specific and recommend the use of more fine-grained, context specific analyses.

1.1.2 Personal Epistemology in Engineering

In 2006, a group of engineering educators defined the key areas of research for the developing field of engineering education. Engineering epistemologies was recognized as one of these key areas for research and was defined as, "research on what constitutes engineering thinking and knowledge within social contexts now and into the future" (Anonymous, 2006). There have been multiple qualitative and quantitative studies that have studied the epistemic beliefs of engineering students taking both domain-general and domain-specific approaches and have drawn on various epistemic belief frameworks; however, many of these studies have used methods and frameworks that are considered to have limited reliability and validity by researchers.

1.1.2.1 Qualitative Studies

Palmer and Marra (2004) conducted a cross-sectional, qualitative study to gain an understanding of students' epistemic beliefs across knowledge domains. For this work, sixty junior and senior engineering and science students were interviewed about their epistemic beliefs within the sciences and the humanities.

The outcome of this work is a conceptual framework, representing engineering and science students' domain specific epistemic beliefs. They proposed two models, each composed of three orientations that progress from simple to complex epistemological views. Upon comparison of students' science and humanities epistemological orientations they found that most of the students had more developed science beliefs and suggest that this may have been the result of design courses, industry experiences, and more coursework in science and engineering. The two conceptual frameworks presented parallel the work of Perry (1968) and Baxter Magolda (1992) in structure and content as a developmental epistemic belief framework. One of the differences between this work and previous studies is that this framework was developed based on the responses of only engineering and science students. This may have resulted in the emergence of fewer epistemological orientations than presented in the other studies as students in similar disciplines may hold similar beliefs about knowledge.

1.1.2.2 Quantitative Studies

Numerous studies conducted in the STEM disciplines have utilized quantitative methods to study students' epistemic beliefs. The quantitative epistemic belief instruments have been met with criticism in recent years due to a lack of reliability and validity (DeBacker et al., 2008). Despite this criticism, some insight can still be gained from the quantitative studies that have been done, but the results have to be interpreted carefully. One of the commonly used instruments is Schommer's Epistemological Reflection (ER) Survey (1990). King and Magun-Jackson (2009) used this instrument in a quantitative study examining the epistemic beliefs of engineering students as a function of academic level. The results of this work support previous findings that show epistemic beliefs becoming more sophisticated with increasing academic level (Baxter Magolda, 1999; Perry, 1968; Felder, Carolina, Brent, & Designs, 2004). More specifically, in this work they found significant increases in two dimensions: certain knowledge and quick learning. Additionally, their work shows that epistemic beliefs are influenced by gender, high school grade point average, and ethnicity. It is important to consider that these results were obtained using a general epistemic beliefs survey in which students are not prompted to consider a specific subject or course. Such surveys have received criticism recently, as students' epistemic beliefs have been shown to be dependent on discipline (DeBacker et al., 2008). Despite this the results from this work add to the field and suggest that more studies be done to further investigate the influence of academic level, course curriculum, and demographics on epistemic beliefs.

There are two quantitative instruments that have been developed to measure engineering epistemic beliefs (Carberry, 2010; Yu & Strobel, 2011). These instruments are in their early stages of development

and both draw from different areas of the personal epistemology literature. Carberry et al.'s (2010) Episte-mological Beliefs Assessment for Engineering (EBAE) is based on Hofer and Pintrich's (1997) model that was originally derived from Schommer's (1990) work. EBAE is composed of four dimensions: certainty of engineering knowledge, simplicity of engineering knowledge, source of engineering knowledge, and justi-fication for engineering knowledge. Compared to other epistemic belief instruments that have been used to study engineering students, this instrument is domain specific and only asks students about their epistemic beliefs in engineering. It is possible that it is still too general as students may think of engineering design very differently than they think of their statics courses and students in mechanical engineering may think differently than those in biomedical engineering. More work is needed to investigate the degree to which epistemic beliefs are domain specific. Additionally, this survey was validated with a sample size below the minimum value suggested for factor analysis. Despite the limitations of the study, EBAE is a step in the right direction for domain-specific epistemic instruments. Yu and Strobel's (2011) instrument was developed to as-sess engineering-specific belief systems, including epistemological beliefs, epistemic beliefs, and ontological beliefs. These authors suggest that engineering epistemology needs to be defined in more detail than it has been previously, using their three dimension framework of engineering beliefs. The epistemological beliefs items in this survey were defined based on Hofer and Pintrich's (1997) framework and have similarities to the items in EBAE. This instrument has been used in a limited number of studies and needs further validation to ensure the construct and face validity of the instrument.

1.1.3 Undergraduate Research Experiences

Within the last decade there has been an increase in empirically based research on the outcomes of undergraduate research experiences (UREs). Prior to this time, most published articles discussed the perceived benefits to UREs with little supporting evidence. Additionally, the published program evaluation studies (which were limited in number) lacked clear descriptions of methods used or made claims that were not supported by the results presented (Laursen, Hunter, Seymour, Thiry, & Melton, 2010). More recent evaluation of and research on UREs has shown a number of substantiated positive gains for students. These include the retention of students in STEM (Adedokun & Burgess, 2011; Nagda, Gregerman, Jonides, von Hippel, & Lerner, 1998); clarification of career goals (Lopatto, 2004, 2007; Seymour, Hunter, Laursen, & DeAntoni, 2004); enhancement of basic research skills (Kardash, 2000; Kremer & Bringle, 1990); and increased understanding of the research processes (Lopatto, 2004, 2007; Seymour et al., 2004).

One goal of UREs is to improve students' research skills. Studies presenting gains in research skills

do not often distinguish skills based on characteristics or level of difficulty (Seymour et al., 2004). One exception is Kardash's (2000) study of summer and academic-year research participants in which skills are grouped as "lower-order" and "higher-order". She found that students felt significant gains in "lower-order" skills that included communicating research results orally, observing and collecting data, relating their results to the "bigger picture", and understanding contemporary concepts in their field. In contrast, she found lesser gains in many of the "higher-order" skills such as "identifying a specific question for investigation, translating the question into a working hypothesis, designing a theoretical test of a hypothesis, and reformulating the hypothesis on the basis of ones experimental results" (Kardash, 2000, p.196). Kardash concludes that while UREs may improve a number of basic scientific skills, "the evidence is less compelling that UREs are particularly successful in promoting the acquisition of higher-order inquiry skills that underlie the foundation of critical, scientific thinking" (Kardash, 2000, p.196).

Additionally, a limited number of studies have shown positive impacts of UREs on both students' ability to think like scientists and their understanding of the nature of scientific knowledge. It has been shown that students who participate in UREs join a community of practice, a group of individuals with shared practices and beliefs, (Lave & Wenger, 1991) that encourages students' intellectual and professional development (Hunter, Laursen, & Seymour, 2006; Seymour et al., 2004). Hunter et al. (2006) utilized a social constructivist lens that includes both communities of practice and identity to investigate the gains of students participating in an apprenticeship style research program at four liberal art colleges. Students and faculty reported similar gains including thinking and working like a scientist; personal-professional (e.g. gains in confidence to do science); clarification, confirmation, and refinement of career/education plans; and working independently. Faculty were more likely to view student development as "becoming a scientist" than the students, viewing student development as moving from legitimate peripheral participation towards a more centralized role in the community of scientists (Hunter et al., 2006). The effect of undergraduate research on students' adaptation to the norms, values and professional practice of science has been examined from the perspective of the student-advisor relationship in UREs (Thiry, Weston, Laursen, & Hunter, 2012). Findings revealed that novice and experienced student researchers have different needs in terms of mentoring and participation in the research community of practice. Additionally, the study acknowledged the effect of UREs on students' identities and career paths.

One limitation of prior studies is that the majority focus on summer UREs with rigorous admissions requirements that prevent many students from participating. A few studies, such as Robertson and Blacker (2006), focus on students with no research experience. In both cases, students who participate in research

projects during the academic year or as part of their regular curricula are excluded.

1.1.4   Personal Epistemology in the Research Lab

Samarapungavan and colleagues (2006) studied the development of epistemic beliefs as a function of chemistry expertise and research experience. Their work was guided by three research questions: 1) "Do the participants' epistemic beliefs vary as a function of chemistry expertise?", 2) "Are there discipline-specific values and heuristics that guide chemistry research?", and 3) "How does research experience influence the participants' epistemic beliefs?" (Samarapungavan et al., 2006, p.471). To answer these questions, high school students, undergraduate students (with and without research experience), graduate students, and research chemists were interviewed about their epistemic beliefs in chemistry. Their interview questions spanned five epistemic themes: "description of own work", "choice of problems and methods", "models for handling empirical anomalies", "criteria for evaluating own work", and "what is science?". During analysis, they initially coded responses to each interview question based on the level of sophistication using a number from one to seven. After this first round of coding, the initial codes were grouped based on the range, elaboration, and specificity of the response. Taking a mixed-model approach (qualitative data is analyzed with quantitative methods) they found that epistemic beliefs differ based on chemistry expertise, there are discipline specific values and heuristics expressed by research chemists, and that research expertise influenced their epistemic beliefs. Their results contrast the work of others who previously suggested that scientists have relatively unsophisticated views of the nature of science (Bell & Lederman, 2003). One explanation for this may be the unique approach these researchers adopted exploring enacted epistemologies by grounding their interview questions in the work and area of expertise of their participants. This likely made the seemingly abstract and decontextualized questions found in most research on epistemic beliefs more understandable and approachable. Additionally, their work suggests that participation in an authentic research experience is important for chemistry students' epistemic development. Their work does not provide information about how the types of experiences (ex. keeping a lab notebook, research group meetings, presenting research, and training others) within a research lab may influence epistemic development.

1.2   Organization of the Dissertation

This dissertation is composed of three articles (Chapter 2, 3, and 4) that have been prepared to submit for publication. These papers seek to meet the following research aims:

1. Assess the reliability and validity of a quantitative instrument designed to measure engineering epistemic beliefs and need for closure

2. Identify and describe homogenous groups that exist among bioengineering students based on their engineering epistemic beliefs and need for closure

3. Understand students' epistemic cognitions when solving an open-ended homework problem

4. Examine the connections between students' engineering epistemic beliefs, need for closure, and epistemic cognition in the context of classroom problem solving

5. Understand students' epistemic cognitions when making research decisions

Chapter 2 addresses aims 1 and 2, Chapter 3 addresses aims 2-4, and Chapter 4 addresses aim 5. Each of these chapters seek to further understand students' personal epistemologies, focusing on the discipline of engineering and the context of problem solving. Students in an undergraduate biomechanics course were invited to participate in these studies. The connections between each chapter are further outlined in Figure 1.1.
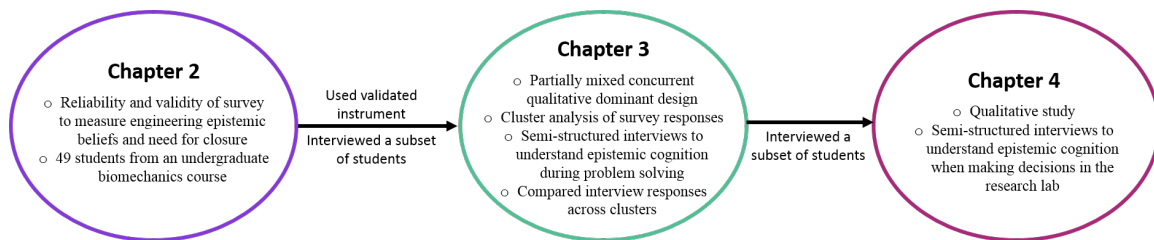
Figure 1.1: Graphic representation with a description of each chapter and how the chapters are connected.

1.3 Positionality Statement

I believe that in qualitative research the researcher and participant share the process of creating the data. As such, it was important for me to be aware of how my experiences and beliefs may influence my work. Prior to conducting the work presented in this dissertation, I conducted a thorough literature review of studies in the field of personal epistemology and was taking a course on epistemic cognition while I collected the data. As a result of my literature review and reflection on my beliefs about personal epistemology, I selected the framework presented by Chinn and his colleagues (2011) to use as the primary theoretical lens for my

work. One reason I selected this conceptualization of epistemic cognition was because it presented a clear and robust definition and favored a fine-grained approach to investigate students' beliefs. Prior to identifying this framework I knew I wanted to further understand how students' beliefs about knowledge and knowing in engineering influenced their approach to problem solving in the classroom and research lab. I became interested in this area of work after investigating K-12 teachers' and undergraduate students' development of their identity as a researcher (Faber & Benson, 2015a; Faber, Hardin, Klein-Gardner, & Benson, 2014). A component of this development included the evolution of their beliefs about how new knowledge is created in their field. I also adopted Kruglanski's and Yu and Strobel's (2011) instruments to understand both need for cognitive closure and engineering epistemic beliefs, respectively. I initially planned to used these instruments to select participants for semi-structured interviews centered around students' problem solving. I went into this study skeptical of the results I would obtain from the quantitative surveys because of the papers I had read. I was particularly skeptical of the engineering epistemic belief instrument because of the criticism in the literature of these instruments and the lack of reliability and validity studies done with this particular scale. As such, I allowed for students to provide written explanation of their numerical response to the engineering epistemic belief survey items so that I could assess validity of these survey items.

I selected a junior level biomechanics course at Clemson University as my study population because of their use of open-ended homework problems that require students to evaluate multiple sources and justify their answers and the large number of students in the department that participate in undergraduate research experiences. Both of these things would ensure that I could investigate students' epistemic cognitions in the context of classroom problem solving and research experiences. Another reason for selecting this population was because of my familiarity with the discipline. I graduated from Clemson University in 2010 with a B.S. in Bioengineering and a minor in Chemistry. I started doing research as an undergraduate student during my freshman year in the Chemical Engineering Department with Dr. Hirt and started a second project during my junior year in the Bioengineering Department with Dr. Dean. Because I completed a nearly identical curriculum to the students I interviewed, I was familiar with the courses they described and the professors who were teaching the classes. While this allowed me to easily understand the material my participants were talking about, I had to be careful to not make assumptions about what they were saying based on my experiences in the department. After completing my B.S., I went to Cornell University and completed a M.S. in Biomedical Engineering. Between my undergraduate and graduate studies in biomedical engineering, I have approximately six years of experience doing biomedical engineering research. I faced multiple roadblocks in all of the research studies I worked during that time. These challenges significantly impacted my view

of biomedical engineering research. I have come to believe that the research done in the field of biomedical engineering is less applied than I originally thought and most of the knowledge that is created is very context specific and often cannot be translated to other systems. I was very cautious during the interviews to get the students' beliefs about their research studies while not letting my beliefs alter theirs.

Chapter 2

Engineering Students' Epistemic Beliefs and Epistemic Motivation: An Instrument Validation Study

2.1 Abstract

This study utilized a quantitative survey instrument and open-ended items to understand engineering students' epistemic beliefs and epistemic motivation. The survey instrument used in this study combined items from two pre-existing instruments, the Need for Cognitive Closure scale and the Engineering-Related Beliefs Questionnaire (ERBQ). Fifty undergraduate bioengineering students enrolled in a junior-level biomechanics course completed the survey. Survey items were measured on a seven point anchored scale from strongly agree to strongly disagree. For each item from the ERBQ, students were also asked to provide short written explanations of their responses in a text box below each item. This was only done for the items from the ERBQ because of a lack of reliability and validity studies with this scale and general concern with the reliability and validity of similar instruments designed to measure epistemic beliefs. The internal consistency reliability and convergent validity were assessed for all of the items on the survey. Students' open-ended responses associated with the ERBQ items were analyzed qualitatively to assess their face validity and gain a general understanding of students' engineering epistemic beliefs. The quantitative survey responses were further analyzed using a k-means cluster analysis around the factor scores of the constructs certainty of knowl-

edge, source of knowledge, and closed-mindedness, resulting in three homogenous sub groups. These factors may be useful in distinguishing groups of engineering students based on their epistemic beliefs and need for cognitive closure. The constructs discomfort with ambiguity and simplicity of knowledge were not included in the cluster analysis because of low internal consistency reliability. Qualitative analysis of students' open-ended survey responses revealed a number of inconsistencies with how students interpret the items from the ERBQ. Recommendations are made for improving reliability and validity of quantitative measures of students' engineering epistemic beliefs.

2.2 Introduction

One method to prepare students for working in a rapidly changing, multi-disciplinary environment is by encouraging students to make critical evaluative judgments and develop self-regulated learning and problem solving strategies throughout their undergraduate studies. These skills have been shown to be influenced by students' epistemic beliefs (Muis, 2007; Bromme et al., 2009; Montfort, Brown, & Frye, 2012). Additionally, epistemic beliefs or their beliefs about the nature of knowledge and knowing have been shown to have an underlying influence on other attributes of learning and development such as metacognition and conceptual change (Franco et al., 2012; Hofer, 2001).

2.2.1 Prior Quantitative Studies on Engineering Epistemic Beliefs

Numerous studies conducted in Science, Technology, Engineering, and Mathematics (STEM) disciplines have utilized quantitative methods to study students' epistemic beliefs. These quantitative epistemic belief instruments have been met with criticism in recent years due to a lack of reliability and validity (DeBacker et al., 2008). However, some insight can still be gained from the quantitative studies that have been done, providing the results are interpreted carefully.

Schommer (1990) developed one of the first quantitative surveys to study epistemic beliefs, the Epistemological Questionnaire (EQ). This instrument is domain general and seeks to understand students' beliefs about certain knowledge, omniscient authority, simple knowledge, quick learning, and innate ability. Certain knowledge is conceptualized as an individual's beliefs about whether knowledge is stable or can change. Omniscient authority is the belief that knowledge is handed down by an authority figure rather than being constructed by an individual. Simple knowledge means that knowledge is made up of a series of facts rather than complex, interconnected concepts. Quick learning is the belief that individuals learn knowledge

quickly or not at all. Innate ability is the idea that you are born with the ability to learn and this ability cannot be acquired. The ER survey has been used to study the epistemic beliefs of students in a variety of disciplines. King and Magun-Jackson (2009) used the EQ in a quantitative study to examine the epistemic beliefs of engineering students as a function of academic level. The results of this work support previous findings that show epistemic beliefs becoming more sophisticated with increasing academic level (Baxter Magolda, 1999; Felder et al., 2004; Perry, 1968). Specifically, related to the certainty of knowledge and quick learning. Additionally, their work shows that epistemic beliefs are influenced by gender, high school grade point average, and ethnicity. It is important to consider that these results were obtained using a general epistemic beliefs survey in which students are not prompted to consider a specific subject or course. Such surveys have received criticism recently, as students' epistemic beliefs have been shown to be dependent on discipline (DeBacker et al., 2008). However, results from previous work add to the knowledge in the field and suggest that more studies be done to further investigate the influence of academic level, course curriculum, and demographics on epistemic beliefs.

Hofer and Pintrich (1997) developed a multi-dimensional theory of epistemic beliefs similar to Schommer's (1990) that includes the nature of knowledge (certainty and simplicity of knowledge) and the nature of knowing (source of knowledge and justification for knowing). Based on this conceptualization of epistemic beliefs, Hofer (2000) developed a discipline specific instrument to assess students' epistemic beliefs within a specific domain. Hofer's (2000) instrument is similar to Schommer's (1990); however, it includes justification for knowing and excludes innate ability and quick learning. This is important because innate ability and quick learning are not considered to be epistemic in nature as they measure students' beliefs about intelligence rather than knowledge (Hofer & Pintrich, 1997).

Drawing on Hofer's (2000) instrument, the Epistemological Beliefs Assessment for Engineering (EBAE) was developed and is composed of thirteen items across four dimensions: certainty of engineering knowledge, simplicity of engineering knowledge, source of engineering knowledge, and justification of engineering knowledge. The items on this instrument are measured using a 100 point scale. Compared to other epistemic belief instruments that have been used to study engineering students, this instrument is domain specific and asks students about their epistemic beliefs in engineering. Carberry et al. (2010) conducted a pilot study (n = 43) to validate the EBAE instrument and assess first-year engineering students' epistemic beliefs. Analysis of students' general engineering epistemic beliefs revealed that the first-year engineering students surveyed hold relatively sophisticated epistemic beliefs. These students had the least sophisticated views about the certainty of engineering knowledge and the most sophisticated views about the simplicity

of engineering knowledge. This suggests that first-year engineering students believe engineering knowledge is relatively fixed, which the authors hypothesize may be due to the majority of their prior learning coming directly from fixed knowledge sources like textbooks.

Their results also suggest that these students have an understanding that engineering knowledge is comprised of interconnected concepts. Despite the discipline specific nature of the survey items, they may still be too general for engineering students, as they may think of knowledge in engineering design very differently than they think of their content knowledge in courses such as statics. Also, students in different engineering disciplines may think differently (i.e. mechanical engineering vs. bioengineering). More work is needed to investigate the degree to which epistemic beliefs are domain specific. Additionally, this survey was validated with a sample size below the minimum value suggested for factor analysis, which brings into question the validity of the instrument. Despite the limitations of the study, EBAE is a step towards a validated, domain-specific instrument to investigate epistemic beliefs in engineering.

Yu and Strobel (2011, 2012) developed the Engineering Related Beliefs Questionnaire (ERBQ) to measure beliefs about the nature of knowledge and knowing. Items on the ERBQ were informed by Hofer and Pintrich's (1997) framework and have similarities to the EBAE. This instrument was developed through a two step process that included a systematic literature review followed by a content validity study. Once an initial pool of items was established, a focus group was held with faculty and doctoral students in engineering and education disciplines. The focus group evaluated the items by matching them to one of the three constructs (simplicity, source, and certainty of knowledge). This instrument has not been widely used and further validation tests are needed to ensure reliability and validity of the instrument.

2.2.2 Prior Quantitative Studies on Epistemic Motivation

Epistemic motivations, like epistemic beliefs, have been suggested to influence aspects of learning and social psychological phenomena (Kruglanski, 1990; Kruglanski & Webster, 1996; Webster & Kruglanski, 1994). Two types of epistemic motivations that have been identified in the literature are epistemic virtues and vices. Epistemic virtues are dispositions that aid in the achievement of gaining knowledge and understanding. In contrast, epistemic vices are dispositions that hinder gaining knowledge or understanding. Two commonly considered epistemic vices are discomfort with ambiguity and closed-mindedness (Chinn et al., 2011; Kruglanski, 1990). These epistemic motivations can be measured using Kruglanski's (1990) Need for Cognitive Closure Scale, which has been used to study the epistemic motivations of individuals in a variety of contexts. Two consequences of high need for cognitive closure have been identified 1) "seizing" or making

decisions based on the most assessable information and 2) "freezing" on a decision and showing a reluctance to change that decision when additional information is presented (Kruglanski & Webster, 1996; De Grada, Kruglanski, Mannetti, & Pierro, 1999).

The need for cognitive closure and the consequences that result have been investigated in a variety of contexts. Kruglanski and Webster (1996) suggest that an individual with high need for closure may process less information prior to making a decision due to "seizing" and "freezing". This was investigated in the context of a negotiation task by De Dreu and colleagues (1999). They studied the influence of cognitive need for closure on undergraduates performing a negotiation task and found that the students' approaches to negotiation was influenced by their need for cognitive closure. De Grada and colleagues (1999) studied the influence of high vs. low need for cognitive closure on the group interactions among psychology students at the University of Rome. Their studies reveal that members with high need for cognitive closure encouraged group dynamics in which some members of the group dominated conversation and decisions. While this represents a brief review of the studies conducted using Kruglanski's Need for Cognitive Closure Scale (1990), it is meant to represent the breadth of contexts in which the instrument has been applied.

2.2.3 Objectives of Research Study

The goals of this study were to 1) investigate the face validity, convergent validity, and internal consistency reliability of existing engineering epistemic belief items, 2) investigate the convergent validity and internal consistency reliability of existing need for cognitive closure items, and 3) further understand undergraduate bioengineering students' epistemic beliefs and need for closure through a quantitative survey instrument and open-ended questions related to the engineering epistemic beliefs items.

2.3 Theoretical Frameworks

2.3.1 Engineering Epistemic Beliefs

The quantitative instrument used in this study included items from Yu and Strobel's (2012) ERBQ. This instrument is based on Hofer and Pintrich's (1997) epistemic beliefs framework and was designed to assess students' beliefs about the certainty, simplicity, and source of engineering knowledge. Beliefs about the certainty of knowledge range from absolute to contextual to relative. The structure of knowledge can be conceptualized from simple to complex based on the complexity of underlying concepts. Beliefs about

the source of knowledge range from reliance on authority to self-construction. In Yu and Strobel's (2012) instrument, these constructs (certainty, simplicity, and source of knowledge) are situated in the context of engineering. This instrument was used in our study to gain a general idea of the epistemic beliefs that students hold about engineering knowledge. Additionally, these items were assessed for their face validity, convergent validity, and internal consistency reliability. We assessed the face validity of the engineering epistemic belief items because of the limited use of the ERBQ and the general concern in the field about the reliability and validity of scales measuring epistemic beliefs.

An example item from the certainty of engineering knowledge construct is "Principles in engineering cannot be argued or changed." One of the items from the simplicity of knowledge construct is "Engineering knowledge is an accumulation of facts." "First-hand experience is the best way of knowing something in engineering." represents one of the items from the source of knowledge construct.

2.3.2   Epistemic Motivation

Epistemic motivation is defined by Kruglanski and Webster (1996, p. 264) as,"an individuals desire for a firm answer to a question and aversion toward ambiguity". It has been suggested to influence an individuals' actions, motivations, and choices based on whether closure is threatened or facilitated (Kruglanski & Webster, 1996). The Need for Cognitive Closure Scale was designed to measure an individuals' "motivation with respect to information processing and judgment"(Webster & Kruglanski, 1994, p.1049). This instrument has five sub-scales: desire for predictability, preference for order and structure, discomfort with ambiguity, decisiveness, and closed-mindedness. Discomfort with ambiguity and closed-mindedness have been suggested to inhibit the acquisition of knowledge and understanding (Chinn et al., 2011). As such, items from these two constructs were includes on the instrument used in our study. "I dislike questions which could be answered in many different ways." and "When thinking about a problem, I consider as many different opinions on the issue as possible" represent items from the constructs discomfort with ambiguity and closed-mindedness, respectively.

Multiple validations studies have been conducted to assess the reliability and validity of this instrument (Webster & Kruglanski, 1994; Neuberg, Judice, & West, 1997). Neuberg and colleagues' (1997) study suggests that the items factor into multiple dimensions, which is in contrast to Webster and Kruglanski's (1994) work. It is believed that an individual's need for closure is dependent on situational factors such as time and pressure. Research suggests that individuals with a high need for closure make judgments based on stereotypes, assimilate new information to existing beliefs, and often resist persuasion when they have prior

knowledge (Neuberg et al., 1997). The convergent validity and internal consistency reliability were assessed for these items in this study. We did not investigate the face validity of these items because of the extensive use of the Need for Cognitive Closure Scale in various disciplines and contexts.

2.4 Research Methods

2.4.1 Participants

Participants were recruited from a junior-level biomechanics course in the Bioengineering Department at Clemson University. Students in the course were invited to complete the survey instrument, described in detail below and in Appendix A, to gain extra credit in the class. These students were not required to participate in the study to get the extra points. Fifty of the sixty-eight students in the course completed the survey and were included in this study. Of the 50 students, 12 had been at Clemson University for two years, 34 for three years, and 3 for four years. Twenty-eight of the students had at least one semester of research experience, two students had co-operative education experience, six students had industry experience, and fifteen had clinical experience. Additional demographic information such as gender, race, and ethnicity were not collected from the students because this information was outside the scope of this study.

2.4.2 Instrument

The survey instrument (see Appendix A) was divided into three parts that sought to understand students' epistemic motivation (need for cognitive closure), epistemic beliefs, and backgrounds. Part one of the survey included 16 items from the discomfort with ambiguity and close-mindedness constructs from Kruglanski's Need for Closure (NC) Scale designed to measure epistemic motivation (Kruglanski, 1990). Part two of the survey included Yu and Strobel's 22 item ERBQ, which includes the constructs of certainty, simplicity, and source of knowledge in Hofer's (2001) and Chinn's (2011) frameworks. Part three of the survey included items about co-curricular experiences (research, clinical, and industry experiences), years at Clemson University, and semesters in a research experience.

The items from the NC scale and the ERBQ were measured on a seven point scale anchored from strongly agree to strongly disagree. For each item from the ERBQ, students were asked to provide an additional written explanation of their response on the anchored scale in a text box below each item. This open-ended component was included for these items to allow for deeper exploration of students' beliefs and

to assess face validity of the items. This was particularly important for these items because of the lack of reliability and validity associated with many of the instruments developed to measure epistemic beliefs.

2.4.3   Quantitative Analysis

Cronbach's α was calculated for each construct from the NC scale and ERBQ to assess the internal consistency reliability of the items. Internal consistency reliability defines how well items within the same construct deliver similar responses. Constructs with a Cronbachs α of 0.7 or above are considered to have acceptable internal consistency reliability (Nunnally & Bernstein, 1994). For constructs that had an α below 0.7, the convergent validity of the items within each construct was assessed by calculating the correlations between each of the item in the construct. Items within the same construct should be highly correlated with each other because they were designed to measure theoretically similar concepts (Trochim & Donnelly, 2007). Items with low correlations to the other items in the construct were removed one at a time. This was repeated until the α for the construct was at least 0.7 at which point the construct was acceptable. Items were not removed from constructs that had less than three items, regardless the α. Constructs with an α below 0.7 were excluded from further analysis. This was done to ensure that the items within each construct returned consistent scores suggesting that they measure the same concept.

A k-means cluster analysis around the factor scores was utilized to identify homogenous subgroups based on epistemic beliefs and motivation. This analysis seeks to minimize the variance within a cluster while maximizing the variance between clusters. With a k-means cluster analysis, the number of clusters is determined by the researcher and must be decided prior to obtaining the clustering solution. A plot of the percent variance explained as a function of the number of clusters and a plot of the principle component analysis were used in combination to determine that the optimal number of clusters was three. The mean of each construct was compared between the clusters using a pairwise t-test to determine whether the difference in construct scores for each cluster was statistically significant. All quantitative analyses were performed in R (Team, 2012). The cluster analysis was performed using the cluster package (Maechler, Rousseeuw, Struyf, Hubert, & Hornik, 2015).

2.4.4   Qualitative Analysis

For each item from the ERBQ, students were prompted to explain their response in a text box below each item. Students' explanations of their responses were analyzed qualitatively to assess the face validity of

the survey items and gain a deeper understanding of students' engineering epistemic beliefs. These responses were analyzed using conventional qualitative content analysis (Hsieh & Shannon, 2005). First, all responses to a single item were read through multiple times to gain a general understanding of students' beliefs in relation to that item and the diversity in the responses to that item. Next, statements about a single item were coded using open coding, allowing codes to emerge from the data. During the coding process, the researcher used both the quantitative and qualitative responses to the survey item to develop the codes to ensure that the students' beliefs were appropriately captured.

2.5 Results

2.5.1 Quantitative Results

Ideally, an exploratory factor analysis would have been performed first to determine the factor loadings for each item in the instrument, empirically determining the items that go into each construct. Given the low sample size (n = 50) in this study, exploratory factor analysis could not be reliably used. As such, the constructs used in this study were determined based on Yu and Strobel's (2011) and Kruglanski's (1990) work. The internal consistency reliability was calculated using Cronbachs α for each predefined construct in the survey (see Table 2.1).

Overall, one item from the construct discomfort with ambiguity and two items from the constructs certainty of knowledge, source of knowledge, and closed-mindedness were removed because of low correlations with other items in the construct. The item that was removed from the closed-mindedness construct was "I feel irritated when one person disagrees with what everyone else in the group believes." This item seems to be less about the individual's open- or closed-mindedness and more about how they deal with someone else not being open-minded. This difference may explain why the item had low correlation with the other items in the construct. The two items removed from the certainty of knowledge construct were, "All engineering experts understand engineering problems in the same way" and "Words in engineering knowledge have one clear meaning." Both of these items had low correlations with the other items in the certainty of knowledge construct and appear to be qualitatively different from the other items in the construct. The item, "All engineering experts understand engineering problems in the same way" is the only item in this construct that is about engineering experts. Likewise, the item "Words in engineering knowledge have one clear meaning" seems more specific than the other items, and it is not clear that "words in engineering" is analogous

19

to engineering principles, problems, and knowledge. The two items that were removed from the source of knowledge construct were "Correct solutions in the field of engineering are more a matter of opinion than fact" and "Engineering knowledge should rely on a combination of experts' observation, experimental evidence, and rational arguments." These items had low correlations with the other items in the construct which may be the result of qualitative differences in the items and the structure of these items. The item "Correct solutions in the field of engineering are more a matter of opinion than fact" does not seem to be directly about the source of knowledge in engineering because of how it is phrased relative to a problem solution. Additionally, the item "Engineering knowledge should rely on a combination of experts' observation, experimental evidence, and rational arguments" is a compound item, potentially making it difficult for students to answer.

The simplicity of knowledge and discomfort with ambiguity constructs had Cronbach's α values well below the 0.7 cutoff and were not used in later quantitative analysis. Once items were removed as described above, the Cronbach's α for the source of knowledge, certainty of knowledge, and close-mindedness constructs were determined to suggest acceptable internal consistency reliability and were used in later quantitative analysis (see Table 2.1).

Table 2.1: Number of items and Cronbach's α of items in each construct on the survey after items were removed that had low convergent validity. The simplicity of knowledge and discomfort with ambiguity constructs were not included in further analysis due to low internal consistency reliability as indicated by Cronbach's α ¡ 0.7 rule of thumb.

	Construct	**Number of Items**	**Cronbach's**
ERBQ	Simplicity of knowledge	2	0.48
Engineering Epistemic Beliefs	Source of knowledge	10	0.70
Yu and Strobel 2011	Certainty of knowledge	5	0.72
Need for Cognitive Closure Scale	Close-mindedness	5	0.70
Kruglanski 1990	Discomfort with ambiguity	4	0.58

The next step for this study was to identify subgroups of students based on their responses to items in the constructs of source of knowledge, certainty of knowledge, and close-mindedness using a k-means cluster analysis. The optimal number of clusters for this data set was determined to be three based on the plot of the percent variance explained as a function of the number of clusters and the plot of the principle component analysis. The construct means (source of knowledge, certainty of knowledge, and close-mindedness) for each cluster is presented in Figure 2.1.

Overall, students in cluster one are more open-minded and believe that knowledge is subject to change more than students in clusters two and three. The students in cluster one also have a stronger belief that knowledge is constructed than students in cluster three. Based on the responses to the survey, students in cluster two were equally open and close-minded, but were still significantly more close-minded than students in the other two clusters. The students in cluster two held the belief that knowledge is constructed at the same level as students in cluster one and were between students in clusters one and three in terms of their belief that knowledge is subject to change.
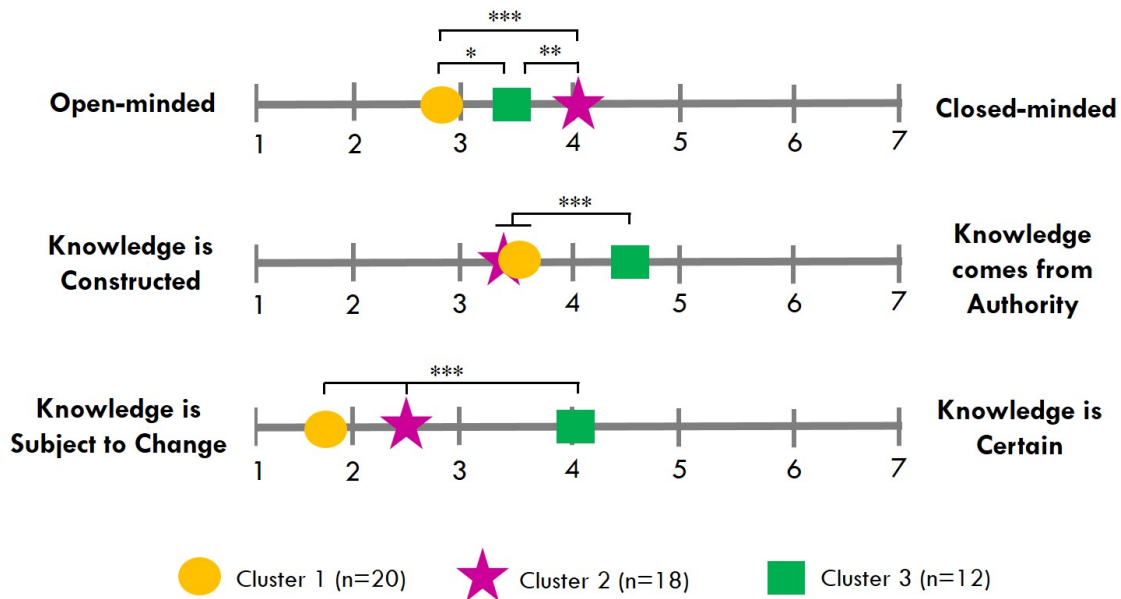
Figure 2.1: Representation of the mean for each cluster on the constructs of open mindedness, source of knowledge, and certainty of knowledge. The tick-marks on the line for each construct represent the 7-point anchored scale used for the items on the survey, where 1 indicates "strongly agree" and 7 indicates "strongly disagree" with survey items. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$ (pairwise t-test)

2.5.2 Qualitative Results

The aim of the qualitative portion of this study was to access the face validity of the items from the ERBQ and gain a more detailed understanding of the students' engineering epistemic beliefs. This was accomplished by asking students to elaborate on their response to the anchored survey items by typing an explanation of their response in a text box below each item. A summary of suggestions for rephrasing the engineering epistemic belief items based on these data can be found in Table 3.1.

2.5.2.1 Items on the Certainty of Engineering Knowledge

There were seven items on the ERBQ that were originally designed to measure students' beliefs about the certainty of knowledge. Two of these items were removed from this construct after determining that they had low correlations with the other items and seemed to be qualitatively different than the other items. The open-ended responses about the five remaining items were used to assess the face validity of each item.

Principles in engineering cannot be argued or changed. Many students disagreed with this item and reflected on their belief that engineering knowledge is constantly changing. One student stated, "We are discovering new things every day, so we may learn we were wrong about some sort of engineering principle." A few students made statements that suggested that their belief is dependent on the type of knowledge they are considering. The students who expressed this idea did not provide a consistent numerical response to this item, ranging from two to seven. One student that responded with a five stated,"Principles such as equations cannot be changed and these are the foundation to solve many engineering problems. However, different approaches can be argued or changed." Another student with a similar written response whose numerical response was two explained, "Basic mathematical and physical laws cannot be changed but the ideas and implementations can." The similarity in the students' written responses but difference in the students' numerical response suggest that students might not be responding to this item in a manner that accurately reflects their beliefs. This may be further explained by data collected in a later qualitative study that sought to investigate students' conceptualization of what makes up engineering knowledge. Data collected as part of that study suggests that bioengineering students may not have a clear idea of what a principle in engineering is and are not able to think of an example of one. This may result in students interpreting this item in many different ways, leading to results that cannot be compared across students. This was evident in students' responses to the open-ended component of the survey instrument used in this study. Students' interpretations of the phrase "engineering principle" included mathematical equations, laws, theories, and founding ideas. Rephrasing this item to use language that the students are more familiar with, such as theories or laws, may lead to students interpreting this item more consistently.

Engineering problems have only one right answer. While most of the students disagreed with this item, there was some inconsistency in students' written explanations. Some students referred to a problem's answer and others referred to the solution. For example, one student responded with a two on this item and stated, "While there may be one answer to a problem, there can be multiple conclusions as far as how it

was achieved." This statement suggests that this student's beliefs about the answer and the solution to an engineering problem are different. If other students hold a similar belief, then students' responses should only be compared to one another if they are both referring to the answer or the solution to a problem. Perhaps rephrasing the item to "Engineering problems have only one right *numerical* answer" would decrease this ambiguity.

Of the students that marked a four or higher for this item, many of their written responses suggested that the students have different beliefs about engineering problems in the classroom compared to the broader engineering community. One student stated, "Perhaps not in real world scenarios with many variables, such as cost and effectiveness." Another student made a similar comment and explained, "It depends on the situation. There are many different ways to fix different fractures and medicines, however given problems tend to be only one answer." Both of these students made statements suggesting that they were thinking about both problems in the classroom and in the broader engineering community. Additionally, their beliefs about problems are dependent on context, problems in the classroom and outside the classroom. For most of the other students' responses, it is not possible to tell what context they are thinking about when they answered this item. This presents a challenge for data analysis because it creates inconsistency across student responses making it difficult to compare students' responses. To account for this ambiguity the item could be rephrased to specify the context that the researcher wants the participant to think of when answering the item, such as the engineering classroom, an engineering research lab, or in engineering practice.

There is one universal engineering method. Almost all of the students disagreed with this item. Students described that they disagreed because there are multiple ways to solve problems and everyone thinks differently. For example, one student stated, "There are multiple methods to solving [a] problem." Another student said, "Definitely not, people have different techniques to solve problems which gives us [in] the engineering world an advantage to have many solutions because everyone's doing it differently." Students' numerical and written responses to this item suggest that students are interpreting this item in similar ways and rewording is not necessary.

Engineering knowledge should be accepted as an unquestionable truth. Almost all of the students disagreed with this item and said that engineering knowledge should not be accepted as unquestionable truth. Students stated that they disagreed with this item for multiple reasons, such as engineering has failed in the past, nothing is certain, and everything should be questioned and tested multiple times. One student said, "Engineering fails all the time. To call it unquestionable would be to ignore every collapsed bridge, every recalled drug, and every failed automobile." Another student explained, "No, it can always be questioned. The

focus of engineering is developing the best possible solution, there is always a better way to do something."
Like the previous item, students' responses to this item were consistent and rewording is not necessary.

Engineering knowledge cannot be subject to change with new observations by individual engineering students. While most of the students had a similar numerical response to this item, their written responses suggest that had unique beliefs that were not being captured in the statement. Within the students that disagreed with this item, there were students that believed an individual student could influence change while others believed it takes a group of individuals. For example, one student explained, "Usually the students work non-individually, but when they work in groups, engineering knowledge absolutely can change." In contrast, another student stated, "If one person makes an observation, it can begin a cycle of new discoveries." While both of these students disagreed with this item, it is clear that their beliefs were not the same; however, the instrument is not able to capture this difference. A number of other students expressed beliefs that align with one of the two example quotes given. Based on the students' responses, it appears that students are not necessarily thinking about their beliefs related specifically to individual engineering students, but rather individuals *or* engineering students. This presents a challenge with data analysis because it creates unintended inconsistency across students' responses, again making it difficult to compare students' responses. Additionally, some of the students' description of their responses suggested that they hold different beliefs about whether students or individuals can influence engineering knowledge. Breaking this item into two separate items may capture students' beliefs about both individuals and engineering students changing engineering knowledge. This will allow students to consider both individuals and engineering students independently, resulting a more consistent interpretation of the item.

2.5.2.2 Items on the Source of Engineering Knowledge

There were twelve items on the ERBQ that were originally designed to measure students' beliefs about the certainty of knowledge. Two of these items were removed from this construct after determining that they had low correlations and seemed to be qualitatively different than the other items. Students' beliefs and the face validity of the ten remaining items was assessed using the open-ended portion of the survey.

New engineering knowledge is produced as a result of controlled experimentation. The majority of the students agreed with this item, explaining that new engineering knowledge comes from experimentation and that controlled experimentation is necessary to truly test a hypothesis. One student expressed that "Engineers use experiments to develop new ideas and theories." Another student stated, "You need to have a controlled experiment to reduce the different variables that can affect it." Based on students' responses to

24

this item it seems like some students are thinking about experimentation and others are specifically thinking about controlled experimentation. This may lead to inconsistency in their responses. The detail of "controlled experimentation" might also make it more difficult for students to answer as some of the students expressed the belief that in engineering it is impossible to control anything, "Yes and no. I don't think you can control an environment too well in engineering but to be certain, technically it should be a controlled experiment." Rephrasing this item to read "New engineering knowledge is produced as a result of experimentation" may help students more reliability respond to this item.

The best way to develop engineering knowledge is by an engineering expert transmitting his or her knowledge to us. Students' responses to this item were split between agreeing and disagreeing. The students who agreed with this item seemed to hold the belief that learning from an expert is the easiest way to learn. One of the students stated, "The best way to learn is to learn from someone who knows significantly more and can explain the background," suggesting that this student believes that she is gaining an additional benefit by learning from an instructor. Another student that agreed with this item said, "...and to teach the knowledge interactively," adding a stipulation about what she feels like good instruction. Based on this students' justification of her answer it does not seem like this student truly agrees with the statement as it is written despite her numerical response of 6. Perhaps this student read past the "transmitting his or her knowledge" piece of the item, slightly changing the item's meaning. This was not the only student who struggled with the phrase "transmitting his or her knowledge." Another student said, "If by transmit his or her knowledge it is meant that the expert acts as an adviser and facilitator to experimentation, then yes. If by this you mean lectures, then no." This student's statement suggests that the phrasing of this item is ambiguous and adding more detail might help to clear it up. This may also decrease some of discrepancies that seemed to exist between students' numerical and written responses.

If your personal experience conflicts with the 'big ideas' in a book, the book is probably right. Students' responses to this item are split between agreeing and disagreeing with the statement. A few of the students who agreed expressed that "I trust the books selected for us" and "If it is published then it should be right." While other students who agreed did not seem to believe as strongly that the book should be trusted and stated, "The book is usually right because there are multiple professors that have written and researched about. However, there is always a chance that they are wrong." Based on these two students' written responses it is apparent that these students hold different beliefs about this item; however, this item is not capturing this difference. Removing "probably" from this item may help distinguish students' responses and further differentiate students who hold different beliefs. Additionally, a number of students expressed a similar belief

as the second example, but disagreed with the item stating "there is a chance the book is wrong." The fact that students who hold similar beliefs are not providing the same numerical response suggests that this item is not consistently capturing students' beliefs. Other students who disagreed with this item mentioned that "there's probably more to it" and that "for a grade-yes. in reality, the book probably just goes about it in a different way." These statements suggest that for some students their beliefs are influenced by the context of the situation, but this item does not currently take context into consideration. Based on students' responses, making this item more specific to a context such as the engineering classroom or engineering practice will help ensure that the students are thinking about the same context and their responses are being interpreted correctly.

Engineering textbooks written by experts present the best way to learn engineering. The majority of the students disagreed with this item. Students described that textbooks may not help understanding. "No, books are the worst, they are missing that ability to help new minds understand the material, they just say it." Additionally, students believed that everyone thinks differently and that interactive teaching methods are the more helpful, "In class practice and exercise would be more useful than just reading a book." Students responses to this item did not seem to suggest problems with how the item is worded; however, it might be useful to be more specific about how the books are being used. For example, the item could be rephrased to read, "Reading engineering textbooks written by experts present the best way to learn engineering." This might be necessary for the use of this instrument with a larger, less homogenous population where there might be more unique interpretations of this item.

A theory in engineering should be accepted as correct if engineering experts reach consensus. Most of the students agreed with this item; however, they provided two unique explanations for their responses, which included the idea that theories can be disproven and that if experts agree then the theory is most likely the truth. Despite agreeing with this item, some students described that even after being accepted as correct the theory could be disproven. One student stated, "...at least until a better theory is found", showing how she believes that new knowledge can prove prior knowledge to be inadequate. The students who mentioned that it could be accepted unless it is disproven seem to be expressing their belief about the certainty of engineering knowledge more so than their belief about the source of engineering knowledge. These students' responses suggest that even though the item was developed to measure students' beliefs about the source of knowledge it is also getting at their beliefs about the certainty of knowledge. This is important to keep in mind and may help explain why the Cronbach's α was lower for this construct than the others.

Other students' explanations of their responses seem more consistent with their numerical responses

than the example above. Some students believe a theory should be accepted since it was accepted by experts: "If experts agree the theory is correct then it should be considered correct seeing as that the experts should be the most knowledgeable on the subject." Other students described that it should be accepted since multiple people agree: "If multiple people reach the same consensus then it is most likely true." This item does not allow the distinction between expert consensus and a consensus among multiple people regardless of expertise. If this distinction is important to the researcher, then this item could be split and rephrased to make two distinct items to capture this nuance.

Traditional engineering ideas should be considered over new ideas. The majority of the students disagreed with this item and described how the new ideas may improve upon traditional ones. One student described, "If the new ideas are corrected and takes into account variables that have not been looked at before then you should definitely look at the new ideas." Other students expressed the belief that all ideas should be considered: "They should be utilized but new ideas are valid too." Based on students' numerical and written responses to this item there do not seem to be any major inconsistencies that would suggest rewording is needed.

Engineering knowledge is created only from an expert's logical thinking. Most students disagreed with this item either because they believed that anyone can create engineering knowledge or because it takes more than logical thinking to create new knowledge. Based on students' responses to this item it seems like students either focused on whether they believe an expert *or* logical thinking can create engineering knowledge. It is unclear if a student's belief would be different if they considered both parts of this compound item (expert and logical thinking). Perhaps students' beliefs about one trumps the other. For example, a student might believe that engineering requires experimentation and not just logical thinking, so the fact that an expert is doing the thinking does not matter. One student said, "Logical thinking alone either does not give you new information or can be wrong. Engineering utilizes experimentation and results combined with logical thinking to come to its conclusions." Likewise, a student might hold the belief that anyone can create engineering knowledge and disagree with the item because it says "expert". One student described, "Nope can be a crafty soccer mom on pinterest making her life easier with a new way to fold socks." Based on students' responses to this item, it may be beneficial to split this item into two items to capture students' beliefs about knowledge coming from experts and knowledge being created by logical thinking.

First-hand experience is the best way of knowing something in engineering. The majority of the students agreed with this item and explained that this type of instruction helps them learn better, stating that "Experiencing something yourself helps you learn and understand how something works." Students'

responses on this item appeared to be consistent with their numerical response. Additionally, there did not appear to be any inconsistencies with how students were interpreting this item. Since there is not much variation, this item may not prove to be very valuable when comparing students; however, the lack of diversity in responses may have been the result of the population that was surveyed. A few students either disagreed or gave a neutral response, stating that "It is a good way but if you don't have the basic knowledge to understand what is happening it does no good" and "[it is] not necessarily the best for everyone". It would be interesting to investigate these specific cases to further understand the students' responses and possibly modify this item to capture more diverse beliefs.

You can count on the information you find in engineering books to be true. Most of the students agreed with this item; however, there were a number of students who disagreed. Many of the students who disagreed made a statement that revealed their belief that engineering knowledge is constantly changing, which gives insight into students' beliefs about the certainty of knowledge in engineering. As previously described, this may negatively influence the internal consistency of this construct (source of engineering knowledge). Some of the students who agreed with this item also expressed the belief that engineering knowledge is constantly changing. One student said, "For the most part, yes. But in a developing field, it's hard to say that anything is true absolutely." The fact that students hold similar beliefs, but are responding with different numerical responses to this items suggests that this item may not be reliably measuring students' beliefs. Perhaps rephrasing this item to say, "You can count on the information you find in engineering books" may help students focus on the source of engineering knowledge rather than the certainty of engineering knowledge.

A few of the students who agreed with this item expressed that the book should be used as guidance rather than pure fact, saying "Most of the time the information you find in books is correct for the situation the book describes. All the information in the world is no good without the perspective to use it." Other students that agreed with this item expressed that the knowledge in engineering books is true because "it is proven and accepted" and "they were able to be published for a reason". Currently this item is not able to distinguish these beliefs and based on students' responses it is unclear how the item can be rephrased to capture these differences.

Engineering students learn when a teacher or expert transmits his or her knowledge to them. Most of the students agreed with this item but expressed that this is not the only way to learn, and experience is needed as well. One student said, "It is helpful to learn from someone with so much background knowledge, but the teacher must also be able to relate the knowledge to students at a level they can understand." Based

Con students' responses to this item there does not appear to be any major inconsistencies that need to be mitigated by rephrasing the item; however, the item is nearly identical to a previous item on the survey, "The best way to develop engineering knowledge is by an engineering expert transmitting his or her knowledge to us." As such, one of the items should either be rephrased or removed to get rid of this redundancy. This item could be rephrased to read "Engineering students learn when a teacher transmits his or her knowledge to them."

Table 2.2: Summary of suggested edits to source of knowledge and certainty of knowledge items on the ERBQ.

Original Item	Suggested Phrasing
Principles in engineering cannot be argued or changed.	Theories in engineering cannot be argued or changed.
Engineering problems have only one right answer.	Classroom engineering problems have only one right numerical answer. Engineering problems outside the classroom have only one right numerical answer.
There is one universal engineering method.	No change needed.
Engineering knowledge should be accepted as an unquestionable truth.	No change needed.
Engineering knowledge cannot be subject to change with new observations by individual engineering students.	Engineering knowledge cannot be subject to change with new observations by individuals. Engineering knowledge cannot be subject to change with new observations by engineering students.
New engineering knowledge is produced as a result of controlled experimentation.	New engineering knowledge is produced as a result of experimentation.
The best way to develop engineering knowledge is by an engineering expert transmitting his or her knowledge to us.	The best way to develop engineering knowledge is from an expert's teachings.
If your personal experience conflicts with the 'big ideas' in a book, the book is probably right.	In an engineering class, if your personal experience conflicts with the 'big ideas' in a book, the book is right.
Engineering textbooks written by experts present the best way to learn engineering.	Reading engineering textbooks written by experts present the best way to learn engineering.
A theory in engineering should be accepted as correct if engineering experts reach consensus.	Remove item because it is not specific to the source of engineering knowledge.
Traditional engineering ideas should be considered over new ideas.	No change needed.
Engineering knowledge is created only from an expert's logical thinking.	Engineering knowledge is created only from logical thinking. Engineering knowledge is created by an expert.
First-hand experience is the best way of knowing something in engineering.	No change needed.
You can count on the information you find in engineering books to be true.	You can count on the information you find in engineering books.
Engineering students learn when a teacher or expert transmits his or her knowledge to them.	Engineering students learn when a teacher transmits his or her knowledge to them.

2.6 Discussion

This study sought to investigate the convergent validity and internal consistency reliability of a quantitative instrument designed to measure undergraduate bioengineering students' engineering epistemic beliefs and epistemic motivation. Additional qualitative data was collected to assess the face validity and fur-

ther explore the students' engineering epistemic beliefs. The results of this study identified three constructs with acceptable internal consistency reliability and convergent validity that were used in further quantitative analysis in this study and can inform the use of this instrument in other studies with engineering students. Simplicity of knowledge and discomfort with ambiguity were found to have Cronbach's alpha's below the acceptable value of 0.7, suggesting that these two constructs are not measuring a single theoretical concept. In future iterations of this survey, more items should be added to the simplicity of knowledge construct to further establish this construct. The version of the ERBQ used in this study only had two items in this construct, which may explain the low internal consistency reliability. These additional items should be developed by looking at other epistemic belief instruments such as Schraw et al.'s (2002) Epistemic Beliefs Inventory, Hofer's (2000) Discipline Focused Epistemological Beliefs Questionnaire, and Carberry et al.'s (2010) Epistemological Beliefs Assessment for Engineering.

Further quantitative analysis was conducted using the constructs source of knowledge, certainty of knowledge, and close-mindedness to identify homogenous sub-groups of students. Three unique clusters of students with differing engineering epistemic beliefs and motivations were identified using a k-means cluster analysis. The largest difference between these three clusters was in the construct of certainty of knowledge. Future work will seek to further investigate the differences between these clusters using qualitative methods. The low sample size (n = 50) for this study was low for conducting robust quantitative analysis, thus future studies will include larger samples of engineering students. Mulitple engineering disciplines will be included to understand if there are differences in epistemic beliefs across engineering disciplines. The results of our analysis suggest that students can be characterized based on their epistemic beliefs and need for cognitive closure. This analysis adds to the current knowledge in the field of epistemic beliefs because there have been a limited number of studies that have utilized cluster analysis to identify groups of students with similar epistemic beliefs. Buehl and Alexander (2005) utilized a cluster analysis to identify students' domain-specific epistemic belief profiles within the domains of history and mathematics. Their study suggested that there were four clusters based on epistemic beliefs in history and mathematics within their sample of students. As in our study, Buehl and Alexander (2005) saw the largest difference between the groups in their beliefs about the certainty of knowledge in history and mathematics. In contrast to our study, their study found larger differences between the clusters' based on beliefs about the source of knowledge and simplicity of knowledge. The construct of simplicity of engineering knowledge was not included in this study because of its' low internal consistency reliability (Cronbach's α), which will be addressed in future studies. In our study, there was not major variation in the clusters' close-mindedness; however, this construct may still provide

useful insights about engineering students, but future work is needed to determine this. The similarities in the means for this construct may be influenced by the fact that all of the students in this study were undergraduate bioengineering students in their second through fourth year and have taken multiple classes together and are in the same major. Expanding this study to include students from different engineering disciplines or at different stages in their undergraduate studies may reveal differences in close-mindedness between students.

Overall, the bioengineering students surveyed in this study expressed neutral beliefs about the source of knowledge in engineering. Perhaps this neutral response is because the items on the instrument do not specifically refer to engineering in the classroom or in other contexts. It is very likely that students hold unique beliefs about knowledge inside and outside of the engineering classroom. This is supported by the qualitative open-ended survey data that was collected. Designing the survey to target students' beliefs about specific contexts may help to further distinguish different beliefs about sources of engineering knowledge. The findings in our study support current research in epistemic beliefs, suggesting that epistemic beliefs are both discipline and context specific (DeBacker et al., 2008; Hofer, 2006). Future studies should aim to clarify items so that there is no ambiguity about the context that students are thinking about when responding to an item.

Other ambiguities with the survey items were identified through students' explanations of their responses to the engineering epistemic belief items. Students interpreted the phrase "principles in engineering" to mean laws, theories, founding ideas, and mathematical equations, which precludes comparisons between student responses. When asked about engineering problems having only one right answer, some students thought of a problem solution while others thought of an answer to a problem. This result may be an artifact of the biomechanics course the students were taking. In the course, the instructor placed an emphasis on the problem solving process, which may have had an impact on students' epistemic beliefs and/or caused the students to consider both a problem's solution as a process and answer as numerical.

A few items were interpreted by students in two ways, suggesting that these items were compound. To help ensure that students are interpreting the item in a similar way, these items should be split into two separate items. Two of the items designed to measure the source of engineering knowledge ("A theory in engineering should be accepted as correct if engineering experts research consensus" and "You can count on the information you find in engineering books to be true") elicited responses from students that revealed students' beliefs about the certainty of knowledge. The overlap between these two constructs may help explain the lower Cronbach's α for the source of engineering knowledge construct. These items should either be reworded to be more specific to the construct source of engineering knowledge or removed in future

iterations of the survey to improve the internal consistency reliability of this construct. Future work should also include the implementation of this survey with a larger sample of engineering students from different majors. The survey was given to students in a single biomechanics course for this study. These students had similar curricular experiences and backgrounds, which may have limited the ways in which students interpreted the items. Giving the survey to a more diverse group of students may reveal additional ambiguities with the instrument that need to be addressed.

2.7   Conclusions

The results of this work suggest that engineering epistemic beliefs and epistemic motivations can be used as a mechanism to quantitatively characterize bioengineering students into subgroups. Additionally, this work adds to our current understanding of engineering students' engineering-specific epistemic beliefs through both quantitative and qualitative survey data. The results of this work can also be used to inform the development and revision of items to establish more reliable and valid instruments to capture engineering students' epistemic beliefs.

Chapter 3

Relationship between Epistemic Beliefs, Need for Cognitive Closure, and Epistemic Cognition within the Context of Problem Solving in the Classroom

3.1 Abstract

This study utilized a partially mixed concurrent qualitative dominant design (quant + QUAL) (Powell, Mihalas, Onwuegbuzie, Suldo, & Daley, 2008) to understand the relationship between students' epistemic cognitions on a biomechanics homework problem and their engineering epistemic beliefs and need for cognitive closure. The quantitative phase of this study used a survey instrument that combined items from two pre-existing instruments, the Need for Closure scale (Kruglanski & Webster, 1996) and the Engineering-Related Beliefs Questionnaire (ERBQ) (Yu & Strobel, 2012). Fifty undergraduate bioengineering students enrolled in a junior-level biomechanics course completed the survey. The items were measured on a seven point anchored scale from strongly agree to strongly disagree. The internal consistency reliability, convergent validity, and face validity of the items were assessed in a previous study using the same sample of students to establish reliability and validity of the survey items. The quantitative survey responses were analyzed using a

k-means cluster analysis around the factor scores of the constructs certainty of knowledge, source of knowledge, and close mindedness, which resulted in three homogenous sub-groups. In the qualitative portion of the study, 18 of the students who completed the quantitative survey were interviewed to gain an understanding of their epistemic cognitions when solving an open-ended homework problem from their biomechanics class. Their interview transcripts were analyzed to understand their goals for the problem, perceived gains from solving the problem, general thoughts on the problem, and process used to solve the problem. The quantitative cluster results were interpreted with the qualitative interview transcripts to examine the connections between students' engineering epistemic beliefs, need for closure, and epistemic cognition in the context of problem solving. This analysis revealed similarities in their goals and approaches for students within the same cluster and differences between students in different clusters.

3.2   Introduction

The need for one million additional science, technology, engineering, and mathematics (STEM) graduates over the next decade has resulted in calls to improve undergraduate STEM education by producing graduates capable of approaching real world engineering problems and working in a rapidly changing, multi-disciplinary work environment (PCAST, 2012; Kenny, 1998; Haghighi, 2005). One potential mechanism to address these challenges is by giving students open-ended, ill-structured problems to solve, encouraging the development of self-regulated learning strategies, and providing students with authentic research experiences (PCAST, 2012). Both self-regulated learning and problem solving achievement have been shown to be influenced by students epistemic beliefs (Bromme et al., 2009; Muis & Franco, 2009a, 2009b). Additionally, epistemic beliefs (beliefs about the nature of knowledge and knowing) have been shown to have an underlying influence on attributes of learning and development such as metacognition (Hofer, 2004; Muis & Franco, 2009b) and conceptual change (Franco et al., 2012). Epistemic beliefs have been studied in a number of disciplines, including physics and chemistry, and in the context of research labs. These studies suggest that epistemic beliefs impact multiple aspects of the academic domain.

3.2.1   Prior Research on Personal Epistemology

Individuals' epistemic beliefs or personal epistemology have been studied using both qualitative and quantitative approaches in educational psychology. In addition to the variety of methods used, researchers also use various terminology and conceptualizations, including epistemic beliefs (Muis, 2007), epistemic

cognition (Chinn et al., 2011; Greene, Azevedo, & Torney-Purta, 2008), epistemological reflection (Baxter Magolda, 2004), and personal epistemology (Hofer & Pintrich, 1997). In this paper, the term "personal epistemology" will be used to refer to the work done in the general field and when describing the work of a specific researcher or a specific framework, we will use their own terminology.

The first model that emerged from research exploring personal epistemology was a developmental model that viewed epistemic beliefs as progressing through set stages. The first study to look at the epistemic beliefs of college students examined how the beliefs of male students at Harvard and Radcliffe develop (Perry, 1968). Through this longitudinal, qualitative study, a framework with nine positions ranging from simple to complex was developed. This model and other earlier models conceptualized personal epistemology as domain general and developmental, with beliefs becoming more sophisticated with age.

More recent models take a multi-dimensional look at personal epistemology, viewing it as a collection of individual beliefs. Schommer's (1990) initial research conceptualized personal epistemology around five dimensions: the extent that students believe 1) knowledge is complex, 2) knowledge is certain, 3) learning is quick, 4) the ability to learn is innate, and 5) knowledge is handed down by authority. An instrument was developed as part of Schommer's (1990) initial study and became widely used. Recent work has brought attention to this instruments' lack of reliability and validity, resulting in the adoption of other models. Hofer and Pintrich (Hofer & Pintrich, 1997) added to the multi-dimensional models by considering how epistemology has been studied in philosophy and conceptualized epistemology as "an area of philosophy concerned with the nature and justification of human knowledge" (1997, p. 88). Based on this definition, Schommer's (1990) quick learning and innate ability dimensions are not considered to be epistemic in nature. Hofer and Pintrich (1997) suggest that personal epistemologies consist of beliefs about the nature of knowledge and the processes of knowing. The nature of knowledge is conceptualized by two dimensions: the simplicity of knowledge and the certainty of knowledge. Likewise, the process of knowing is composed of two components: the sources of knowing and justification. This framework has been adopted by a number of researchers and multiple instruments exist that strive to measure both discipline specific and domain general epistemic beliefs of students. More recently, Chinn et al. (2014) proposed the AIR Model of epistemic cognition that combines elements from psychology and philosophy to expand Hofer and Pintrich's (1997) conceptualization of epistemic cognition. Additionally, this model suggests that epistemic cognition is situation and context dependent and should be studied taking more fine-grained approach. This is similar to Hammer and Elby's framework of epistemological resources in which epistemic beliefs are conceptualized as being less stable, fine-grained and context specific similar. Individuals are thought to have a range of epistemological resources

available to them and the context they are in determines which resources are activated.

3.2.2 Personal Epistemology in the Context of Problem Solving

Despite numerous studies that have investigated epistemic cognition, there have been a limited number of studies that have investigated epistemic cognitions in the context of problem solving. Kitchener (1983) argues that a three-level model of cognitive processing is required to account for the complex processes used when individuals are solving ill-structured problems. The first level is cognition in which an individual is doing tasks such as, reading, memorizing, perceiving, and computing. Metacognition is the second level and individuals monitor and evaluate their cognitions or first level processes. The third level is epistemic cognition and individuals reflect on the nature of knowledge to evaluate resources, make judgments about sources of information, and assess alternative solutions. This third level of cognition will be influenced by an individual's beliefs about the certainty, source, and simplicity of knowledge (Kitchener, 1983). Kitchener's (1983) work provides a model of epistemic cognition that could be operationalized to investigate epistemic cognition in the context of problem solving. It suggests that an ill-structured problem rather than a problem that is more similar to an exercise (for example, one involving repetition (Jonassen, 2004)) should be used because it requires judgments to be made about sources and alternative solutions that require the use of epistemic cognitions.

3.2.3 Objectives of this Research Study

The goal of this study was to answer the question, "How do undergraduate bioengineering students' epistemic beliefs and need for closure relate to their activation of components of epistemic cognition during problem solving?". Taking a partially mixed concurrent qualitative dominant approach (Powell et al., 2008) this project aimed to (1) understand bioengineering students' epistemic beliefs and need for closure, (2) understand the components of epistemic cognition that students draw on when solving an open-ended problem in the classroom, and (3) understand the connections between students' epistemic beliefs, need for closure, and epistemic cognition during problem solving.

3.3 Theoretical Frameworks

This study combines elements of need for cognitive closure (Kruglanski & Webster, 1996), engineering epistemic beliefs (Yu & Strobel, 2012), and epistemic cognition (Chinn et al., 2011, 2014) to gain a

more complete understanding of how engineering students approach an open-ended homework problem. In this study, epistemic beliefs were defined as students beliefs and attitudes about the nature of knowledge and knowing (Hofer, 2001). Likewise, epistemic cognition refers to a set of cognitions related to epistemic ideals such as, gaining knowledge, understanding, useful models, and explanations (Chinn et al., 2014, 2011).

3.3.1 Engineering Epistemic Beliefs

Yu and Strobel's (2012) Engineering-Related Beliefs Questionnaire (ERBQ) was developed based on Hofer and Pintrich's (1997) epistemic beliefs framework that conceptualizes epistemic beliefs as an individual's beliefs about the certainty, simplicity, and source of knowledge. Beliefs about the certainty of knowledge range from absolute to contextual to relative. The structure of knowledge can be conceptualized as ranging from simple to complex based on the complexity of underlying concepts. Beliefs about the source of knowledge range from reliance on authority to self-construction. Rather than being domain general, like Hofer and Pintrich's (1997) instrument, the ERBQ is specific to the domain of engineering. The items on the ERBQ were designed to assess students' beliefs about the certainty, simplicity, and source of engineering knowledge. This instrument considers engineering as a single domain. Additionally, the items capture students' epistemic beliefs in the context of the engineering classroom and engineering practice.

An example item from the certainty of engineering knowledge construct is "Principles in engineering cannot be argued or changed." One of the items from the simplicity of knowledge construct is "Engineering knowledge is an accumulation of facts." "First-hand experience is the best way of knowing something in engineering." represents one of the items from the source of knowledge construct.

3.3.2 Need for Cognitive Closure

The Need for Cognitive Closure Scale was designed to measure an individual's "motivation with respect to information processing and judgment" (Webster & Kruglanski, 1994, p.1049). This instrument has five sub-scales: desire for predictability, preference for order and structure, discomfort with ambiguity, decisiveness, and closed-mindedness. The sub-scales discomfort with ambiguity and close-mindedness have been suggested to influence epistemic cognition (Chinn et al., 2011, 2014). Multiple validation studies have been conducted to assess the reliability and validity of this instrument (Webster & Kruglanski, 1994; Neuberg et al., 1997). Neuberg et al.'s (1997) study suggests that the items factor into multiple dimensions, which is in contrast to Webster and Kruglanski's (1994) work. It is believed that an individual's need for cognitive

closure is dependent on situational factors such as time and pressure (Webster & Kruglanski, 1994). Research suggests that individuals with a high need for closure make judgments based on stereotypes, assimilate new information to existing beliefs, and often resist persuasion when they have prior knowledge (Neuberg et al., 1997).

"I dislike questions which could be answered in many different ways." and "When thinking about a problem, I consider as many different opinions on the issue as possible" represent items from the constructs discomfort with ambiguity and closed-mindedness, respectively.

3.3.3   Epistemic Cognition

The qualitative portion of this study used the AIR Model of epistemic cognition as a lens to study students' epistemic cognition in the context of a homework problem (Chinn et al., 2014, 2011). Chinn et al.'s (2011) framework expands Hofer and Pintrich's (1997) work by clarifying and expanding constructs based on philosophical and psychological considerations. According to Chinn et al., "Epistemic cognition refers to the complex of cognitions that are related to the achievement of epistemic ends; notable epistemic ends include knowledge, understanding, useful models, explanations, and the like" (2014, p.425). The AIR model condenses the five constructs (epistemic aims and epistemic value, structure of epistemic achievements, source and justification of knowledge and epistemic stances, epistemic virtues and vices (motivations), and processes for achieving epistemic aims) from Chinn et al.'s (2011) initial framework into three components: aims and value, epistemic ideals, and reliable processes for achieving epistemic goals (Chinn et al., 2014). Epistemic aims, such as knowledge, understanding, and true beliefs, are defined as a subset of goals that people adopt related to their desire to figure things out. These goals become epistemic achievements once they have been reached and have different epistemic values based on their worth to an individual. Epistemic ideals are the standards an individual uses to evaluate whether an epistemic goal has been achieved. This construct combines the structure of knowledge and justification from Chinn et al.'s (2011) framework. The final component of the AIR Model is reliable processes for achieving epistemic aims, which combines the sources and virtues and vices components of the original model. Chinn et al. (2014) identified beliefs about eight example clusters of processes that can be used to meet epistemic aims: 1) observation and memory, 2) epistemic virtues and vices, 3) emotion in knowledge producing processes, 4) personal evidence gathering processes, 5) processes for reasoning about statistical evidence, 6) peer review processes, 7) survey processes, and 8) media processes.

3.4 Research Methods

This mixed methods study used a partially mixed concurrent qualitative dominant design (quant + QUAL) (Powell et al., 2008) to understand the relationship between students' epistemic cognition on a biomechanics homework problem and their engineering epistemic beliefs and need for closure. The quantitative and qualitative phases of the study were independent of each other and mixing only occurred during interpretation (see Figure 3.1). The study was designed to allow the quantitative and qualitative phases to complement each other, providing a more comprehensive and complete view of students' engineering epistemic beliefs, need for cognitive closure, and epistemic cognition.

Students (n = 50) completed a quantitative survey designed to measure students' engineering epistemic beliefs and need for cognitive closure. In a previous study, this data was analyzed to establish reliability and validity of the instrument Chapter 2. Using the three constructs that were identified as reliable, homogenous subgroups were identified using a cluster analysis. A subset of the students (n=18) who completed the quantitative survey participated in a semi-structured interview designed to investigate their epistemic cognition in the context of an assigned homework problem.
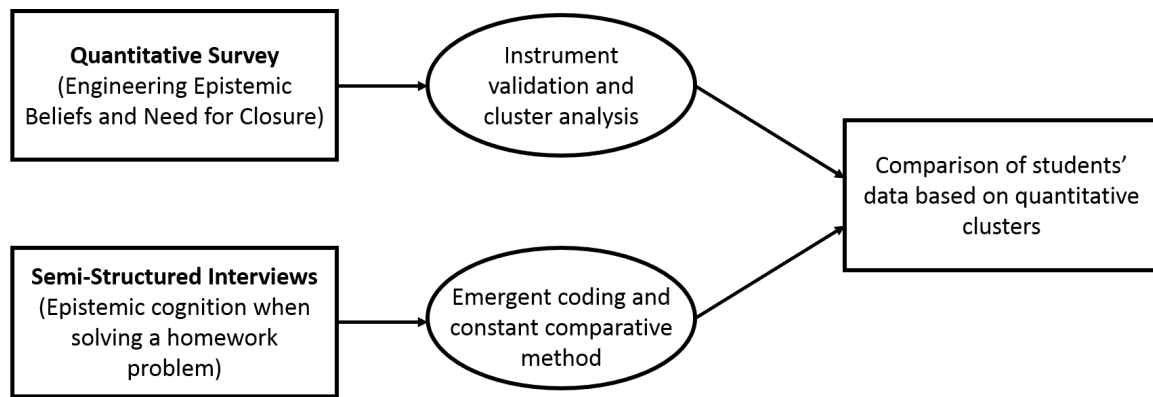
Figure 3.1: Graphic representation of study phases and integration of quantitative and qualitative data analyses.

3.4.1 Participants

Participants were recruited from the undergraduate biomechanics course in the Bioengineering Department at Clemson University. This course was selected because students are assigned open-ended ill-structured problems throughout the semester, which requires them to make judgments using their knowledge

and beliefs about the nature of knowing. Students in the course were invited to complete a quantitative survey, described in detail below and in Appendix A, and participate in a semi-structured interview about one of their homework problems. Students were offered extra credit for completing the survey and/or interview; however, these students were not required to participate in the study to get the extra points. Fifty of the sixty-eight students in the course completed the survey and eighteen students participated in an interview. There was a nested relationship between the students who participated in the two phases of the study where the students interviewed were a subset of the students who completed the quantitative survey.

Of the 50 students who completed the quantitative survey, twelve had been at Clemson University for two years, thirty-four for three years, and three for four years. Twenty-eight of the students had at least one semester of research experience, two students had co-operative education experience, six students had industry experience, and fifteen had clinical experience. A summary of each of the students who completed an interview can be found in Table 3.1. Additional demographic information such as gender and race was not collected from the students because assessing the influence of gender and race on engineering epistemic beliefs, need for cognitive closure, and epistemic cognitive were beyond the scope of this study.

Table 3.1: Summary of interview participants' years as a student at Clemson University, semesters in research, and other experiences. This data was collected from the quantitative survey. Students were asked to select the range that represented the amount of time they had participated in research. The options were 0, 1-2, 3-4, 5-6, 7 or more. The names displayed in the table are pseudonyms.

	Years at Clemson	Semesters in Research	Other Experiences
Lucas	3	3-4	None
Olivia	3	3-4	Clinical
Aiden	2	3-4	Industry
Emma	3	5-6	None
Mason	3	1-2	None
Charlotte	3	0	None
Jacob	3	0	Clinical
Mia	2	1-2	None
Ava	3	3-4	Clinical
Ethan	3	1-2	None
Sophia	3	1-2	Clinical
Harper	4	1-2	Industry and clinical
Lily	2	1-2	Clinical
Benjamin	3	0	Industry
Evelyn	3	3-4	None
Chloe	3	0	Industry
Abigail	3	1-2	Clinical
Ella	2	3-4	Clinical

3.4.2 Context

Biomechanics is a required course for all bioengineering majors at Clemson University. Students typically take this course during their junior year. During the semester that this study was conducted, the instructor of the course utilized a student-centered course design. The students were assigned multiple open-ended problems during the semester and were assessed based on their problem solving process using a specific rubric that outlined the key problem solving steps (Grigg & Benson, 2012). Most of the courses that students

take prior to this course asked students to solve exercises that have only one right answer.

The primary researcher worked with the instructor of the course to identify an optimal time to collect the data for the study. Based on these conversations, an assignment given in the middle of the semester was selected because of its open-ended structure and students' familiarity with solving this type of problem. A homework assignment designed and assigned by the instructor was selected for this study rather than a researcher developed problem to ensure that the students' processes and goals for the problem were authentic to the classroom and the researcher's impact on the students was minimized. For this assignment, students were asked to estimate a numerical answer to the question: "What are the combined effects of strain rate and age on bone strength of a 90-year old subject compared with a 20-year old?" The problem that was selected for this study was initially assigned during the first month of the semester. Since open-ended problems were new to these students, they did not do as well as the instructor expected so the problem was reassigned during the middle of the semester after they had learned more content and students were more familiar with applying the problem solving process to open-ended problems. The fact that students were solving the problem for a second time had an impact on some of the students who participated in the study. The impact that the reassignment of this problem had on students will be discussed throughout this paper.

3.4.3 Data Sources

3.4.3.1 Quantitative Phase

The quantitative survey (see Appendix A) was divided into three parts that sought to understand students' need for cognitive closure, engineering epistemic beliefs, and backgrounds. Part one of the survey included 16 items from Kruglanski's Need for Closure Scale (Kruglanski, 1990). Part two of the survey included Yu and Strobel's 22 item engineering epistemic beliefs instrument (ERBQ). Part three of the survey included items about co-curricular experiences (research, clinical, and industry experiences), years at Clemson University, and semesters in a research experience. The items in parts one and two of the survey were measured on a seven point scale anchored from strongly agree to strongly disagree.

3.4.3.2 Qualitative Phase

All interviews were conducted within a period of two weeks after the homework assignment was completed to ensure that students would remember the problem. The interviews took approximately 45 minutes and included questions about the students' 1) goals when solving the problem (e.g. "What was your goal

43

when you first approached this problem?" and "What, if anything, did you hope to gain by solving this problem?"); 2) strategies and processes used to solve the problem (e.g. "What strategies did you use?" and "How did you decide what strategies to use?"); and 3) perceptions of problem solving as it is portrayed in the classroom (e.g."How is problem solving portrayed to you?" and "How do your teachers talk about approaches to problem solving?"). (See Appendix D for the complete protocol) Participants were asked follow-up questions based on their responses to the quantitative surveys to gain a more complete understanding of individual students' need for closure and engineering epistemic beliefs. A single interviewer conducted all of the interviews (n=18) to ensure consistency between interviews. An additional interviewer sat in on most of interviews to help take notes and ask follow-up questions.

3.4.4 Analysis

3.4.4.1 Quantitative Phase

A k-means cluster analysis around the factor scores was utilized to identify homogenous subgroups based on epistemic beliefs and need for cognitive closure. Factors were identified based on the theoretical constructs identified by Yu and Strobel (2011) for the engineering epistemic belief items and Kruglanski (1990) for the need for cognitive closure items (for more details about this analysis see Chapter 2). This analysis seeks to minimize the variance within a cluster while maximizing the variance between clusters. With a k-means cluster analysis, the number of clusters is determined by the researcher and must be decided prior to obtaining the clustering solution. A plot of the percent variance explained as a function of the number of clusters and a plot of the principle component analysis were used in combination to determine that the optimal number of clusters was three. The mean of each construct was compared between the clusters using a pairwise t-test to determine whether the difference in construct scores for each cluster was statistically significant. All quantitative analyses were performed in R (Team, 2012). The cluster analysis was performed using the cluster package in R (Maechler et al., 2015).

3.4.4.2 Qualitative Phase

Interviews were analyzed using a combination of *a priori* and open coding. The *a priori* codes were informed by the AIR model of epistemic cognition (Chinn et al., 2011). These codes included students' initial goals when approaching the problem, perceived gains from solving the problem, justification of their answer, and evidence of evaluation. The researcher began analyzing the transcripts by reading through them to gain

a general impression of each interview. This was followed by open coding, in which emergent codes were developed, staying close to the participants' own words (Charmaz, 2014). Open coding was followed by *a priori* coding in which the codes informed by the AIR model of epistemic cognition were applied. The goal of the initial open and *a priori* coding process was to identify and name the phenomena found in the text. Axial coding followed, in which codes identified during open coding were compared to one another looking for relationships (Strauss & Corbin, 2007; Charmaz, 2014). The process of coding the transcripts was iterative, in which the transcripts were read multiple times to ensure that the codes appropriately reflected the students' responses. Throughout the process, the researcher memoed to keep a record of her analysis, thoughts, interpretations, questions, and directions for further data collection (Strauss & Corbin, 2007; Charmaz, 2014). A constant comparison approach was taken during the analysis in which emerging ideas were compared across participants (Strauss & Corbin, 2007; Charmaz, 2014; Strauss & Corbin, 1990). Transcripts were coded using RQDA, a software package for R that facilitates analysis of qualitative data (Huang, 2010).

3.4.4.3   Integration of Quantitative and Qualitative Data

The clusters identified through quantitative analysis were interpreted with the qualitative analysis of interviews with students to understand the connections between engineering epistemic beliefs, need for cognitive closure, and epistemic cognition in the context of problem solving. This analysis was performed for each participant by making a summary of the mean score for each construct on the survey, participant's cluster, and a description of how the major codes (goal for the problem, perceived gains, justification of answer, and use of evaluation) emerged from the interview. This allowed the researcher to make comparisons between students within the same cluster and in different clusters.

3.4.5   Quality

Quality throughout the research process was established using the Q3 framework developed to ensure quality in interpretive engineering education research (Walther, Sochacka, & Kellam, 2013). This framework places emphasis on assessing the quality of interpretive research throughout the process of making the data and handling data. This framework is composed of six quality types: 1) theoretical validation, 2) procedural validation, 3) process reliability, 4) communicative validation, 5) pragmatic validation, and 6) ethical validation. The definitions that follow were adapted from Walther et al. (2013; 2014). *Theoretical validation* focuses on the fit between the social reality and the theory produced. *Procedural validation* concerns aspects

of the research design. *Process reliability* focuses on using strategies that aim to make the research process independent from random influences. *Communicative validation* accounts for co-construction of knowledge between the researcher and participant. *Pragmatic validation* investigates the compatibility between theories and the empirical reality. *Ethical validation* concerns aspects of integrity and responsibility during the research process.

3.4.5.1 Quality considerations embedded in making the data

Prior to conducting interviews, an expert in the field of epistemic cognition reviewed the interview protocol to ensure that the questions are likely to elicit information about students epistemic cognition during problem solving (procedural validation). Since the interview protocol was dependent on a specific problem assigned to students in a biomechanics class, it was difficult for the interview protocol to be piloted in a comparable environment. As such, the first few interviews were treated as pilot interviews, incorporating meta-questions about the interview process, allowing the researcher to evaluate and revise the protocol as needed prior to conducting additional interviews (theoretical, procedural, and communicative validation). To ensure consistency of all the interviews, the same researcher conducted all the interviews (process reliability). To help reduce interviewer bias, many of the interview were conducted by two interviewers (process reliability, procedural validation, communication validation, and ethical validation). An hour of free time was set aside after each interview so that the interviewer(s) could reflect on the interview, noting ideas that triggered additional questions and aspects of the interview that stood out (procedural and communicative validation). Additionally, time was set aside during the two weeks of interviews to meet with other researchers to reflect on what was emerging and seek input about revisions to the interview protocol (procedural and communicative validation). Interview transcripts from the audio recordings were read and corrected while listening to the recorded interviews to ensure the accuracy of the transcript (procedural validation and process reliability). All participant names were removed from the transcripts and replaced with pseudonyms to maintain the confidentiality of the participants (ethical validation).

3.4.5.2 Quality considerations embedded in handling the data

Deidentified interview transcripts were presented to other researchers in the field for input about the appropriateness of the analytical methods (theoretical, procedural, pragmatic, and communicative validity). Interviews were coded using conventional content analysis through the lens of epistemic cognition (Chinn et al., 2011) (process reliability, theoretical and communicative validation). Throughout the analysis pro-

cess, emerging findings were presented to other members of the research community to seek their advice on analysis decisions (theoretical, pragmatic, communicative, and procedural validation, and process reliability).

3.5 Results and Discussion

3.5.1 Students' Goals when Solving the Problem

During the interview, students were asked about their goals when they first approached the problem and what they hoped to gain from the problem. Students expressed a variety of goals for solving the problem. These goals were coded and classified based on whether they were epistemic in nature using Chinn et al.'s (2011, 2014) conceptualization as a guide. Epistemic goals included gaining knowledge, validating current beliefs, and seeking explanatory connections. Many of the students expressed having more than one goal for the problem and were identified as having an epistemic goal if one of their stated goals was epistemic in nature. Ten students were identified as having explicit epistemic goals (gaining knowledge, verifying one's beliefs, and seeking understanding) and eight as having non-epistemic stated goals (finishing the problem, getting done as quickly as possible, and proving a pre-existing belief).

During the interpretation phase of this study, students were grouped by the type of goal they set for the problem; however, there seemed to be limited similarities in their approaches to problems based on goals. This is in contrast to Chinn et al.'s (2014) suggestion that the epistemic aim an individual adopts influences their text processing. This difference may be explained by the difference in context between the two studies or because of the types of epistemic aims that were adopted by the students in this study. Chinn et al.'s (2014) work is situated in the context of text processing, while this study was situated in solving a homework problem that used data, graphing, and calculations. This difference in context may result in different relationships between epistemic aims and processes across students. In addition, it is possible that the actions one takes to gain knowledge, seek explanatory connections, and verify one's beliefs are not as unique as those for acquiring true beliefs and avoiding false beliefs which is the example given by Chinn et al. (2014).

3.5.1.1 Epistemic Goals

Epistemic goals are aims that individuals adopt that are related to inquiry and finding things out. The epistemic goals that students set for this problem included gaining knowledge, verifying one's beliefs,

and seeking understanding (Chinn et al., 2011).

Gain Knowledge

Four students, Emma, Chloe, Benjamin, and Lucas, had a goal related to gaining factual or procedural knowledge. These students described that by solving this problem they hoped it would add to their knowledge of solving open-ended problems and their general knowledge of biomechanics and the human body. Chloe states that she hopes to gain, "the knowledge of how to solve these sorts of things, like open-ended problems and interpretation of things," expressing her desire to gain procedural knowledge about solving problems. Emma and Benjamin both hoped to gain factual knowledge from the problem; however, their statements about what they want to learn are very different. Benjamin's goal is "to get a reasonable answer and to learn the material I was supposed to learn". While his goal is very focused on the expectations that he feels his instructor has, this goal is still epistemic in nature because he is still striving to increase his knowledge. Emma's goal is more general; she hopes to gain "a better knowledge of the human body and...biomechanics". Unlike Benjamin she does not express having specific ideas about what she is supposed to learn from this problem. Lucas' goal for this problem is not as straight forward as the other students' goals. He hopes to "gain the idea like there is a general answer like I feel like this isn't the exact answer but it is in the proximity like the range". At first read Lucas's goal does not necessarily appear to be epistemic; however, looking at the rest of his interview helps clarify what he means. Lucas does not believe that this problem has a single right answer or single way that it can be solved. Knowing this helps clarify his goal and suggests that his goal is epistemic in nature, as it suggests that he wants to "gain the idea" or knowledge of the approximate relationship explored in this problem.

Seek Understanding
Seeking understanding is a unique epistemic goal compared to gaining knowledge because it focuses on the connections between pieces of information rather than the individual pieces. It was identified as a distinct epistemic goal by Kvanvig (2003).

Six students, Jacob, Charlotte, Aiden, Emma, Mia, and Evelyn, stated that they sought understanding by solving the problem. Many of these students described wanting to understand the relationship and connections between concepts in the problem. One of Aiden's goals for this problem was to "make some sort of graph that used some relationship. I didn't know what relationship that would be. I just wanted, I wanted a graph so I could visualize it better...numbers are great and all, but I am really bad at I am better at visualizing what sort of relationships exist between things if I have a graph...". This is a very specific goal and was classified as an aim to seek understanding because to Aiden, the graph would allow him to better see the relationship between the variables, helping him understand it.

Other students sought to understand their own process for solving the problem. It is likely that students had this goal for this problem because it was the second time they were asked to solve the problem and many students described that when they looked over their first solution it did not make sense to them. Charlotte's goals for this problem were "to answer it correctly and hopefully understand what I was saying. The first time around like I said I just kind of regurgitated this information and didn't really understand what I was saying. This time around I felt like yeah this actually makes sense to me now...".

Verify Current Belief Verifying current beliefs is an epistemic aim for problem solving similar to the goal of gaining knowledge. It is unique in that it begins with the individual having a strong belief about what solving the problem will reveal and the individual focusing on validating his or her belief.

Two students, Mason and Ava, mentioned that they already knew the answer to the problem and wanted to verify their belief by solving the problem. When asked about his goals, Mason said, "I mean besides find the answer. I wanted to I guess bring all these bits of knowledge that I knew together and like I said *I knew the general like what the outcome should be* um...that the strain the bone would be weaker it would fail at a lower strain and *I wanted to be able to prove that*". Likewise, Ava said, "Well I kind of had in my head that the stress-strain for older bones would be less so I just wanted to make sure I was right and find it in the paper".

While these students stated having a similar goal, they approached the problem very differently. Ava only spent 15 minutes on the problem and was very focused on getting the problem done quickly. Even though the goal she states seems to be epistemic, her actions appear to be non-epistemic, with her primary focus on completing the problem as quickly as possible. Based on her actions it seems like Ava "seized" on her belief quickly and did not give alternatives much consideration (Kruglanski, 1990). The AIR Model of epistemic cognition would consider this to be the adoption of the non-epistemic aim of attaining any belief regardless its validity (Chinn et al., 2014). This idea is further backed up by her score on Kruglanski's (1990) Need for Cognitive Closure items, which suggest that she may "seize" and "freeze" on any belief because she does not like the feeling of being undecided (Kruglanski, 1990). In contrast, Mason spent a few hours on the problem and explained that he evaluated the method he used to calculate the difference in bone strength. Mason's actions suggest that his goal was in fact epistemic as he sought to gain knowledge. Both of these students felt like they gained understanding by completing the problem, but only Mason felt that he gained knowledge. This difference between Ava and Mason suggests that goals alone do not fully explain how a student goes about approaching a problem and it is important to look at the student's actions and surrounding context.

3.5.1.2   Non-Epistemic Goals

Non-epistemic aims are any goal not directed at seeking knowledge, understanding, or truth beliefs and include goals such as avoiding effort, finishing as quickly as possible, outperforming others, and protecting one's positive self-image (Chinn et al., 2014).

Eight of the students interviewed approached the homework problem with only non-epistemic goals. These students were primarily focused on completing the assignment, finishing quickly, and getting a good grade. When asked about her goal when she approached the problem, Abigail said "To do them correctly, yeah. Yeah, no, not really, just to do them right and get them done." Most of these students payed close attention to what they felt their professor wanted on the assignment and used this to guide their approach to the problem. This is expressed in Olivia's statement, "To answer the questions I guess in the way that she was looking for. She has like this whole process whatever rubric that she has so I was trying to get most of the stuff on that. I have kind of like wimpy assumptions and sort of a wimpy justification..."

3.5.2   Connections between Students' Epistemic Beliefs, Need for Closure, and Epistemic Cognition

3.5.2.1   Students' Engineering Epistemic Beliefs and Need for Closure: Description of Clusters

Three homogenous subgroups of students based on their responses to items in the constructs of source of knowledge, certainty of knowledge, and closed-mindedness were identified using a k-means cluster analysis. The construct (source of knowledge, certainty of knowledge, and closed-mindedness) means for each cluster are presented in Figure 2.1. All construct means were found to be statistically different between clusters, except for the source of knowledge, where clusters one and two were not significantly different (see Figure 2.1).

Overall, students in Cluster 1 were more open-minded and believed that knowledge is subject to change more than students in Clusters 2 and 3. The students in Cluster 1 also had a stronger belief that knowledge is constructed than students in Cluster 3. Based on the responses to the survey, students in Cluster 2 were equally open and close-minded, but were still significantly more close-minded than students in the other two clusters. The students in Cluster 2 held the belief that knowledge is constructed at the same level as students in Cluster 1 and were between students in Cluster 1 and 3 in terms of their belief that knowledge is subject to change.
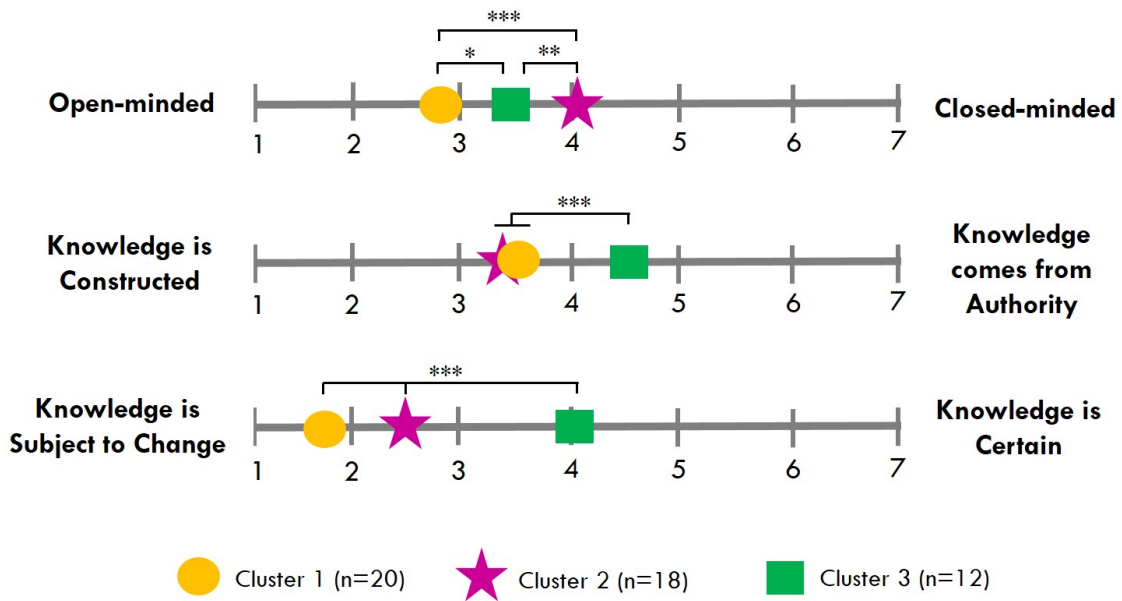
Figure 3.2: Representation of the mean for each cluster on the constructs of open mindedness, source of knowledge, and certainty of knowledge. The tick-marks on the line for each construct represent the 7-point anchored scale used for the items on the survey, where 1 indicates "strongly agree" and 7 indicates "strongly disagree" with survey items. *p< 0.05, **p< 0.01, ***p< 0.001 (pairwise t-test)

3.5.2.2 Comparison of Epistemic Cognition based on Clusters

Table 3.2: Brief description of the characteristics of each cluster relative to the other clusters, and a summary of the number of students interviewed from each cluster and their pseudonyms.

	Characteristics Compared to Other Clusters	Number of Students	Names of Students
Cluster 1	Most open-minded Believes that knowledge is constructed Believes that knowledge is subject to change	8	Lucas
			Olivia
			Aiden
			Emma
			Mason
			Charlotte
			Jacob
			Mia
Cluster 2	Least open-minded Believes that knowledge is constructed Believes that knowledge is subject to change (less than Cluster 1)	5	Ava
			Ethan
			Sophia
			Harper
			Abigail
Cluster 3	Moderate open-mindedness Believes knowledge comes from authority Believes knowledge is certain (more than Cluster 1 and 2	5	Lily
			Benjamin
			Evelyn
			Chloe
			Ella

Cluster 1 Students in Cluster 1 were characterized by being more open-minded and believing that knowledge is subject to change more than students in the other two clusters. Compared to students in Cluster 3 these students also had a stronger belief that knowledge is constructed. The students in this cluster typically spent over an hour working on this problem even though it was the second time they were asked to work on this particular problem. Seven of the eight students interviewed from this cluster approached the homework problem with at least one epistemic goal, with the majority of the goals being to seek understanding. All

of the students with an epistemic goal in this cluster felt like they gained knowledge and understanding by solving the problem. The majority of these students also took time to either evaluate the two different percent difference equations that they had been presented or their final answer to the assignment. Five of the students placed an emphasis on meeting what they perceived to be the teacher's expectations. For many of these students, this desire is reflected in their approach to solve the problem and dictated the resources and processes used. When describing what resources she used, Emma states, "I guess my thought process was like why else would they give us these equations if we were supposed to like plug in numbers to compare them. So yeahI guess I was just like I should probably use the information they give us."

The one student in this cluster who did not have an epistemic goal was Olivia. When asked about her goal for the homework problem, Olivia states,

> ....my main goal starting it the second time was to make sure to include that and to make sure to include stuff that I had missed out the first time because I thought that my answer was relatively solid the first time...I wish she would have given us like a mock grade so that I could have like seen what I would have had to what it was actually worth for and not just what I was missing.

This goal is unique compared to the other students in Cluster 1, which may be explained by the fact that Olivia expressed being frustrated with having to complete this problem again and feeling like her first answer was good. She also expressed a strong desire for a step-by-step method to solve the problem and seemed to make decisions about what to do on the problem based on what she felt like the instructor expected. Olivia's responses to questions about the homework problem do not seem to align with her engineering epistemic beliefs that were captured using the quantitative survey. It is important to remember that the quantitative survey asked about students' engineering epistemic beliefs in the context of the classroom and outside the classroom. It is possible that Olivia's epistemic beliefs in the context of a class homework problem are very different than her beliefs outside the classroom. Her approach to the homework problem may be guided by her motivation to get a good grade more so than her epistemic beliefs. The connection between epistemic beliefs and epistemic cognition remain unclear and it is possible that one's epistemic beliefs makes an individual more likely, but does not guarantee an individual, to adopt an epistemic aim in all contexts. For Olivia, it appears that factors related to the specific context of the situation influenced the goal she set for the problem.

Cluster 2 Students in Cluster 2 were characterized by being less open-minded than students in the other two clusters. They had similar beliefs as Cluster 1 about the source of knowledge and were between Cluster 1 and 3's beliefs about the certainty of knowledge. Unlike students in Cluster 1, four of the five

students interviewed from this cluster spent less than an hour on the problem and none of the students reported approaching the problem with an epistemic goal. In general, the students in Cluster 2 seemed to be focused on getting the problem completed as quickly as possible. In general these students described that they had to redo the problem because the instructor said that they all did it wrong the first time. This was frustrating to them because they had been told that this problem did not have a specific right answer. Ethan described, "I didn't enjoy doing this at all...it was...because we did it before. The first time I did it I was like this is fine like I tried. I put in a lot of effort for it and then she was like they are all wrong and gave it back to us, so I was like welp...not like I quit but I definitely didn't try as hard. I copied the first one and then added something about viscosity so...".

Two of the students felt like they gained knowledge by completing the problem and only one felt like she gained understanding. These students both expressed that they felt like they gained knowledge because they had never thought of the problem in this way before. When asked if she gained knowledge Harper states, "I never really thought of it that way...yeah you are going to think that they are going to have less strength, the 90 year old, but I mean I never really took the microstructure into account and how you fall and all the different compressive and tensile strains." The student who said she gained understanding expressed that she had a better idea of the problem solution and understood the relationships between the variables after completing the problem the second time. Two of the students expressed that they sort of gained understanding by solving the problem. These students described gaining understanding in a broad sense. Sophia said,

> Yeah...like it is just a very specific questions so I don't know if biomechanics necessarily like biomechanics is such a broad field so technically it helps with my understanding of biomechanics, but I don't know how to explain it...like right now we are looking at you know...we looked at shear forces and bending moments totally that completely helps with understanding of biomechanics but this is more like strain rate and bones and yes and no. I just feel like this is more information that you could just look up if you had to as opposed to I would be given this question and asked to solve it. I just feel like this is an already answered question.

Cluster 3 Students in Cluster 3 were characterized by believing that engineering knowledge comes from an authority and is certain more so than students in the other two clusters. These students were also more open-minded than closed-minded and fell between students in clusters one and two on this scale. Two of the five students that were interviewed from this cluster set goals for this problem that were epistemic in nature, seeking explanatory connections and gaining procedural knowledge. Like the students in Cluster 1, all of the students in Cluster 3 spent at least an hour on the problem; however, fewer of them felt like they gained either knowledge or understanding by solving the problem.

Only one of the students in this cluster expressed that he or she gained understanding from solving

54

the problem, while four of the students described that they gained procedural knowledge. These students felt like solving this problem helped them develop the skills needed to solve open-ended problems in the future, a form of procedural knowledge. When asked what she gained by solving the problem, Evelyn said, "Yeah I think I gained a little bit about the process of approaching a problem, not like...since I kind of knew where the problem was going to go I didn't learn that. I learned how to put together stuff from graphs, figure out how to solve it."

It is interesting to note that none of the students in this cluster described gaining declarative knowledge. Many of the students expressed that there was a right way to do the problem and wished the instructor would have gone over the solution in class, so that they could learn the material. Benjamin expressed his frustration with not receiving the answer in the following statement,

> I mean the problem I mean even the first I didn't think...what we learned really would help the second time I feel like doing this problem it would be better if I got the answer the first time after doing the problem and then I could understand and now it is just kind of frustrating and I could have done this way the first time I did the problem. It is not like I am doing anything different.

The students' desire for their instructor to go over the "right" answer is consistent with these students' engineering epistemic beliefs measured using the quantitative instrument which showed that in general these students believe engineering knowledge comes from authority and is certain. It is not surprising that many of these students did not feel like they gained declarative knowledge or understanding after solving this problem as their instructor provided individual feedback to the students on their assignments but did not go through a solution or post an answer online.

For some of the students in this cluster, the idea that this problem had a "right" answer was confirmed by how they interpreted the gesture made by their instructor of reassigning the problem. The students were asked to rework the problem after the instructor looked over the solutions and realized that the students were missing key information about viscoelasticity, a concept that would be taught later in the course. Ella and other students in this cluster interpreted the fact that this problem was reassigned as a statement that there was a "right" answer to the question despite the instructor telling them that the problem did not have a single right answer. Ella's belief is reflected in her response to the question, "Do you believe this problem has a single right answer?" "Oh no, not necessarily. Just from what she was looking for, if that makes sense. I guess in her mind there's a right answer because she already gave them back to us once and said that they were wrong."

Like many of the students in Cluster 2, a few of the students in this cluster showed evidence of

"seizing" and "freezing" on an answer early in the process of working on the problem (Kruglanski, 1990). This likely resulted in these students not utilizing processes that lead to an epistemic aim and may explain why these students did not feel like they gained declarative knowledge or understanding. Lily expressed how her approach to the problem was guided by her belief about the right answer:

> In my mind, I knew that it should be the 90-year-old that has the stronger bone. Of course, my filtering through information or writing my assumptions, I'm kind of trying to make sure that whatever I'm saying is not going to disprove what I'm trying to solve. I wasn't looking for articles that talked about healthier bone always being stronger. I'm trying to find information that will support what I'm trying to prove, which you probably shouldn't do when you write out your research paper. You should probably have all aspects, but it was homework assignment number four, not a big research paper.

In addition to "seizing" and "freezing" on what they believed the answer was, two students also fixated on the idea that the answer to the problem may be counter-intuitive (Kruglanski, 1990). On the homework assignment and when the instructor introduced the problem to the students, she noted that part of the problem may seem counter-intuitive. Lily and Chloe are the only students interviewed that mentioned this idea. Both of these students got an answer that seemed strange to them and quickly explained it by stating that the instructor said something would be counter-intuitive. In addition to being an example of "seizing" and "freezing", this is also an example of these students accepting information given to them by an authority, their instructor, rather than their own experiences. In the following statement, Lily describes her thoughts when she got an answer that seemed counter-intuitive to her,

> ...there was one part because my strain percentage for the older bone was lower on the graph than the 20 year old bone and it looked to me that the strain was more elastic for the adult the older bone which would not make sense because it is more brittle and it would break. It would fracture faster and so it was...I took that as counter-intuitive and tried to explain it further by drawing the graph...Yeah I was like okay it is counter intuitive.

3.5.2.3   Influences on the Goals Students Set and the Processes they Use

During the interview, many students described what influences the goals they set for their homework problems and their general goals for problem solving. Students discussed that their beliefs about context (i.e. what is required for a homework problem versus other tasks), interest, utility value, and perceived expectations of their teacher influence students' approaches and goals.

Beliefs about Context Ava described that she has different goals for problem solving depending on whether she is studying for a test or doing a homework assignment. This is an example of how context can influence the goals and subsequent processes an individual adopts. When asked about her general goals with

problem solving, Ava states, "If I am like doing homework it is usually like just get an answer but if it is for like studying for tests or like redoing the homework it is like let me look at it now and see why I did this so that I actually understand."

A few students also described very specific beliefs about what is required for a homework assignment. Stating that the length of time given to do the assignment signals to them the amount of time and effort they should put into the assignment. Other students mentioned that they would have taken a different approach to solve the problem if it had been assigned as a project rather than a homework assignment. Ethan describes, "Yeah I mean if it was like if I do a project I want a good grade but I will also try to learn about whatever I have done." Lily holds a similar belief about homework and describes how this directly influenced her approach to solving the problem. When asked about how the assignment being homework impacted what she did, Lily said,

> Yeah, if this was like a huge part of my grade, or was a big test or big group project, I definitely would have looked further than on my online book, my textbook and my slides. I would have gone to the library and found books on osteoporosis, and pulled my information to support my ideas, or talked about things that could oppose what I was trying to prove. Because it was just a homework assignment, I did not do that.

Interest A few students described that their interest in the problem and subject influences their goals and approach to the problem. For these students, if they are interested in the topic then they will do extra to try to really understand the details of what is going on. In contrast, if it is something they are not interested in then they will just do the minimum that is expected of them so that they can get the grade and be done. These ideas are expressed in the statements made by Aiden and Ethan. When asked about his general goals with problem solving, Aiden said,

> If it is a topic that I enjoy then my goals are to usually learn something and to sort of just go about it in any sort of way that I find it most interesting. If it is something that I don't enjoy then usually I just try to find an answer...well if I don't enjoy it then I am just basically going for the bare minimum and am basically trying to get my grade to where it needs to be but if I do enjoy it then that is then it is like I have there is no reason for me not to do it. It is something that is interesting I sort of want to go out and find out more about it so I am just doing it based on it is something that I want to do.

When asked what he hoped to gain by solving the homework problem, Ethan stated, "A good grade. I think that is it. Once again this isn't really my, what I am passionate about, so I didn't sit there and try to learn about it as much as I would have about something else."

Utility Value In previous studies, utility value has been shown to have an impact on students achievement and actions in the classroom (Hulleman, Durik, Schweigert, & Harackiewicz, 2008; Eccles, 2005). Stu-

dents' perceptions of the utility of the problem and/or biomechanics had an impact on the aim they set for the problem. Charlotte believed that she will use biomechanics for the rest of her life and believes it is a big aspect of what she needs to learn in college. She further explained that this has an impact on the goals that she sets and stated,

> I think so to an extent. Sometimes if I am in thermo. I mean obviously thermo. is very important but I am like this isn't really what I am going to be doing probably I will need some of this but not all of this so I am just trying to get the problem done whereas with this I want to understand what I am doing because I know I will need it later you know so I would say it definitely does

Perceived Expectations of their Teacher Many of the students placed an emphasis on meeting the expectation of their teacher during their interview. This had an impact on the approach the students took when solving the problem. These students made most of their decisions about the problem based on what they thought their teacher wanted them to do. This had an impact on how they evaluated knowledge claims, rather than seeking "truth" they focused on doing and using what they perceived their teacher to believe was correct. For example, when asked about which percent difference equation she believed was true, Harper explained that "Umm...well I want the right grade so I did what she wanted us to do." Rather than evaluating the two equations for herself and trying to understand the difference, she accepts the one that the teacher showed them because she knows the instructor is grading her assignment and that if she uses the other one it will not be "right" according to her teacher.

Other students focused on trying to put enough information down on page, so that the "right" answer is somewhere in their assignment. This is an example of an unreliable process for producing an epistemic outcome (Chinn et al., 2014). When asked how he decided he was finished with the problem, Jacob described:

> I think I know we were asked for percent differences, she wanted numbers for those so I put them in there for both strain and stress. I think the actual question asked for just stress but I did both just to be safe because I was a little confused on that...and then other than that I think it asked to explain why the strain and stress differed and...I think I did a pretty good job of that it is long enough...oh I just put enough words in there that I would have even if I didn't get the idea of it at first somewhere in there it is definitely answered.

3.5.3   General Discussion

This study shows that there are some connections between students' engineering epistemic beliefs, measured using a quantitative survey, and their epistemic cognition and approach to solving an open-ended homework problem. Having epistemic beliefs that are more constructivist (believing knowledge is con-

structed and subject to change) in nature does not guarantee that one will set aims that are epistemic in nature or make epistemic gains, as seen when comparisons were made between clusters. Cluster 1 was noted as having the most constructivist epistemic beliefs as well as the highest number of students (seven out of eight) who approached the problem with an epistemic aim and described gaining knowledge and understanding. Additionally, all of the students interviewed from Cluster 1 reported spending at least an hour working on the problem. In contrast, Cluster 2 also had very constructivist epistemic beliefs (slightly less than Cluster 1); however, none of the five students interviewed from this cluster had an epistemic aim when approaching the problem. All of these students reported spending less than an hour on the problem. Two of the students from Cluster 2 felt like they gained knowledge by completing the problem and only one felt like she gained understanding. Overall, the students in Cluster 2 seemed very frustrated with having to complete the problem again because they felt that their initial answer was sufficient. This is likely reflected in the fact that while having constructivist epistemic beliefs, these students were the most closed-minded out of the three clusters. Their lack of desire to consider other ideas once they have made up their mind about something seems to have had a larger impact on the goals they set for this problem than their engineering epistemic beliefs. Cluster 3 was characterized as having the least constructivist epistemic beliefs out of the three groups. Unlike Cluster 2, two of the five students interviewed from this cluster approached the problem with an epistemic goal and like the students in Cluster 1, these students all reported spending at least an hour on the problem. One of the students in this cluster expressed that they gained understanding from solving the problem, while four of the students described that they gained procedural knowledge. This is unique to Cluster 3 because students in the other clusters more often reported gaining declarative knowledge rather than procedural knowledge. The fact that these students felt like the knowledge that they gained was procedural in nature rather than declarative may be explained by their beliefs that engineering knowledge comes from an authority. Since the solution was not posted for this problem, these students did not feel like they could gain declarative knowledge, only procedural.

The epistemic aims, epistemic gains, and processes described above represent the differences between the three clusters, showing that engineering epistemic beliefs and need for closure affects the approaches students take when solving an open-ended homework problem. They further show that having more constructivist epistemic beliefs does not necessarily mean students are more likely to approach a problem with an epistemic aim and use similar processes, as seen when comparing Clusters 2 and 3. This disconnect between a student's epistemic beliefs and aims is further seen in both Hammer's (1989) and Elby's (1999) work with college physics students. They both present evidence that students with constructivist epistemic

beliefs may adopt processes they perceive will allow them to be successful in the course, such as rote memorization, rather than processes that are more consistent with their epistemic beliefs. Chinn et al. (2011) suggest further investigations to understand the connections between students' epistemic beliefs and aims as this has not been an area of focus in the past.

It is interesting to note that in clusters two and three the students who described having an epistemic gain (knowledge or understanding) from solving the problem were not always the students that approached the problem with an epistemic aim. This concept of epistemic gains without an initial epistemic aim is not discussed in Chinn et al.'s (2011, 2014) work. Chinn et al. (2011) describe that an epistemic achievement is when an individual accomplishes an epistemic aim. This definition does not leave room for an individual that does not approach a task with an epistemic aim to have an epistemic achievement, such as gaining knowledge or understanding. Chinn et al.'s (2011, p.147) further suggest that "...epistemic cognitions are cognitions directed at epistemic aims and their achievement; epistemic aims are central to EC [epistemic cognition] because aims determine whether other cognitions should be classed as epistemic or not."

Based on the findings in our study it seems that an individual may have an epistemic gain through problem solving without initially setting out to do so (having an epistemic aim). Perhaps these students did not initially approach the problem with an epistemic aim but developed one as they got closer to completing the problem. It is also possible that the students had an epistemic aim but did not state this during the interview. Developing a reliable way that does not influence the participants' goals but allows the researcher to capture their goals is more challenging than anticipated in this study. It is likely that in this study the number of students with an epistemic aim was underestimated. Our work also brings up some larger questions for the field of personal epistemology: 1) What should be considered epistemic cognition? Is an epistemic aim required for epistemic cognition (Chinn et al., 2011)? Is epistemic cognition a third level of cognition that is activated when solving ill-structured problems (Kitchener, 1983)?, 2) Is epistemic cognition required to have an epistemic gain?, 3) Is there a difference in the cognitions of an individual that approaches a problem with an epistemic aim compared to one who does not?.

3.6   Conclusions

Ten of the students in this study approached their homework problem with at least one explicit epistemic goal. The epistemic goals that students adopted in this study included, gaining knowledge (both procedural and factual), verifying one's beliefs, and seeking understanding. Eight of the students interviewed

did not mention having an epistemic goal when they approached the problem. These non-epistemic goals included, finishing the problem, getting done as quickly as possible, and proving a pre-existing belief. Students' goals were identified through interview questions and were classified as epistemic or non-epistemic by considering both students' stated goals and their description of their process for solving the problem. Students further described that their beliefs about context (i.e. what is required for a homework problem versus other tasks), interest, utility value, and perceived expectations of their teacher influence students' goals and approaches in problem solving.

Students in Clusters 1 and 2 were characterized as having more constructivist epistemic beliefs than the students in Cluster 3, while students in Clusters 1 and 3 were more open-minded than the students in Cluster 2. The majority of the students in Cluster 1 spent at least an hour on the problem, approached the problem with an epistemic goal, and evaluated their solution. Students in Cluster 2 expressed frustration with having to complete the problem again, spent less than an hour on the problem, and did not approach the problem with an epistemic goal. Like the students in Cluster 1, the students in Cluster 3 spent at least an hour on the problem, but not all of them approached the problem with an epistemic goal and felt like they gained knowledge or understanding from solving the problem. Additionally, students in Cluster 3 more often described gaining procedural knowledge rather than a deeper understanding. This suggests that differences in students epistemic beliefs and need for cognitive closure affects students' goals, approaches, and gains in problem solving.

3.7   Future Work

This study utilized stimulated recall to understand students' epistemic cognitions when they were solving a homework problem. This was a useful method in that it ensured that the problem solving environment was authentic to the classroom with all of the affective elements that are normally present. One of the limitations with this method was that it required students to reflect about a problem they completed up to two weeks before, bringing the reliability of their reflections into question. As such, future work will seek to utilize alternative methods of capturing students' epistemic cognition during problem solving that allow for both the affective elements associated with the classroom to be present, but with less time between solving the problem and reflecting on the problem. It may also be more reliable to have students reflect about their goals when approaching the problem prior to solving the problem. Again this creates some logistical challenges, when trying to keep the environment true to the classroom.

The problem used in this study was developed by the instructor of the course and was intended to be an open-ended problem that required students to seek outside resources to answer. The instructor provided the students with a handout with the results from one related research study; however, most of the students interviewed only used this and their class notes as a resource because they found this material to be sufficient. This meant that the students did not have to use a wide range of processes to make judgments about information and evaluate the resources they selected to use. Future work will seek to use problems that are less structured and more open-ended in an effort to capture a wider range of reliable and unreliable processes for achieving epistemic aims.

This study was focused on a single class of biomedical engineering undergraduate students in a biomechanics course. From previous work, we know that biomedical engineering students are unique compared to other engineering students. Additionally, the students interviewed in this study self-selected to participate and may represent a unique subset of students from the class. Future work will seek to expand this population to understand how the results of this work are transferable to other populations.

Chapter 4

Undergraduate Engineering Students' Epistemic Cognition during Problem Solving in a Research Environment

4.1 Abstract

This study utilized a qualitative approach to understand students' epistemic cognitions within an authentic problem solving environment, an undergraduate research experience in biomedical engineering. This study used semi-structured interviews to understand 1) why students select specific research projects, 2) how students conceptualize the goals of the research projects and what they hoped to gain from the experiences, and 3) what processes students use to make research decisions. Six undergraduate biomedical engineering students with varying amounts and types of research experiences completed a semi-structured interview that lasted approximately 30 minutes. The interview questions were developed using Samarapungavan et al.'s (2006) work as a guide. Transcripts were analyzed using an iterative process that employed emergent and *a priori* coding using Chinn et al.'s (2011, 2014) and Samarapungavan et al.'s (2006) work as a lens. This analysis revealed how students chose a research topic and what processes students' use when making research decisions. Many of the students' processes aligned with processes that are commonly used in the field of biomedical engineering, representing students' integration into the community of practice and adoption of the community's epistemic processes. A few of the students exhibited less evidence of enacting the epistemic

beliefs of the research community of practice, which may be explained by their struggles with their project or the structure of their research experience. The results of this work can inform the development of authentic problem solving environments, such as research experiences and inquiry activities that aim for students' to develop the epistemic practices of a specific community.

4.2   Introduction

The need to increase the number of science, technology, engineering, and mathematics (STEM) graduates entering the U.S. workforce who are capable of working in a rapidly changing, multi-disciplinary work environment has resulted in calls to improve undergraduate STEM education (Kenny, 1998; Committee on Prospering in the Global Economy of the 21st Century, 2007; Haghighi, 2005; PCAST, 2012). These graduate will need to be self-regulated learners with strong problems solving skills. While these skills can be developed in a classroom environment, undergraduate research experiences (UREs) provide students with authentic experiences in their fields, solving complex, open-ended problems. Additionally, UREs do not have the same pressures, restrictions, and perceptions of expectations as the classroom resulting in some students feeling like they can be more creative in the research environment 3. Research on UREs have shown that these programs lead to a number of positive gains, including retention of students in STEM majors, clarification of career goals, establishment of collegial working relationships, increased understanding of how science research is done, increased ability to work and think independently from faculty, and increased critical thinking and problem solving skills (reviewed in (Laursen et al., 2010)). In addition, students who participated in UREs experienced deeper learning (Brownell & Swaner, 2009; Kuh, 2008) and enhanced academic experiences (Wenzel, 1997). Although much is known about outcomes of UREs, little is understood about how UREs influence students approaches to problem solving and beliefs about the nature of knowing and knowledge in engineering.

4.2.1   Prior Research on UREs

Within the last decade there has been an increase in empirically based research on the outcomes of UREs. Prior to this time, most published articles discussed the perceived benefits to UREs with little supporting evidence. Additionally, the published program evaluation studies (which were limited in number) lacked clear descriptions of methods used or made claims that were not substantiated by their presented results (Laursen et al., 2010). More recent evaluation of and research on UREs has shown a number of substantiated

positive gains for students. These include the retention of students in STEM (Adedokun & Burgess, 2011; Nagda et al., 1998); clarification of career goals (Lopatto, 2004, 2007; Seymour et al., 2004); enhancement of basic research skills (Kardash, 2000; Kremer & Bringle, 1990); and increased understanding of the research processes (Lopatto, 2004, 2007; Seymour et al., 2004).

A common goal of UREs is to improve students' research skills. Studies presenting gains in research skills do not often distinguish skills based on characteristics or level of difficulty (Seymour et al., 2004). One exception is Kardash's (2000) study of summer and academic-year research participants in which skills are grouped as "lower-order" and "higher-order". She found that students felt significant gains in "lower-order" skills that included communicating research results orally, observing and collecting data, relating their results to the "bigger picture", and understanding contemporary concepts in their field. In contrast, she found lesser gains in many of the "higher-order" skills such as "identifying a specific question for investigation, translating the question into a working hypothesis, designing a theoretical test of a hypothesis, and reformulating the hypothesis on the basis of ones experimental results." (Kardash, 2000, p.196). Kardash concludes that while UREs may improve a number of basic scientific skills, "the evidence is less compelling that UREs are particularly successful in promoting the acquisition of higher-order inquiry skills that underlie the foundation of critical, scientific thinking" (Kardash, 2000, p.196).

A limited number of studies have also shown positive impacts of UREs on both students' ability to think like scientists and their understanding of the nature of scientific knowledge. It has been shown that students who participate in UREs join a community of practice that encourages students' intellectual and professional development (Seymour et al., 2004; Hunter et al., 2006) . Hunter et al. (2006) utilized a social constructivist lens that includes both communities of practice and identity to investigate the gains of students participating in an apprenticeship style research program at four liberal art colleges. Students and faculty reported similar gains including thinking and working like a scientist; personal-professional; clarification, confirmation, and refinement of career/education plans; and working independently. Faculty were more likely to view student development as "becoming a scientist" than the students, viewing student development as moving from legitimate peripheral participation towards a more centralized role in the community of scientists (Hunter et al., 2006). The effect of undergraduate research on students' adaptation to the norms, values and professional practice of science has been examined from the perspective of the student-advisor relationship in UREs (Thiry et al., 2012). Findings revealed that novice and experienced student researchers have different needs in terms of mentoring and participation in the research community of practice. Additionally, the study acknowledged the effect of UREs on students' identities and career paths.

One limitation of prior studies is that most focus on summer UREs with rigorous admissions requirements that prevent many students from participating. A few studies, such as Robertson and Blacker (2006), focus on students in a summer URE with no prior research experience. In both cases, students who participate in research projects during the academic year or as part of their regular curricula are excluded. We expanded on previous work by studying students with URE during the academic year to gain an understanding of the components of epistemic cognition drawn on by these students during problem solving in the research lab.

4.2.2 Prior Research on Epistemic Cognitions in a Research Environment

Samarapungavan et al. (2006) studied the development of epistemic beliefs as a function of chemistry expertise and research experience. Their work was guided by three research questions: 1) "Do the participants epistemic beliefs vary as a function of chemistry expertise?", 2) "Are there discipline-specific values and heuristics that guide chemistry research?", and 3) "How does research experience influence the participants epistemic beliefs?" (Samarapungavan et al., 2006, p.471). To answer these questions, they interviewed high school students, undergraduate students (with and without research experience), graduate students, and research chemists about their epistemic beliefs in chemistry. Their interview questions spanned five epistemic themes: "description of own work", "choice of problems and methods", "models for handling empirical anomalies", "criteria for evaluating own work", and "what is science?". During analysis, they initially coded responses to each interview question based on the level of sophistication using a number from one to seven. After this first round of coding, the initial codes were grouped based on the range, elaboration, and specificity of the response. Taking a mixed-model approach (qualitative data is analyzed with quantitative methods) they found that epistemic beliefs differ based on chemistry expertise, there are discipline specific values and heuristics expressed by research chemists, and that research expertise influenced their epistemic beliefs. Their results contrast the work of others who previously suggested that scientists have relatively unsophisticated views of the nature of science (Bell & Lederman, 2003). One explanation for this may be the unique approach these researchers adopted exploring enacted epistemologies by grounding their interview questions in the work and area of expertise of their participants. This likely made the seemingly abstract and decontextualized questions found in most research on epistemic beliefs more understandable and approachable. Additionally, their work suggests that participation in an authentic research experience is important for chemistry students' epistemic development. Their work does not provide information about how the types of experiences (ex. keeping a lab notebook, research group meetings, presenting research, and training others) within a research lab may influence epistemic development.

4.2.3   Objectives of Study

In a previous study, we have investigated engineering students' epistemic cognition elicited during problem solving in the classroom (see Chapter 3). Some students discussed how their approaches to problem solving differ in the research lab versus the classroom. A female junior in biomedical engineering student explained: "Yeah, I feel like I am willing to be more creative, like when it comes to our [research] or something like that, but in class, I just know there's a right answer. And you could get an A if you know how to do it. So it's a little more frustrating in the school setting if you are given a problem that doesn't have a specific answer." This quote reveals a difference between this student's beliefs about knowledge in the engineering classroom and research lab despite being presented with open-ended problems in both contexts. This dichotomy may be due to differing standards between research and classroom environments and added to the motivation to investigate students' epistemic cognition in the context of a URE.

Given that the research laboratory can be considered a unique problem solving space (Nersessian, 2006), the overall objective of this study was to understand undergraduate engineering students' epistemic cognitions in the context of a research experience. The specific aims of this study were to understand 1) why students select specific research projects, 2) how students conceptualize the goals of their research projects and what they hoped to gain from the experiences, and 3) what processes do students use to make research decisions (selecting methods and evaluating outcomes). We also sought to understand how the aspects (time in research, research group structure, etc.) of students' experiences and students' dispositions (goals for the project, beliefs about the nature of knowledge, and need for cognitive closure) influence their epistemic cognitions.

4.3   Theoretical Frameworks

Situated learning and epistemic cognition were used as analytic lens to understand how undergraduates conceptualize and approach research and integrate into a research community. We adopted the viewpoint that "a laboratory might be understood not simply as both the physical space plus its collection of artifacts, such as instruments and specially designed technologies, but also an organized social group with shared agenda that undergirds the particular problem-solving goals undertaken by any researcher at any given time." (Osbeck, Nersessian, Malone, & Newstetter, 2011, p.47). Additionally, we conceptualized the laboratory as a problem solving space made up of researchers and artifacts (Nersessian, 2006).

4.3.1 Situated Learning

The theory of situated learning developed by Lave and Wenger (1991) centers on relationships between learning, identity, and membership in communities of practice. Learning inherently occurs in tandem to one becoming a member of a community of practice and is an "evolving form of membership." These communities affect a person by shaping perceptions, values, and interactions with others where the members engage in a process of collective learning in a common domain and share a repertoire of resources (Lave & Wenger, 1991). Situated learning in communities of practice has been used in prior research on UREs (Thiry et al., 2012), as undergraduates integrating into and learning from a research community of practice are integral to effective UREs. UREs will serve as the communities of practice in our study, as we first focus on examining their situated learning in this setting. According to situated learning theory, students learn best by doing what experts in that field are doing (authentic tasks), and their gained knowledge is socially, culturally, and physically situated (Lave & Wenger, 1991; Winn, 1993). Situated theories of learning further suggest that knowledge is a matter of competence related to a valued enterprise, and that knowing is a matter of participating in the pursuit of such enterprises (Wenger, 1998). The concept that situated learning is usually unintentional rather than purposeful is embodied in the process of "legitimate peripheral participation" in a community of practice (Lave & Wenger, 1991). Ultimately, this is what learning environments, including classrooms, seek to produce and what research experiences are designed to provide.

4.3.2 Epistemic Cognition

Epistemic beliefs can be defined as students beliefs and attitudes about the nature of knowledge and knowing (Hofer, 2001). We applied Chinn et al.'s (2011, 2014) conceptualization of epistemic cognition to more deeply understand students epistemic cognition in the research community of practice. Chinn et al.'s (2011, 2014) framework expands Hofer and Pintrichs (1997) work by clarifying and expanding constructs based on philosophical and psychological considerations. Epistemic cognition is conceptualized as a network of interconnected cognitions that cluster into five separate constructs: 1) epistemic aims and epistemic value, 2) structure of epistemic achievements, 3) source and justification of knowledge and epistemic stances, 4) epistemic virtues and vices (motivations), and 5) processes for achieving epistemic aims. Epistemic aims, such as knowledge, understanding, and true beliefs, are defined as a subset of goals that people adopt related to their desire to figure things out. These goals become epistemic achievements once they have been reached and have different epistemic values based on their worth to an individual. An individual may choose to believe

knowledge claims to different extents, taking various epistemic stances. Structure, source, and justification of knowledge have all been expanded in this model to account for the situation specific nature of epistemic cognition. An individuals perceptions about the processes that produce valuable and reliable data can also be investigated to help explain the learning processes of individuals as they engage in inquiry and evaluation task. Additionally, Chinn et al.(2011) suggest that epistemic cognition is situation specific and recommend the use of more fine-grained, context specific analyses. As such, in this study the situation was accounted for by considering components of epistemic cognition elicited by scenarios in the research lab. Additionally, this study focused on the constructs of epistemic aims, source and justification of knowledge, and processes for achieving epistemic aims from Chinn et al.'s (2011) framework.

4.4 Research Methods

4.4.1 Participants

Participants with research experience were recruited from an upper-level biomedical engineering course at Clemson University. Students were invited to participate in a semi-structured interview that focused on their experience with research and approaches to doing research. Students were given a $25 card for completing the interview. Six students completed the interview. These students did research with four different faculty mentors in the department. Three of the students had experience working in a single research group, two of the students had worked in two research groups, and one student had worked in three unique research groups. Two of the students were actively working on two separate projects in different research groups while the other four students were currently working on a single project. Two of the students had experience working on a single project while the other four students had or were working on multiple projects. The students interviewed in this study had been working on their current projects for as short as three months to as long as two years.

4.4.2 Interviews

The interview questions used in this study were informed by Samarapungavan et al.'s (2006) work with chemistry students and research chemists. The questions used were designed to gain an understanding of the students' research experiences and their epistemic cognitions as they make research decisions, see Appendix E for the complete protocol. Specifically, we sought to understand how students selected their

research projects and their specific research methods, the process students use to evaluate the outcomes of their work, and their approach to unexpected results. There were also questions included to gain a general understanding of how each research group functions and the roles the students believe they play in each group. Participants were asked follow-up questions based on their responses. A single interviewer conducted all of the interviews (n=6) to ensure consistency across interviews. Each interview lasted approximately 30 minutes.

4.4.3 Analysis

Interviews were analyzed using emergent coding followed by *a priori* coding. The *a priori* codes were informed by the AIR model of epistemic cognition (Chinn et al., 2011, 2014) and the themes that emerged from Samaragungavan et al.'s (2006) study of undergraduate chemistry students and research chemists. The codes included students' description of their project, choice of the project, choice of methods, models for handling unexpected results, criteria for evaluating work, personal and project goals, sources of knowledge, perceived gains, and views on what is engineering. All of the interviews were professionally transcribed and reviewed by the primary researcher prior to analysis to ensure accuracy of the transcription. Each transcript was read multiple times to gain a general understanding of each students' interview. This was followed by emergent coding in which the researcher identified key phrases and developed codes to represent them staying close to the participant's own words (Charmaz, 2014). Emergent coding was followed by *a priori* coding in which the researcher applied the themes identified in Samaragungavan et al's (2006) and Chinn et al.'s (2011, 2014) work. The purpose of the initial coding process was to identify and name the phenomena found in the transcripts. The next stage of analysis used axial coding to identify connections and relationships between the codes (Strauss & Corbin, 2007; Charmaz, 2014). Transcripts were analyzed using an iterative process in which each transcript was read multiple times to ensure that the codes and themes accurately reflected the students' statements. Throughout the analysis process the primary researcher kept a record of emerging thoughts, questions, and directions for analysis (Strauss & Corbin, 2007; Charmaz, 2014). Emerging ideas were compared across participants throughout the analysis process, taking a constant comparative approach(Strauss & Corbin, 2007; Charmaz, 2014; Strauss & Corbin, 1990). Transcripts were coded using RQDA, a software package for R that facilitates analysis of qualitative data (Huang, 2010), and by hand using a table to facilitate the comparison of students across the major themes identified.

4.5 Results and Discussion

Table 4.1: Summary of interview participants' semesters in research, research advisors, personal goals, and approaches to choosing methods and evaluating their work.

	Semesters in Research	Research Advisor	Personal Goals	Choice of Methods	Evaluating Work
Mia	Less than 1	Dr. B Dr. A	Figure out what she wants to do Understand why things are done certain ways	Given to her by research mentor	Get through process without messing up
Olivia	4	Dr. C	Get a job Get innovative results	Literature Run by research mentors Trial and error	Turns out the way you want Get reliable results
Sophia	3	Dr. D	Put on resume Put something out there that others can use Gain something insightful	Literature Research group Trial and error	Compare to regulations Compare to results in other papers Replication
Lucas	4	Dr. C	Gain problem solving skills Develop lab skills	Consider device and material limitations Literature Research group Trial and error	Outcome is something that will be useful to others Replication Based on empirical results
Ava	4	Dr. C Dr. A	Put on resume Develop professional skills Develop relationship with faculty	Literature	Ask research mentor Compare to where they started Get feedback from research group Reproducibility
Ethan	3	Dr. B	Put on resume Gain the experience	Given to him by research mentor	Get past the first step

4.5.1 Choice of Research Projects

The department that this study took place in has a prominent undergraduate research program. The students in this department have the opportunity to participate in multiple types of research experiences. The

two most common types are Creative Inquiry groups and independent research studies. Creative Inquiry (CI) groups are teams of undergraduate students that are advised by a faculty mentor. These groups are very team and student oriented. One student in this research study described that she believes "The purpose of the CI, I think, is more of a learning thing for undergraduates." These groups typically meet once a week to discuss research progress and plans. Each semester the bioengineering department sends a list of available CI's to the undergraduate students in the department. The independent research studies have more of an apprenticeship style structure, with an undergraduate researcher being paired with a graduate student and faculty mentor. The graduate student directly works with the undergraduate student training him/her on the lab equipment and techniques. When describing the difference between her CI and independent research experiences one student said, "The Creative Inquiry is not as much results focused. It's more what you learned and your mistakes you make but that you're directing the process of the whole experiment and when I did it for Dr. A [independent research], it was more like this is our goal. We need to get it as soon as possible."

The students who participated in this study got involved with research through a variety of avenues, including responding to a departmental email about opportunities, contacting a professor they met through a previous experience, and acting on recommendations from academic advisors or siblings. All of the students interviewed in this study mentioned that one of the reasons they selected the projects that they were currently working on was because of an interest in the topic that was being investigated. For two of these students, this interest was directly connected to a project they had just completed in a course they were taking and were interested in continuing to study that area. When asked how she selected her current project, Sophia explained "I just got an email that said these are the CIs that are available and send in an application. I had just done a project on intervertebral discs in the spine so I thought it was interesting so I just sent in an application and he was like yeah sure, come on in." Like Sophia, Ethan picked his research topic because of a class project he had just completed. Other students mentioned that they picked their project because they wanted to see if they liked that particular aspect of bioengineering. These students saw URE as a way to get experience with a different aspect of biomedical engineering than what they were exposed to in their classes.

4.5.2 Description of Project and Personal Goals

At the beginning of each interview, students were asked to describe their current and past research experiences. Students were also asked to elaborate on the goals of their projects and what they hoped to gain through their URE.

4.5.2.1   Project Goals

Most of the students provided detailed descriptions of the goals of their research projects. These descriptions often included the long-term impact of the project and intermediate goals required to meet the larger goal of the project. Mia believes that the purpose of one of the projects she is working on is to have an impact on people's lives:

> The goal of the research, the overall goal, is obviously to create this polymer that can actually deliver the drug to the colon. Right now, we're still working on...the immediate goal is to create the polymer successfully repetitively. That's really what my position is in the lab. I know they also are doing cell culturing and growing the amoeba so that we can actually test the drug to make sure the drug is effectively killing the amoeba. That's another sector of the lab right now. I'm working more on the polymer contribution.

When talking about the goals of their project, many of the students described how their research will impact the lives of others and connects to the field of bioengineering. This represents that these students understand the long-term implications of their work and can see how their everyday work in the lab may impact the lives of others in the future.

> The purpose would be to basically when the intervertebral disc slips the only thing that you can do really is spinal fusion and that limits mobility. What we-re trying to do is decell the intervertebral discs from a cow tail and then be able to seed it with human stem cells to put it back into the body basically.

Two of the students had a difficult time articulating the impact that their work in the lab could have in the field. When asked to summarize the overall goal of the study Ethan was working on he said, "We're supposed to experiment and test a certain method, a certain product, I think, is what the first idea was. But, we haven't gotten there yet." Ethan was interviewed during his fourth semester on this project, but still struggled to describe its purpose. This may have been because of all of the struggles that his group had over the semesters and lack of progress on the project causing him to question if the goal was the same as when he had started. The group that Ethan worked in may have also impacted how he described his project. Mia, a student in the same group as Ethan, had been working on the project for about three months when the interviews took place. She also struggled to describe the goal for the project and said,

> I'm really not sure what the overall goal is for the tissue one. I think the goal is, obviously, to create myocardial tissue. I don't really see that happening this semester because we've run into a lot of bumps where we've contaminated our cells, or our cells have dried out in the incubator because we weren't putting enough media in. Just learning problems where we have run into issues. I think that's kind of the goal of the creative inquiry, is to teach you while you're trying to get to this place. That is definitely the goal, is to actually use the steroids and the soap and everything to actually create the myocardial tissue.

This research group may have focused on the short-term and semester goals and did not discuss the long-term implications of the research. This may have been a result of all of the challenges they faced with this project and would explain why both Ethan and Mia had a difficult time expressing the goals of the project.

4.5.2.2 Personal Goals

The students described a number of personal goals and desired gains from their URE. These goals were coded and classified based on whether they were epistemic in nature using Chinn et al.'s (2011, 2014) conceptualization as a guide. Epistemic goals included gaining personal knowledge, seeking understanding, and expanding the existing knowledge in the field. Most of the students expressed having multiple goals for their URE and were identified as having an epistemic goal if one of their goals was epistemic in nature. Five of the six students (Oliva, Ava, Lucas, Mia, and Sophia) were classified as having a goal that was epistemic in nature.

Gaining personal knowledge Many of the students described that they hoped to develop specific skills through their URE. These skills included problem solving skills, lab skills (e.g. pipetting, cell culture, and imaging), and professional skills (e.g. working on teams and oral and written communication). Problem solving and lab skills can both be classified as a type of procedural knowledge. Developing professional skills, in the way that the students in this study talked about them, is similar to developing knowledge about how the larger field functions. This includes learning how professionals in the field communicate and interact with one another. When asked what she hoped to gain Ava explained, "I hope to gain lab technique and professional skills. We do presentations and we talk to people who know a lot more than us and who know a lot less than us...Working together and also working for yourself. I applied for a lot of internships and that was the main thing that all of them said..."

Seeking understanding Mia did not directly mention that she hoped to gain understanding through her experience; however, her description of her actions revealed this as one of her goals. While she is working in the lab with her graduate student mentor, Mia said she is constantly trying to understand why he is doing certain steps and using particular methods. When she was interviewed she had only been working on her two current projects for a few months, making her the newest to research. This may explain why she described herself as being curious and asking so many questions in the lab. The other students interviewed in this study may have expressed similar goals when they first started their projects, but since they had been working on their projects a few semesters this general understanding may not have been a focus of them anymore. Mia

described the questions she asks in the lab and stated,

> Mostly, like I said, the reassuring questions, like, 'Why are you doing that? Do I need to do that part of that every time?' If that makes sense. If maybe he's rinsing three times, I'm like, 'Do I need to rinse three times, do I need to rinse five times?' Just making sure that I'm fully doing everything properly every time I do it. Those are really the kind of questions I'm doing. I really do try to understand what's happening. Why we have to wait two hours or why...I ask him, too, 'How do you know that? Where did you get that information from?' That's what I wonder when I go into these projects...

Expanding existing knowledge in the field Two of the students interviewed, Olivia and Sophia, described that one of their goals was to add to the knowledge in the field. These students specifically expressed that they wanted to get innovative results and put information into the field so that others can use it. Through these statements, both of these students show an understanding of how their work adds to the field of biomedical engineering and how new knowledge is created. When asked what she hopes to gain from the project she is working on Olivia said, "I feel like there's really neat stuff, there's a lot of really cool opportunities and I'd like to be able to contribute to that." Likewise Sophia stated, "...I would hope to gain something insightful from it. Hopefully get something published or put something out there that's helpful to others so that maybe they can complete the process. Whatever that might be."

Non-epistemic goals All of the students mentioned having at least one non-epistemic goal for their URE. One of the more common non-epistemic goals expressed by the students was adding to their resumes. The students saw their URE as something that would set them apart and often decided to start doing research because they believed that it would help them get a job in the future by setting themselves apart from other applicants. When asked what he hoped to gain from his URE Ethan said, "It looks great on a resume, I think." Olivia directly mentioned that she hoped she would gain a job through her experience: "I'd really like a job. I do like research. I think it's interesting." They saw that their URE would set them apart when trying to find jobs even through some of them wanted to do something outside of research. This is not surprising since all of the students in the study chose to do research in addition to their required coursework. They all decided to make the time to do research because they saw that it would help them in the future no matter what they decided to do with their degrees in bioengineering.

Students also hoped to gain first-hand experience in their field through their experiences. Many of the students saw their UREs as a more authentic environment than the classroom and hoped to gain practice working in that environment. Mia hoped that her UREs would help her figure out what area of biomedical engineering she was most interested in and if she wanted research to be part of her career: "The biggest thing is trying to figure out what I want to do and what interests me, and whether I do like doing research and

working in a lab. That was my overall goal. Obviously, if I find a project that I'm really interested in, that would also be ideal, because I'm considering graduate school at this point and I need somewhere to go with that."

4.5.3 Processes Used to Select Methods and Evaluate Their Work

The students were asked to describe how they select methods to use in their research and how they evaluate the outcomes of their work. The students described a variety of processes they use in their research. The specific processes reveal students' beliefs about the sources of knowledge in the context of research. All of the students described seeking their research mentors to verify what they were doing or to guide them in their process. The research mentors included both faculty and graduate student mentors. All of the students expect Mia mentioned consulting peer-reviewed sources either in the development of methods or to assess their outcomes. It is likely that Mia did not conceptualize the literature as a source of knowledge because she had only been working on her research projects for a few months and was always working with either her graduate student mentor or another undergraduate student.

Students' descriptions of the process they used to make research decisions were compared based on students' personal goals for their URE and their cluster identified in Chapters 2 and 3. Students were compared based on these two factors because of Chinn et al.'s (2014) suggestion that a student's goal will influence how they approach a reading task and our previous finding that different clusters (based on epistemic beliefs and need for cognitive closure) approached a class homework problem differently (see Chapter 3).

4.5.3.1 Choice of Research Methods

During the interviews, students were asked to describe how they developed the methods they are using in their current study and how they would develop methods to carry out a new study. Students described that they got the methods they used from their mentors, the literature, through group discussions, and trial and error. Mia and Ethan both described that they are handed the methods they use by their research mentors. When asked how he approaches problems in the lab, Ethan said "I'm pretty much given all the information we need, so I just kind of gather things together and force them...Dr. B pretty much gives us all the information we need. Yeah that's pretty much it." They described that they decide when to go into the lab but are not involved in making the decision about what methods to use. The dynamics of Ethan's and Mia's lab group appears to have an impact on the processes they use to develop their research methods. By their research

mentors handing them the methods to use, these two students are not given the opportunity to experience all aspects of scientific research. There is little that can be said about a connection between these students goals and processes used in research since the structure of their group does not give them the chance to make these decisions. For Mia, who has only been working on her two projects for a few months, it is not surprising that she is given all of the steps she needs to follow because she is still trying to learn and understand how research is done in biomedical engineering. In contrast, this is Ethan's fourth semester on his research project. At this point in his experience, it is surprising that he is not being asked to make evaluative decisions about the methods being used in the project. This might be connected to his lack of an epistemic goal for his URE. It is possible that his lack of an epistemic goal is influencing his approach to research or that his approach to research and goal is tied to the structure of the lab he is working in. Perhaps more autonomy in research would help initiate Ethan's development of an epistemic aim and processes that align with the standards in the field of biomedical engineering. Based on the results of this work, it is not possible to separate these two effects out to determine cause and effect; however, examining the cultures within research groups will be the focus of future work to allow for these distinctions to be made .

Ethan, Mia, and Ava are all working on projects that rely on cell culture of specific cell types. All of these students mentioned that they use known protocols to guide their cell culture techniques. Ava described, "We usually look up protocols online a lot of times. How do we culture these cells? And there will be a protocol or how do we test them out in the solution? Oh, use this machine. It has a protocol. There are known things that we can do." This is not surprising as companies that sell cells typically publish a protocol that outlines the type of media, the growth factors, and the conditions that the cells need to live. For cell culture work, this is the standard method used to get information about culturing techniques for specific cell lines and types as such these students are utilizing a standard heuristic in the field.

Additionally, Ava mentioned that her and her lab group did an extensive literature review at the beginning of the year to develop the initial protocol they use for their work. She described that it is difficult to find information in peer-reviewed journals that is relevant to their project because their project is very unique. Olivia, Sophia, and Lucas also mention developing their methods based on the literature. Olivia's current research project was derived from a paper that she read a previous semester. All of these students mentioned that they will look up literature to find relevant papers and then discuss these papers with the members of their research group to decide how to adapt them to their work. Using the literature is a common practice in scientific research when trying to develop methods for a new project.

Lucas mentioned that to decide between multiple methods his research group often has to consider

the limitations of the instruments and materials they are using: "You can't use a laser cutter to get precise, small...because the laser itself is pretty wide, you can't get really small shapes with that, so we started using a 3-D printer and we've been 3-D printing more small dimensions." This shows recognition of research practices beyond that observed by Samaragungavan et al. (2006) for undergraduate students doing research in chemistry. Their work suggests that these pragmatic considerations were most frequently considered by the research chemists and not the graduate, undergraduate, or high school students in the study.

Since most of these students are working on projects with novel goals and are adapting other people's methods to their work, they described that they often select their methods by using trial and error. They described selecting a few possible methods and then testing all of them at once to determine what works best and then will use that method for their future studies. Lucas described this process during his interview and said,

> A lot of times it's trial and error. We will go through it in our minds and in our meetings and everything it sounds like it's a good idea until we do it. then we realize all these problems come up and once those problems come up, we'll try to modify it to see if it works. Like, if you use a different solution or different dimensions. But then we realize those problems are still there and so we'll try a different method.

The students described that many times they did not realize that a method was not going to work until they tried it in the lab. When they described using trial and error it was typically very intentional and analogous to developing a small scientific study. The students and their research mentors would often develop a plan that included controls and multiple samples of each condition to determine how the factors in question influenced the outcome. The results would then be used to inform the methods of their next study or add to their developing protocol.

4.5.3.2 Evaluating Their Work

Students were asked to describe how they evaluate the success of their studies and how they know if their results are accurate. This question was particularly difficult for Ethan and Mia to answer because they were struggling with their studies and did not feel like they had gotten results yet. At the time of the interview, these students were struggling to get their cells to stay alive. As a result, these students struggled to answer this question because they did not feel like they had outcomes in their work to evaluate. When asked how he knows the results he is getting are accurate Ethan explained, "I don't. I mean, if they live. We're not really getting results, so I don't know if I can answer that one." Both Ethan and Mia, who work on the same project, mentioned that if their cells are alive then their work was successful because they can

move on to the next step. These descriptions are similar to how 90% of the chemistry undergraduate trainees in Samarapungavan et al.'s (2006) study evaluated the outcomes of their work. Samarapungavan et al. (2006) found that most of the undergraduate researchers evaluated their work based whether they were able to run the procedure accurately. For Mia and Ethan's work, running the procedure correctly would mean that their cells stay alive because they attributed their cells dying to errors that they made in the lab. When asked about why the cells are dying Ethan explained, "Some of them die just because we forget to change the media."

Like Ethan and Mia's project, Ava's research had a number of struggles and was not moving forward as fast as expected. One way that Ava described evaluating the success of her work was "...by reviewing where we started from. Like absolutely nothing. Let's grow cells on this thing and see if it works. But now we're like realizing there's a lot more you have to do, so we are like how successful we are is how far we've progressed in the past, not knowing anything and not having a plan. Having steps for what we need to do and knowing what we need to do now." Likewise, Lucas expressed that the success of his research is based on what he has done even if they are not the results he expected. Ava also explained that she evaluates the accuracy of her results based on whether they can be replicated. Sophia, Lucas, and Olivia also mentioned that they think of the reliability of their results when they are evaluating their work. These students mentioned running a bunch of samples when they do a study so that they can determine what effects are due to the specific treatments used. The process of establishing reliable results through reproducibility is a common heuristic used in scientific research.

Sophia and Lucas also stated that they evaluate their work based on external metrics. Sophia's project aims to develop a scaffold that can be implanted into the human body, as such, they use the Food and Drug Administration's regulations as their benchmark and evaluate their results based on how close they are to the regulations. Similarly, Lucas evaluates the work he is doing is if the results will be useful to others. Both of these students are considering the metrics that are in place within the field of biomedical engineering to assess the outcomes of their work. In Samarapungavan et al.'s (2006) work he found that all of the research chemists in his study evaluated their work by considering multiple criteria, including its impact to the field and design criteria. These are analogous to the metrics used by Sophia and Lucas.

4.5.3.3 Adding to the Field of Knowledge

Three of the students (Olivia, Sophia, and Lucas) explained that their research is adding to the current knowledge in the field of biomedical engineering because their work is pushing previous work forward through replication and the development of a new protocol. These beliefs are consistent with the field of

biomedical engineering and represent these students' understanding of how knowledge is created in this field. Olivia, Sophia, and Lucas all had experience working in the same research group for at least three semesters and had only done research with a single group.

The other three students in the study (Ava, Mia, and Ethan) did not believe they were adding to the knowledge in the field of biomedical engineering. These three students were all working on at least one project that they described as being held up by roadblocks. Ava does not feel like she is adding to the field's knowledge because her work has not been published and others are not able to learn about it. She seems to believe that you are not adding to the field's knowledge until your work is known by others. Likewise, Ethan does not feel like he is adding to the knowledge in the field because he does not believe that his work is producing or informing anything. Ethan seems to believe that in order to add to the field's knowledge the work you are doing must be "successful". Mia feels like research is adding to her personal field of knowledge, but does not think that her knowledge is adding to the field's knowledge. She went on to explain that once she is more independent in the lab she will feel like she is adding to the field's knowledge. Since she is new to the research lab, she feels like she is following someone else's instructions and is not making decisions on her own.

4.5.4   General Discussion

Most of the students who participated in this study selected their research projects from a list or where assigned a topic after selecting a research group with which to work. All of the students selected their project and/or research group because an interest in what was being studied. In a prior study, we found that students felt like researchers because of an interest in the topic, adding to their identity as a researcher (Faber & Benson, 2015b). Additionally, in a different study students said that they approach problems with different goals based on their interest in the topic. For problems that they were interested in, many of the students described that they sought to gain understanding or knowledge while their goal on a problem they did not find interesting was to get it done as quickly as possible (see Chapter 3).

When describing the goals of their research project, most of the students showed an understanding of the short-term and long-term goals of their projects. These students were able to explain how their work had the potential to push the field of biomedical engineering forward. Two of the students, who were from the same research group, struggled to explain how their work fit into the larger field and focused on the immediate goals of their project. From this study it is not clear why these students struggled to connect their research with the larger field. It is possible that it was a result of how this group talked about the goals of their work,

always focusing on the immediate goals.

Five of the six students approached their research with at least one goal that was classified as epistemic in nature. These epistemic goals included, gaining personal knowledge, seeking understanding, and expanding existing knowledge in the field. Through their research experiences students hoped to gain knowledge of lab skills, problem solving skills, and professional skills. These students believed that gaining these skills would be beneficial to them in the future in jobs outside the research lab. Through her research experience, Mia sought to gain understanding which was evident in the questions she asked in the research lab. She described that she frequently asked her research mentors to explain why things were done a certain way and how they knew what to do. She was the only student in this study to express the goal of seeking understanding. This might have been because she was the newest to research and was focused on understanding the details of how and why things are done certain ways in the lab. The other students may have expressed a similar goal when they were newer to research. Two of the students, Olivia and Sophia, expressed that one of their goals was to add to the knowledge in the field. They mentioned a desire for innovative results and publishing their work so that others could use it. These students had an understanding of how their research could impact the field and push other researchers' work forward.

All of the students expressed having a non-epistemic goal for their URE. The most common non-epistemic goal was adding the experience to their resumes. These students believed that doing a URE would set them apart from other undergraduate students when looking for jobs or applying to medical school. They hoped the experience would add to their resumes and give them a unique experience to talk about during a job interview. Many of these students also believed that their URE provided them with first-hand experience in their field, seeing the research lab as a more authentic environment than the classroom.

The results of this study suggest that there is *not* a connection between students' epistemic aims and the processes they use to make research decisions. This is different than Chinn et al.'s (2014) suggestion that the aims individuals adopt influence their text processing. This difference may be due to the unique contexts considered in these two works. Additionally, this work suggests that the processes students use to make research decisions is influenced by the research group that they are working in. Based on the students' descriptions of how their research groups function, each research group has its own set of unique practices and processes. While all of the research groups in this study were from the same department, the individual research groups appear to have their own epistemic culture (Cetina, 1999).

4.6   Conclusions

The students in this study selected their research projects because of an interest in the topics being studied. These students approached their research experiences with a variety of goals, both epistemic (gaining personal knowledge, seeking understanding, and expanding existing knowledge in the field) and non-epistemic (adding to their resume). Student's epistemic cognition when making research decisions was not connected to their goals. Results suggest a possible connection between processes used to make research decisions and the research group students were in.

4.7   Future Work

This study focused on students' perceptions of their approaches to research and the results suggest that these processes are impacted by the research group the students are in rather than the students' epistemic beliefs and need for cognitive closure. Future work will seek to characterize the culture of these research groups through interviews with other members and observations of the group in order to gain a more complete understanding of how research group culture impacts students' epistemic cognition. Additionally, this work focused on students conducting research within a single engineering department. Future studies will aim to understand the similarities and differences in epistemic cognition between research groups in other departments.

The interviews with students also revealed differences in students' perceptions of the learning environment within the classroom and research lab. Many students perceived the research lab as an environment that was more conducive to creatively and curiosity compared to the classroom. Future work will seek to identify the aspects of the research lab and classroom that resulted in these different perceptions and seek to develop pedagogy to encourage students to be creative in the classroom environment.

Chapter 5

Conclusions and Future Directions

As our understanding of students' epistemic cognition increases, we will be able to develop pedagogy that encourages the development and use of reliable processes to gain knowledge and understanding and the development of problem solving skills and self-regulated learning. This work adds to our understanding of undergraduate engineering students' epistemic beliefs and epistemic cognition in two unique problem solving contexts, the classroom and research environment.

5.1   Summary of Results

In Chapter 2, the reliability and validity of an instrument designed to measure students' engineering epistemic beliefs (Yu & Strobel, 2011) and need for cognitive closure (Kruglanski, 1990) were assessed. Three of the five constructs in the original instrument were found to have acceptable internal consistency reliability suggesting that they each measure a single concept. These constructs included closed-mindedness (from need for closure scale (Kruglanski, 1990)), source of knowledge, and certainty of knowledge (from ERBQ scale (Yu & Strobel, 2011)). For the engineering epistemic belief items, students were asked to explain their Likert-type response in a text box below each item. These responses were analyzed qualitatively to gain a better understanding of students' interpretations of the items and their epistemic beliefs. Based on this analysis recommendations were made about how to reword the items to increase the instrument's reliability and validity. Multiple items were interpreted by the students as compound items and some of the phrases used were difficult for students to understand.

In Chapter 3, the connections between students' engineering epistemic beliefs, need for cognitive

closure, and epistemic cognition was investigated through a mixed methods study. In the quantitative portion of this study, students were clustered into three homogenous groups based on their responses to items on a quantitative survey designed to measure engineering epistemic beliefs and need for cognitive closure. The qualitative part of this study included analysis of semi-structured interviews that were designed to gain an understanding of students' epistemic cognitions when solving an open-ended homework problem. These interviews were analyzed to understand the goals students set when first approaching the problem, perceived gains from solving the problem, general thoughts on the problem, and processes used to solve the problem. Students typically set more than one goal for the problem with some of the students seeking knowledge and understanding (epistemic goals) from solving the problem. The clusters identified in the quantitative analysis were analyzed together with the qualitative results to understand the connection between students' epistemic beliefs, need for cognitive closure, and epistemic cognition. This analysis revealed that engineering epistemic beliefs and need for cognitive closure impact the approaches students take when solving open-ended homework problems. The results further suggest that having more constructivist epistemic beliefs does not guarantee that one will set aims that are epistemic in nature or make epistemic gains, seen when the qualitative results were compared across the clusters. This may be further explained by a difference in the students' closed-mindedness across Clusters 1 and 2, with the students who are more closed-minded (Cluster 2) approaching the problem with only non-epistemic goals. Their closed-mindedness may have impacted their ability to see the value in solving a homework problem for the second time. Additionally, students' interest, utility value, beliefs about the context, and perceived expectations of the instructor impacted the goals students set when approaching problems, further explaining the difference seen between the clusters. Some of the students who do not mention having an epistemic goal when they first approached the problem reported that they gained either knowledge or understanding. This finding brings up questions about the definition of epistemic cognition and epistemic achievements proposed by Chinn et al. (2011).

In Chapter 4, students' epistemic cognition within an authentic problem solving environment, an undergraduate research experience in biomedical engineering, was investigated. Undergraduate engineering students with research experience were interviewed to understand their goals and approaches to doing research. Transcripts were analyzed using Samarapungavan et al.'s (2006) and Chinn et al.'s (2011) frameworks as lenses. Analysis of interviews with students revealed how students select a research topic and what processes students use when making research decisions. Five of the six students interviewed describe that they approached their research with at least one goal that was classified as epistemic in nature. This is unique compared to the interviews with students about their approach to homework problems in which fewer stu-

dents approached the problem with an epistemic goal. The students interviewed in this study represented a subset of students who took the survey (Chapter 2) and completed the problem solving interview (Chapter 3). Their survey responses and interview about the homework problem were analyzed together with their research interviews and compared based on quantitative cluster and goals and processes used when approaching the homework problem and their research. This comparison did not result in connections between students' epistemic beliefs, need for cognitive closure, and epistemic cognition in the two contexts investigated (classroom problem solving and research decisions). One factor that influenced students' goals and processes used in the research environment was the structure of the research group the students were working in. Some of the groups gave the students more autonomy than others, expecting them to develop their own methods to conduct their studies, while in other groups students were told what to do and how to run the studies each week. Students from different research groups talked about the goals of their project in different ways, with students from one group focusing primarily on the short-term goals of their project. Future work will seek to further investigate how the culture and structure of a research group influences students' epistemic cognition when making research decisions.

5.2   Implications for Research

There are a limited number of studies that investigate the epistemic cognition of undergraduate engineering students. Additionally, this work is unique because it used a biomechanics problem and research experience to elicit students' beliefs about knowledge and knowing (epistemic cognition). The findings add to current theories of epistemic cognition by expanding existing theories and operationalizing a framework (Chinn et al., 2011, 2014) that had not been previously used in engineering education and problem solving. This work lays the foundations for future studies of epistemic cognition in the context of problem solving. As part of this work, the reliability and validity of the EBRQ instrument (Yu & Strobel, 2011) and the need for closure scale (Kruglanski, 1990) was assessed and suggestions were made to improve the ERBQ items (Yu & Strobel, 2011) based on students' interpretations. These outcomes can be used to inform future studies and the improvement of quantitative scales to measure epistemic beliefs.

5.3 Implications for Practice

The results of this study add to our understanding of how classroom practices and students' perceptions influence students' actions in the classroom. The results presented in Chapter 3 suggest that implicit actions in the classroom send signals to students that impact their approach to their assignments. For example, students in the study were found to have specific beliefs about what homework should look like and how long it should take them. This influenced how some of the students approached the problem they had been assigned and lead to many of them oversimplifying the process by focusing on the materials given to them by the instructor. Despite the instructor telling the students that the problem did not have a single right answer many of the students believed that it did and did not use more rigorous methods to complete the assignment because it was homework and they were only given a short period of time to work on it.

This work also has implications for co-curricular activities such as research experiences. The processes that students adopted appeared to be connected to the structure of their research groups and the expectations that their research mentors set. Students that were in a group where their mentor handed them protocols and did not give students as much autonomy struggled to described the long term implications of their research and did not appear to be developing processes for designing research studies. More work is needed to fully understand the impact of research group culture on students' epistemic cognitions and development as a researcher; however, this work suggests that there is a connection.

5.4 Future Studies

5.4.1 Refine Quantitative Instrument that Measures Engineering Epistemic Beliefs and Need for Cognitive Closure

Quantitative survey instruments allow researchers to conduct studies with large sample sizes adding to the generalizability of the results and allowing researchers to answer different research questions than qualitative studies. Having a validated instrument to measure engineering epistemic beliefs and need for cognitive closure of undergraduate engineering students would allow for more studies to be done that increase our understanding in a different way than qualitative studies. There is currently not a validated instrument that specifically targets undergraduate engineering students' epistemic beliefs. The work presented in this dissertation represents the beginnings of a validated instrument with suggestions to improve individual items. This study primarily focused on assessing the engineering epistemic beliefs items because of the established

challenges with measuring epistemic beliefs using a survey (DeBacker et al., 2008). More work is needed to establish an instrument that can be widely used to study engineering students' epistemic beliefs and need for cognitive closure.

Future work will seek to refine the items on the survey based on the results of the study presented in Chapter 2, conduct further reliability and validity studies, and use the instrument as a tool to investigate the epistemic beliefs and need for cognitive closure of engineering students in different domains (i.e. bioengineering, chemical, mechanical, industrial, and electrical). First, the survey items will be refined based on the data collected in this work to reduce ambiguities. Additionally, Hofer and Pintrich (1997) and Greene et al. (2008) suggest investigating the justification of knowledge when studying an individual's epistemic beliefs. This construct is not represented on the instrument used in this work. Future work will seek to adapt items from non-discipline specific epistemic beliefs instruments to create a justification construct. The survey used in this study had two items in the certainty of knowledge construct and was found to have limited internal consistency reliability. As such, items from non-discipline specific instruments will be adapted to expand this construct to build a more robust instrument.

After an updated survey instrument has been established, reliability and validity studies will be conducted with students in different engineering majors. These studies will seek to establish the face validity, construct validity, and internal consistency reliability of the items. Additionally, these studies will aim to understand if engineering can be considered a single disciple or if it is more accurate to consider engineering as multiple disciplines in terms of epistemic beliefs and need for cognitive closure. This will help to further refine the developing instrument. Ideally, a single instrument could be used to investigate the beliefs of engineering students in different engineering majors. Given the breadth of the field of engineering, it is possible that the same items will not be interpreted in the same way by all students, decreasing the reliability of the instrument. In this case, multiple instruments, tailored to the different domains within engineering, may need to be established.

5.4.2 Further Investigate Epistemic Cognition in the Context of Engineering Problem Solving in the Classroom

The work presented in this dissertation represents one of the first studies to investigate epistemic cognition in the context of classroom problem solving. Future work will seek to refine the method used to study students' epistemic cognitions in this context, focusing on the problem and interview process.

The study presented in this dissertation utilized stimulated recall to understand students' epistemic cognitions when solving a homework problem. The major benefit of this method was that it ensured that the problem solving environment was authentic to the classroom; however, it required that students reflect on a problem that they completed up to two weeks before. Future work will seek to utilize alternative methods of capturing students' epistemic cognition during problem solving that allow for the affective elements associated with the classroom to be present, but with less time between solving the problem and reflecting on the problem.

The problem used in this study was an open-ended problem developed by the instructor of the course. The instructor provided the students with a handout that included the results from a related research study, but intended the students to seek additional external resources. Most of the students interviewed only used the materials provided by their instructor and their class notes because they found this material to be sufficient. As such, the students did not have to use a wide range of processes to make judgments about information and evaluate the resources they selected to use. This may have impacted the diversity in students' epistemic cognitions. Future work will seek to use problems that are less structured and more open-ended in an effort to capture a wider range of reliable and unreliable processes for achieving epistemic aims.

The study presented here was focused on a single class of biomedical engineering undergraduate students in a biomechanics course. From previous work, we know that biomedical engineering students are unique compared to other engineering students (Kirn, Morkos, & Benson, 2012). Additionally, the students interviewed in this study self-selected to participate and may represent a unique subset of students from the class. Future work will seek to expand this population to understand how the results of this work are transferable to other populations.

5.4.3 Study the Influence of Epistemic Climate on Students' Epistemic Cognition

The work presented in Chapters 3 and 4 suggest a connection between students' epistemic cognition and their epistemic climate. In Chapter 3, it was shown that the goals students set when solving a homework problem are influenced by their perception of the teacher's expectations, beliefs about the context (i.e. what is required for a homework problem versus other tasks), interest, and utility value. The results presented in Chapter 4 suggest that the research group the students work in impacts their epistemic cognition when making research decisions. Future work will seek to further explore the connections between epistemic climate and students' epistemic cognition in the context of the classroom and research experiences.

In the classroom, the impact of implicit and explicit classroom practices on students' epistemic

cognition during problem solving and their epistemic beliefs will be explored. This work will not only inform current theories on engineering epistemic beliefs, but will also lead to the development of assignments that facilitate the activation of advanced epistemic beliefs while mitigating risk so that students develop confidence in their abilities.

In the context of research experiences, future work will seek to characterize the culture of these research groups through interviews with other members and observations of the group in order to gain a more complete understanding of how research group culture impacts students' epistemic cognition. Additionally, this work focused on students conducting research within a single engineering department. Future studies will aim to understand the similarities and differences in epistemic cognition between research groups in other departments.

The interviews with students, conducted as part of this dissertation work, revealed differences in students' perceptions of the learning environment within the classroom and research lab. Many students perceived the research lab as an environment that was more conducive to creativity and curiosity compared to the classroom. Future work will seek to identify the aspects of the research lab and classroom that resulted in these different perceptions and seek to develop pedagogy to encourage students to be creative in the classroom environment. The similarities and differences between students' epistemic cognition in the context of the classroom and research environment will also be further explored to understand what students are transferring between these contexts.

5.4.4 Explore Other Methods to Understand Students' Epistemic Beliefs

Epistemic beliefs are tacit in nature, which creates many challenges when trying to study individuals' epistemic beliefs. The most common methods used to investigate an individual's epistemic beliefs are survey instruments and interviews; however, these methods are not without their limitations. Alexander et al. (2012) used an online task where students graphically represented and justified the connections between knowledge, information, and truth to explore students' epistemic beliefs. Drawing on this method, future work will seek to explore engineering students' epistemic beliefs using a task that has students graphically arrange a variety of terms to represent their beliefs about where knowledge comes from in engineering (see Figure 5.1). Students will be able to add and/or delete terms as they see fit, resize the circles to show the relative importance of the terms, and add arrows and move the circles to represent connections. Once they complete their graphical representation, the students will be asked to explain and justify their representation, so that the researcher can fully understand the students' representation and the students can further refine it.
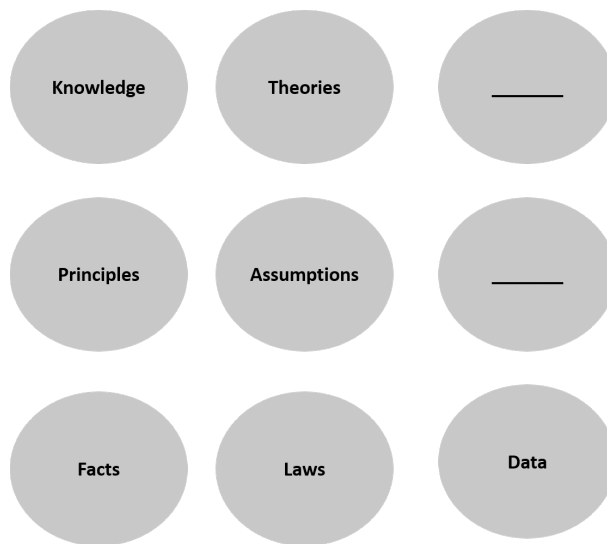
Figure 5.1: Graphical task to understand students' epistemic beliefs. Students can rearrange the circles, add or delete circles, and draw arrows to create a representation that is consistent with where they believe knowledge comes from in engineering.

A preliminary study was conducted using this task to ensure that students are able to complete the task. Two students' graphical representations are displayed below in Figure 5.2 to show the variety in students responses to the task. The results collected in the preliminary study have not been thoroughly analyzed. Future work will explore methods to analyze the data collected in the preliminary study and refine the task to develop a reliable approach to elicit students' engineering epistemic beliefs.
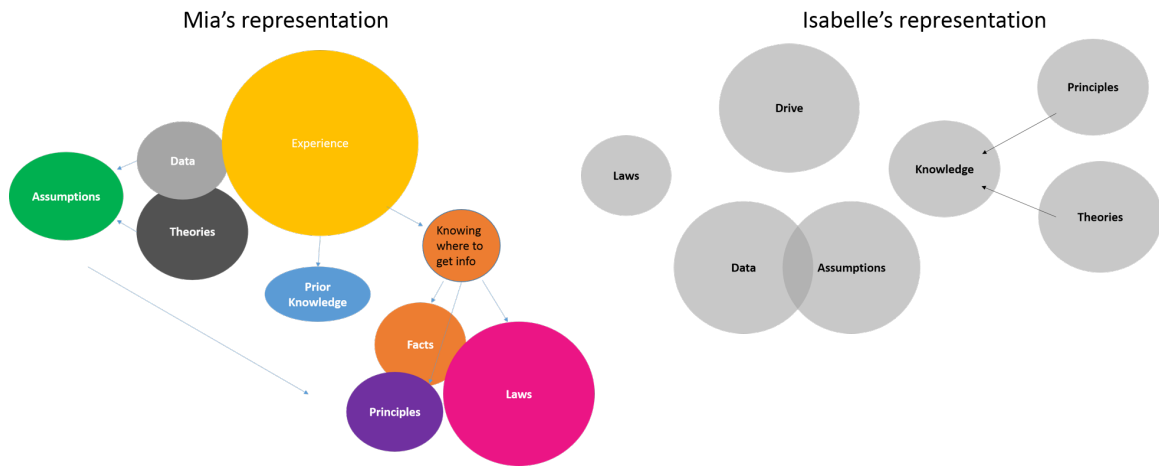
Figure 5.2: Two students' responses to the graphical representation task, displaying the variation in responses. The difference in colors between the two is because of a change in the instrument. The colored representation is version one and the gray is version two. This change was made to eliminate any bias introduced by colors associated with words.

Appendices

Appendix A Epistemic Beliefs and Motivation Survey

Qualtrics Survey Software

Default Question Block

Engineering Students' Beliefs about Knowledge and Knowing

We are interested in your beliefs about engineering knowledge. This survey consists of three parts. The first two parts are related to your beliefs about knowledge and knowing. The third part asks information about your background. Please make your best estimate for each item and answer as many questions as you can. There are no "right" or "wrong" answers.

Before you begin the survey, please download and read the information letter by following the link below.

93

Information for Participation in a Research Study
Clemson University

SPRITE: Student Perspectives on Researcher Identity and Transformation of Epistemologies

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Description of the research and your participation
You are invited to participate in a research study assessing undergraduate engineering students' research experiences, views of research, and epistemic beliefs. We are studying this through the use of open-ended surveys and interviews.

Your participation will involve completing an online survey. You may be asked to participate in up to two follow-up interviews. These interviews will be audio-recorded.

Risks and discomforts
There are no known risks associated with this research.

Potential benefits
Your information may benefit future students by helping us further understand students' thought processes during problem solving and make research programs more effective for undergraduate students at Clemson University. In addition, this research will be disseminated so that students and faculty at other institutions may benefit as well.

Incentives
For completing the survey, you will receive extra credit in biomechanics (BioE 3200). After completion of each follow-up interview, you will receive a $25 Amazon gift card.

Protection of confidentiality
We will do everything we can to protect your privacy. Your name will not be recorded in any way in the compiled survey, interview, or problem solving work. Your responses will be marked with a code. Only the Principal Investigators (Courtney Faber) will have the key which links your identity to that code, and this key will be destroyed as soon as all data have been collected and compiled. Your identity will not be revealed in any publication that might result from this study. The audiorecordings will be destroyed in January of 2019.

Voluntary participation
You may choose not to participate and you may withdraw your consent to participate at any time. Additionally, your decision whether or not to participate in the research will not affect your undergraduate career.

Exclusion Requirements
Participants must be at least eighteen years of age to be eligible to participate.

Contact information
If you have any questions or concerns about this study or if any problems arise, please contact Dr. Lisa Benson at Clemson University at 864.656.0417. If you have any questions or concerns about your rights as a research participant, please contact the Clemson University Office of Research Compliance at 864.656.6460.

94

Part I: Read each of the following statements and <u>decide how much each statement is like your attitudes, beliefs, and experiences.</u> It is important for you to realize that there is no "right" or "wrong" answers to these questions. People are different, and we are interested in how you feel.

	Strongly Disagree						Strongly Agree
Even after I've made up my mind about something, I am always eager to consider a different opinion.	○	○	○	○	○	○	○
I don't like situations that are uncertain.	○	○	○	○	○	○	○
I dislike questions which could be answered in many different ways.	○	○	○	○	○	○	○
I feel uncomfortable when I don't understand the reason why an event occurred in my life.	○	○	○	○	○	○	○
I feel irritated when one person disagrees with what everyone else in the group believes.	○	○	○	○	○	○	○
When I am confused about an important issue, I feel very upset.	○	○	○	○	○	○	○
In most social conflicts, I can easily see which side is right and which is wrong.	○	○	○	○	○	○	○
When considering most conflict situations, I can usually see how both sides could be right.	○	○	○	○	○	○	○
When thinking about a problem, I consider as many different opinions on the issue as possible.	○	○	○	○	○	○	○
I like to know what people are thinking all the time.	○	○	○	○	○	○	○
It's annoying to listen to someone who cannot seem to make up his or her mind.	○	○	○	○	○	○	○
I prefer interacting with people whose opinions are very different from my own.	○	○	○	○	○	○	○
I feel uncomfortable when someone's meaning or intention is unclear to me.	○	○	○	○	○	○	○
I always see many possible solutions to problems I face.	○	○	○	○	○	○	○
I'd rather know bad news than stay in a state of uncertainty.	○	○	○	○	○	○	○
I do not usually consult many different opinions before forming my own view.	○	○	○	○	○	○	○

Part II: Read each of the following statements and <u>decide how much each statement is like your beliefs and experiences</u>. Remember, there are no "right" or "wrong" answers; we are interested in how you feel.

In the text box below each item, please explain why you responded the way you did.

	Strongly Disagree						Strongly Agree
Principles in engineering cannot be argued or changed.	○	○	○	○	○	○	○
New engineering knowledge is produced as a result of controlled experimentation.	○	○	○	○	○	○	○
Engineering problems have only one right answer.	○	○	○	○	○	○	○
Engineering knowledge is an accumulation of facts.	○	○	○	○	○	○	○
The best way to develop engineering knowledge is by an engineering expert transmitting his or her knowledge to us.	○	○	○	○	○	○	○
There is one universal engineering method.	○	○	○	○	○	○	○
Engineering knowledge should be accepted as an unquestionable truth.	○	○	○	○	○	○	○
If your personal experience conflicts with 'big ideas' in a book, the book is probably right.	○	○	○	○	○	○	○
Engineering knowledge cannot be subject to change with new observations by individual engineering students.	○	○	○	○	○	○	○
Engineering textbooks written by experts present the best way to learn engineering.	○	○	○	○	○	○	○
A theory in engineering should be accepted as correct if engineering experts reach consensus.	○	○	○	○	○	○	○
Engineers can solve engineering problems by just following a step-by-step procedure.	○	○	○	○	○	○	○

Part II continued: Read each of the following statements and decide how much each statement is like your beliefs and experiences. Remember, there are no "right" or "wrong" answers; we are interested in how you feel.

In the text box below each item, please explain why you responded the way you did.

	Strongly Disagree						Strongly Agree
Traditional engineering ideas should be considered over new ideas.	○	○	○	○	○	○	○
Correct solutions in the field of engineering are more a matter of opinion than fact.	○	○	○	○	○	○	○
All engineering experts understand engineering problems in the same way.	○	○	○	○	○	○	○
Engineering knowledge is created only from an expert's logical thinking.	○	○	○	○	○	○	○

First-hand experience is the best way of knowing something in engineering.

You can count on the information you find in engineering books to be true.

Engineering students learn when a teacher or expert transmits his or her knowledge to them.

Words in engineering knowledge have one clear meaning.

Engineering knowledge should rely on a combination of experts' observation, experimental evidence, and rational arguments.

How many years have you been at Clemson University?

○ 1 year

○ 2 years

○ 3 years

○ 4 years

○ 5 years

○ 6+ years

How many semesters have you been involved in research?

○ 0 semesters

○ 1-2 semesters

○ 3-4 semesters

○ 5-6 semesters

○ 7+ semesters

Describe your role(s) on any research project(s) you have worked on. If you have not worked on a research project, type NA.

What types of career development experiences have you had? (Select all that apply)

- ☐ Research Experience for Undergraduates (REU)
- ☐ Creative Inquiry
- ☐ Departmental Honors Research
- ☐ Independent Research
- ☐ Co-op Experience
- ☐ Industry Experience
- ☐ Clinical Experience
- ☐ Other

What is your Clemson username? (This is the one that ends with @g.clemson.edu)

Appendix B R-code for quantitative analysis

```
pre <- read.csv("C:/Users/Owner/Dropbox/PhD dissertation/surveyresults.
    csv")
save(pre, file="C:/Users/Owner/Dropbox/PhD dissertation/survey results.
    RData")


#start here
load("C:/Users/Owner/Dropbox/PhD dissertation/survey results.RData")
library(psych)
library(fpc)
library(cluster)
library(car)
library(psy)


##List-wise deletion to handle missing data
pre<-na.omit(pre)


#recode items that were reverse coded in the survey
##ITEM 1
#1st recode to dummy variables
pre$q1<-recode(pre$q1,'1=12;2=11;3=10;4=4;5=9;6=8;7=0')
#recode to correct variables
pre$q1<-recode(pre$q1,'12=7;11=6;10=5;4=4;9=3;8=2;0=1')


##ITEM 8
#1st recode to dummy variables
pre$q8<-recode(pre$q8,'1=12;2=11;3=10;4=4;5=9;6=8;7=0')
#recode to correct variables
pre$q8<-recode(pre$q8,'12=7;11=6;10=5;4=4;9=3;8=2;0=1')
```

```r
##ITEM 9
#1st recode to dummy variables
pre$q9<-recode(pre$q9,'1=12;2=11;3=10;4=4;5=9;6=8;7=0')
#recode to correct variables
pre$q9<-recode(pre$q9,'12=7;11=6;10=5;4=4;9=3;8=2;0=1')


##ITEM 12
#1st recode to dummy variables
pre$q12<-recode(pre$q12,'1=12;2=11;3=10;4=4;5=9;6=8;7=0')
#recode to correct variables
pre$q12<-recode(pre$q12,'12=7;11=6;10=5;4=4;9=3;8=2;0=1')


##ITEM 14
#1st recode to dummy variables
pre$q14<-recode(pre$q14,'1=12;2=11;3=10;4=4;5=9;6=8;7=0')
#recode to correct variables
pre$q14<-recode(pre$q14,'12=7;11=6;10=5;4=4;9=3;8=2;0=1')


##ITEM 33
#1st recode to dummy variables
pre$q33<-recode(pre$q33,'1=12;2=11;3=10;4=4;5=9;6=8;7=0')
#recode to correct variables
pre$q33<-recode(pre$q33,'12=7;11=6;10=5;4=4;9=3;8=2;0=1')


##Item 30
#1st recode to dummy variables
pre$q30<-recode(pre$q30,'1=12;2=11;3=10;4=4;5=9;6=8;7=0')
#recode to correct variables
pre$q30<-recode(pre$q30,'12=7;11=6;10=5;4=4;9=3;8=2;0=1')
```

```R
#Build constructs
pre$closed<-(pre$q1+pre$q9+pre$q12+pre$q14+pre$q16)/5
pre$uncert<-(pre$q4+pre$q10+pre$q11+pre$q13)/4
pre$sourceknow<-(pre$q18+pre$q21+pre$q24+pre$q26+pre$q27+pre$q29+pre$q32
    +pre$q33+pre$q34+pre$q35)/10
pre$certknow<-(pre$q17+pre$q19+pre$q22+pre$q23+pre$q25)/5
pre$simpknow<-(pre$q20+pre$q28)/2
pre2<-subset(pre,select=c("certknow","sourceknow","closed"))


View(pre2)
#Calculate reliability simplicity of knowledge
cronbach(cbind(pre$q20,pre$q28))
#Calculate reliability source
cronbach(cbind(pre$q18,pre$q21,pre$q24,pre$q26,pre$q27,pre$q29,pre$q32,
    pre$q33,pre$q34,pre$q35))
#Calculate reliability cert
cronbach(cbind(pre$q17,pre$q19,pre$q22,pre$q23,pre$q25))
#Calculate reliability closed
cronbach(cbind(pre$q1,pre$q9,pre$q12,pre$q14,pre$q16))
#Calculate reliability amb.
cronbach(cbind(pre$q4,pre$q10,pre$q11,pre$q13))


##correlation source of knowledge
cor((cbind(pre$q18,pre$q21,pre$q24,pre$q26,pre$q27,pre$q29,pre$q32,pre$
    q33,pre$q34,pre$q35)),use="complete.obs",method="spearman")
##correlation cert
cor((cbind(pre$q17,pre$q19,pre$q22,pre$q23,pre$q25,pre$q31)),use="
    complete.obs",method="spearman")
##correlation closed
cor((cbind(pre$q1,pre$q9,pre$q12,pre$q14,pre$q16)),use="complete.obs",
```

```
                  method="spearman")
##correlation closed
cor((cbind(pre$q4,pre$q10,pre$q11,pre$q13)),use="complete.obs",method="
    spearman")


#Cluster Analysis
#Step 1 determine the number of clusters
wss<-(nrow(pre2)-1)*sum(apply(pre2, 2, var))
for (i in 2:15) wss[i]<-sum(kmeans(pre2, centers=i)$withinss)
plot(1:15, wss, type="b", xlab="Number of Clusters", ylab="Within groups
     sum of squares", main="Plot to Determine the Necessary Number of
    Clusters")


#K-means Cluster Analysis for 2 Clusters
fit<- kmeans (pre2, 2) #2 result of cluster solution
#get cluster means
aggregate (pre2, by=list(fit$cluster), FUN=mean)
pre3<-data.frame(pre2, fit$cluster)
View(pre3)


pre2<-data.frame(pre2, fit$cluster)


##Plotting Solution
clusplot(pre3, fit$cluster, color=TRUE, shade=TRUE, labels=2, lines=0)


#K-means Cluster Analysis for 3 Clusters
fit<- kmeans (pre2, 3) #2 result of cluster solution
#get cluster means
aggregate (pre2, by=list(fit$cluster), FUN=mean)
pre3<-data.frame(pre2, fit$cluster)
```

```r
View(pre3)

pre2<-data.frame(pre2, fit$cluster)

##Plotting Solution
clusplot(pre3, fit$cluster, color=TRUE, shade=TRUE, labels=2, lines=0)

#Centroid plot
plotcluster(pre3, fit$cluster)

#Calculating Group Means for Each Factor
#ambiguity Mean by Group
#aggregate(pre3$ambiguity~fit.cluster, data=pre3, FUN=mean)
#Closed-Mindedness Mean by Group
aggregate(pre3$closed~fit.cluster, data=pre3, FUN=mean)
#Simplicity of Knowledge Mean by Group
#aggregate(pre3$simpknow~fit.cluster.1, data=pre3, FUN=mean)
#Certainty of Knowledge Mean by Group
aggregate(pre3$certknow~fit.cluster, data=pre3, FUN=mean)
#Source of Knowledge Mean by Group
aggregate(pre3$sourceknow~fit.cluster, data=pre3, FUN=mean)
#Uncertanity Mean by Group
##aggregate(pre3$uncert~fit.cluster, data=pre3, FUN=mean)

#Calculating the number in each group
aggregate(pre3$sourceknow~fit.cluster, data=pre3, FUN=length)

pre4<-data.frame(pre3, pre$user.name)
View(pre4)
```

```r
#Calculating the difference between the 3 clusters on each construct
pairwise.t.test(pre4$certknow, pre4$fit.cluster, p.adj="none")
pairwise.t.test(pre4$sourceknow, pre4$fit.cluster, p.adj="none")
pairwise.t.test(pre4$closed, pre4$fit.cluster, p.adj="none")
```

Appendix C   Assigned Homework Problem

BioE 3200
Fall 2014
Homework #4

Due Tuesday, September 16, 2014

We started this in class, working on questions related to effects of osteoporosis on bone's stress-strain behavior. For HW 4, estimate a numerical answer to the question: **What are the combined effects of strain rate and age on bone strength of a 90-year old subject compared with a 20-year old?** Refer to handout from class as a starting point for information needed to complete this assignment.

Draw a graph to help explain and justify your answer. Your answer should be expressed as a percent difference between 20 year old and 90 year old bone strength.

Use the standard BIOE 3200 HW cover sheet; this should be a cue to include a statement (including assumptions), sketch/diagram, organized information, documented work (estimates, calculations, etc.) and justification of your answer (*very important for this assignment*). Cite references if you use other sources to justify your answer.

Some things to think about (although this is neither a required nor exclusive list of questions to consider):

- What are the individual effects of loading rate and and aging on bone strength? Are these effects at odds with each other?

- Can you estimate the strength of bone in a 20 year old and 90 year old?

- What assumptions do you have to make when deciding loading rate? Strength?

- Be prepared for your answer to be counter-intuitive. If it is, be sure that you can explain it given what you know about osteoporotic bone.

Case Study: Osteoporosis

Osteoporosis: "Porous bone"

- Caused by loss of balance between bone resorption and bone formation (remodeling)
- Results in:
  - o Decreased bone mass and density
  - o Reduced bone mineral density (BMD)
  - o Deteriorated bone microarchitecture
  - o Altered amount and variety of proteins in bone
- Roles of bone cells:
  - o Osteoblasts
  - o Osteocytes
  - o Osteoclasts

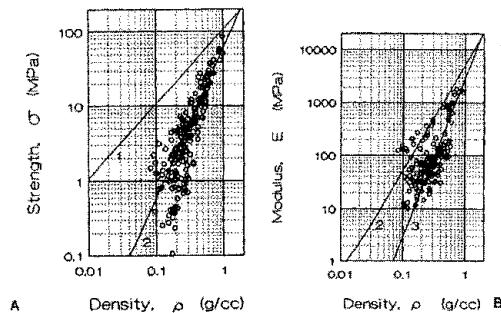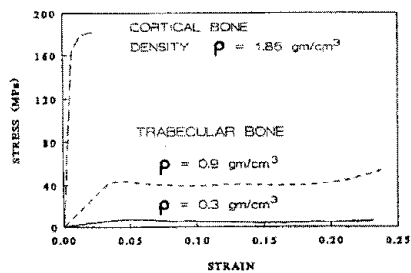*Bone Properties and Apparent Density*

FIG. 11. Compressive strength and modulus of trabecular bone as functions of apparent density: (A) compressive strength varies as a power-law function of apparent density with an exponent of approximately 2; (B) compressive modulus also varies as a power-law function of apparent density with an exponent ranging between 2 and 3. (From Hayes et al., ref. 63, with permission.)

- Under compression, trabecular bone has a long plateau (yield) on the stress-strain curve; trabeculae crush, fill in spaces, so there is little change in stress with large deformations.
- Bone properties depend on apparent density, which is the ratio of the mass of the bone tissue to the bulk volume of the specimen, including volume of vascular pore spaces.
- ρ_{app} for trabecular ranges from ~0.1 g/cm^3 (elderly spine), ~0.3 g/cm^3 (tibia), to ~0.5 g/cm^3 (load-bearing areas in proximal femur). ρ_{app} decreases with age after maturity (20 y.o.) at about 2%/year.

When conducting mechanical testing of bone, appropriate strength properties must be used to establish ranges for applied loads. These properties depend on both age and loading rate (as well as other factors). It is important in any analysis to account for these factors, since unexpected interactions can occur. For example, one could compare cortical bone strength for young healthy bone under slow loading rate condition (such as impact on the femur due to muscle activity during exercise) to that of cortical bone of an osteoporosis patient who experiences an unexpected fall (i.e. without protective maneuvers).

Question: What are the combined effects of strain rate and age on bone strength of a 90-year old subject compared with a 20-year old? Draw a graph to help explain and justify your answer.

Bone Mechanical Properties

Viscoelasticity of Bone

- Viscoelasticity: time-dependent material behavior
- Response of viscoelastic materials to loads depends on rate at which loads are applied
- For bone, elastic modulus and strength increase as loading rate increases
- Figure on right shows the strain rate sensitivity of healthy cortical bone for longitudinal tensile loading
- Majority of physical activities occur in relatively narrow range of strain rates (0.01 – 1.0 %)
  - Cortical bone assumed to behave elastically in this range
  - Increased stiffness and strength, and tendency toward more brittle behavior, become important factors in high strain rate situations such as a fall or high-speed trauma
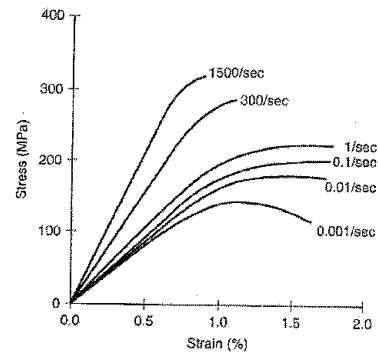
Effects of Age and Disease on Bone Strength, Strain and Elastic Modulus

With age and disease, like osteoporosis, bone stiffness and strength decrease, making the bone behave more like a brittle material. As shown in the figure below, tensile ultimate strength decreases every decade, from almost 5% strain at age 20 years to less than 1% at age 80 years. Old bone is more brittle than young bone, and therefore the energy to fracture (area under stress-strain curve before fracture) is much lower for old bone than for younger bone.

FIGURE 3.16 (a) Reductions of human cortical bone mechanical properties with age. Modulus is not reduced much, if at all, whereas strength is reduced more, at a rate of about 2 percent per decade. From Burstein et al. (1976) *J Bone Jt Surg* 58A: 82–86. (b) Ultimate strain decreases markedly with age, at a rate of about 10 percent of its young value per decade. From McCalden et al. (1993) *J Bone Jt Surg* 75A:1193–1205.
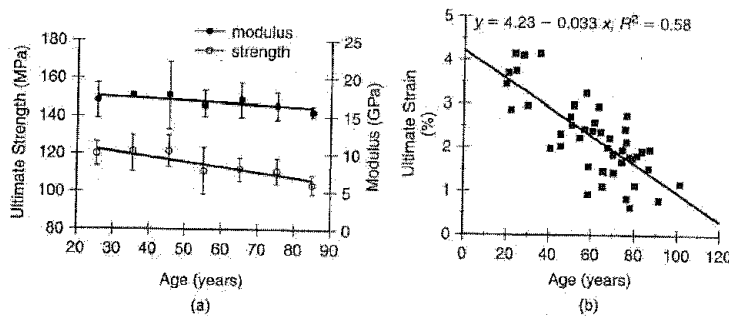
Figures and data from From Bartel, Davy and Keaveny, <u>Orthopaedic Biomechanics</u>, Prentice Hall, 2006.

Appendix D Interview Questions: Homework Problem

1. Please describe the process that you used to get to your solution.

2. Did you work alone or in a group on the problem? What was your role in working on the problem?

Follow-up questions about process

1. What strategies did you use?

2. How did you decide what strategies to use?

3. What information did you use?

4. How did you arrive at this process?

5. Where did you look for information?

6. How did you decide to stop when you did?

7. How did you decide what information to use when solving the problem?

Questions about problem solution

1. How would you justify your solution to another student? How would you justify your solution to an expert in your field? How strongly do you believe your solution reflects the truth?

Question about goal

1. What was your goal when you first approached this problem?

2. What, if anything, did you hope to gain by solving this problem?

3. Do you feel like solving this problem added to your knowledge?

4. Do you feel like solving this problem added to your understanding?

5. About how long did you spend on the problem?

6. Did you find the problem interesting?

General Problem Solving (think about context ie engineering)

1. How do you approach problem solving?

2. How is problem solving portrayed to you?

3. How do your teachers talk about approaches to problem solving?

4. How do your teachers talk about goals of problem solving?

5. How do your teachers talk about the purpose of problem solving?

Knowledge in Engineering

1. How do you develop your engineering knowledge?

2. How do you believe new engineering knowledge is created?

Appendix E   Interview Questions: Research Experiences

1. Tell me about the research experiences that you have had.

2. Tell me about the research you are doing this semester.

3. How did you get involved in this research?

4. What is the purpose of this research?

5. How did you select the specific topics/problems you are working on right now?

6. How did you decide on the specific methods to investigate these problems? How would you go about justifying the use of these methods?

7. How do you evaluate the success of your research?

8. What do you consider to be your best work? Why do you think it is your best work?

9. In the course of your research, have you performed experiments that have yielded unexpected results? (If yes) Can you give me some examples of such situations? How do you decide what to do next? How do you evaluate outcomes?

10. Has there been a time in the lab that you had to troubleshoot a problem? Can you describe that experience?

11. How do you know if your results are accurate?

12. How do you decide what results to publish?

13. When starting a new study, how do you decide what methods to use?

14. Do you feel like you are adding to the knowledge in your field of study?

15. What types of problems do you have to solve in the lab?

16. How do you approach problem solving in the lab?

17. How is problem solving in the lab portrayed to you?

18. What do you hope to gain from research?

19. How do you feel like your research is connected to your classes?

20. Do you feel like your research is engineering?

21. Do you feel like you approach research differently than your classes? If so what is different? Why do you take a different approach? If no, how are they the same? What if anything would make you approach them differently?

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