Understanding the Role of Academic Language on Conceptual Understanding in an Introductory Materials Science and Engineering Course

by

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A Dissertation Presented in Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

Approved April 2012 by the
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ARIZONA STATE UNIVERSITY

May 2012

ABSTRACT

Students may use the technical engineering terms without knowing what these words mean. This creates a language barrier in engineering that influences student learning. Previous research has been conducted to characterize the difference between colloquial and scientific language. Since this research had not yet been applied explicitly to engineering, conclusions from the area of science education were used instead. Various researchers outlined strategies for helping students acquire scientific language. However, few examined and quantified the relationship it had on student learning. A systemic functional linguistics framework was adopted for this dissertation which is a framework that has not previously been used in engineering education research. This study investigated how engineering language proficiency influenced conceptual understanding of introductory materials science and engineering concepts.

To answer the research questions about engineering language proficiency, a convenience sample of forty-one undergraduate students in an introductory materials science and engineering course was used. All data collected was integrated with the course. Measures included the Materials Concept Inventory, a written engineering design task, and group observations. Both systemic functional linguistics and mental models frameworks were utilized to interpret data and guide analysis. A series of regression analyses were conducted to determine if engineering language proficiency predicts group engineering term use, if conceptual understanding predicts group engineering term use, and if conceptual understanding predicts engineering language proficiency. Engineering academic language proficiency was found to be strongly linked to conceptual understanding in the context of introductory materials engineering courses. As the semester progressed, this relationship became even stronger. The more engineering concepts students are expected to learn, the more important it is that they are proficient in engineering language. However, exposure to engineering terms did not influence engineering language proficiency. These results stress the importance of engineering language proficiency for learning, but warn that simply exposing students to engineering terms does not promote engineering language proficiency.

This dissertation is dedicated to my husband and best friend, Cole Kelly.

I owe this accomplishment to his love, support, and inspiration.

I am forever grateful.

ACKNOWLEDGMENTS

There are many individuals who enter and exit one’s life. Some we may hardly notice while others leave lasting impressions. Some provide good company while others change the way we think and live. The following individuals, through my academic experiences, have left lasting impressions on me and helped me grow into who I have become.

To Dr. Dale R. Baker, my dissertation committee chairperson, thank you for teaching me how to open my mind about education. At the start of my graduate studies you taught me how to question and challenge reality. Throughout my practice, you pushed me so that I could grow academically in ways that I did not know I could.

To Dr. Tirupalavanam Ganesh, my dissertation committee member, thank you for your kindness and motivational support. You helped me to remember that I was more than capable of completing this work.

To Dr. Stephen Krause, my dissertation committee member, thank you for providing the opportunities that you did for my graduate education. I am thankful to you for securing grant funding and to NSF for funding this work. Those opportunities have allowed me to move throughout my education with intention and direction.

To Dr. Edward Price, my undergraduate advisor, thank you for originally introducing me to the world of physics education research. Without you, I

wouldn’t have even known that my current passion existed. Thank you for helping me to realize, early in my studies, that I was capable of achieving anything regardless of what others said. Your continued guidance has pushed me to achieve things far greater than I ever imagined. Thank you for being, and continuing to be, such an inspiring mentor.

To Sandhya Sinha, my friend and patient editor, thank you for reading and rereading every word of this dissertation, for listening when I needed it most, and for being my cheerleader. Your edits helped me achieve clarity. Your friendship helped me cope with my stresses and succeed even when circumstances were difficult.

To my friends and family, who provided unwavering support, thank you for listening and supporting me throughout this entire process. And, above all, thank you to my husband, Cole Kelly, for all the sacrifices made that allowed these studies to be possible, the encouragement that helped me maintain my sanity, and the unfailing support that kept me motivated.

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INTRODUCTION

Background of the Study

The National Academy of Engineering (NAE) released two publications detailing significant developments in the field of engineering and how these developments will change the way future engineers should be educated. In 2004, *The Engineer of 2020* was published, highlighting the changing work environment for future engineers (National Academy of Engineering, 2004). A focus of this book is the change from local to global engineering. It discusses how an engineer of 2020 needs to be able to operate with a global perspective, be able to work on international teams, analyze the worldwide impact of their projects, and create global solutions. Four years later, NAE published the *Grand Challenges for Engineering* (National Academy of Engineering, 2008). These grand challenges, including making solar energy economical, managing the nitrogen cycle and securing cyberspace, reinforced the necessity for global and large scale engineering worldwide. Focusing on global problems requires a common speech not only within a common language such as English, Spanish, or Chinese, but also within a more specific academic engineering context. The common engineering speech must be operationally defined and so precise that the terms retain their meanings even across various global languages. This makes it crucial that engineers “speak engineering” and that engineering speak is examined just as a second language acquisition would be. In order to understand this academic language acquisition process within the classroom, we must first understand traditional language development and then explore how the differences between colloquial and academic language effect this development.

Statement of Problem/Rationale

Students can use technical language consistent with engineering norms yet may not know the meaning of these words. This phenomenon was examined in science classrooms by several researchers. In his book *Talking Science* (1990), Jay Lemke observed a series of teacher-student interactions in high school science classrooms. From this work, he developed a list of stylistic norms associated with "talking science." He found that science language values explicit statements, universal claims, technical terms, and use of symbols in speech. On the contrary, he found that science language discourages use of colloquial terms, personification, metaphorical statements, and emphasis on science as a social endeavor. Lemke concluded from his work that the differences in scientific and colloquial language not only discourage science learners but create confusion when communicating concepts. In a literature review of twenty-five previous years of research on scientific language in classrooms, Yore, Bisanz, & Hand (2003) reported that the general trends found were that very few students were able to use vocabulary and language patterns consistent with scientific norms even following science instruction. These trends provide evidence that science students often cannot use technical language to describe and predict phenomena.

However, little work has been done in the context of engineering which requires students to use engineering terms and understand natural science concepts, while also clearly articulating and understanding these concepts with respect to engineering applications. Consider the scientific concept of metallic bonding. One student may describe metallic bonding as, “stationary positive ion cores mutually sharing delocalized electrons” while another student may provide the description, “the electrons float around and the positive parts share them.” While referring to similar phenomena, the first description uses language more consistent with scientific norms than the second. However, for engineering language, this is not where the understanding or language ends. Engineering requires students to relate their understanding of the described micro-scale phenomena to macroscopic properties, processing, and material applications. Engineering language emphasizes these relationships. For example, a student may provide a description such as “the delocalized electrons being shared by the stationary positive ion cores suggest applications that may require high electrical conductivity such as those in electronic or semiconductor devices”. This description is an example of engineering language because it uses the normative technical language of materials engineering and emphasizes the micro-macro connection between material structure, properties, and application.

Consequently, student understanding of science and engineering concepts is not of isolated importance. Students must also become capable of speaking and communicating about concepts accurately, appropriately, and meaningfully so that they can engage in the engineering design process. The challenge in acquiring academic language may result because language in the context of a science or engineering classroom is not necessarily consistent with everyday, colloquial language. Vygotsky illustrated this point by distinguishing between everyday concepts and scientific concepts (Vygotsky, 1986). Everyday concepts, he said, are those that are learned spontaneously and through experience. However, scientific concepts are those learned through explicit and formal instruction. Vygotsky described how native languages are like spontaneous concepts while second languages have characteristics of scientific concepts. While everyday and scientific concepts are different, he argued that they are related such that the development of scientific concepts scaffolds on the understandings of everyday concepts. This, he said, was also the case when learning an additional language. Student proficiency in the second language, such as engineering language, will be dependent on (1) an understanding of the first language, English, and (2) the degree to which it is explicitly taught. So, in terms of an engineering or science course, for students to "speak science" or "speak engineering", we must treat language as a scientific concept and explicitly teach students the languages of science or engineering.

Due to the importance of language in the field of engineering, it is imperative to examine what role student engineering language acquisition plays in conceptual understanding. An understanding of the language-concept relationship will help answer the questions of whether students who are able to speak and communicate like engineers are more capable of thinking and engaging in engineering applications than those who struggle with engineering language acquisition.

Purpose of the Study

The purpose of this study was to understand the relationship between academic language proficiency and conceptual understanding in engineering courses. In this study, conceptual understanding, academic language proficiency, academic language use, and predictors of language proficiency were used to gain insights to the relationship being explored.

To fulfill the purpose of the study, thirty-five students in an introductory materials science and engineering course were observed. At the start and end of the semester, students were given the Materials Concept Inventory in order to assess their conceptual understanding. Four times throughout the semester, an engineering written design task was administered, asking students to use as much of their engineering knowledge and vocabulary as possible to discuss the design of a bicycle. The engineering design task was then analyzed to understand student conceptual understanding and academic language proficiency. Student language use was monitored during in-class group work in order to understand the frequency of technical language used throughout their group interactions. This was done by recording the number of technical terms used for a set observation time. These observations allowed for understanding how often students used or were immediately exposed to academic language throughout the learning process. Additionally, a demographic survey was administered to find out if students had previous experience with engineering academic language through other courses. The survey also assessed whether students were proficient in multiple languages in order to determine if this provided an advantage when learning academic language. For the purpose and context of this study, academic language in the context of engineering will be referred to as *engineering language*.

Research Questions

To examine the overall role of engineering language development on conceptual understanding of introductory materials science and engineering concepts, several research questions were identified:

Research Question One: How does exposure to engineering language through peer discussion during team tasks influence proficiency of individual engineering language in the context of an engineering design task?

Research Question Two: How does exposure to engineering language through peer discussion during team tasks influence conceptual understanding in the context of an engineering design task?

Research Question Three: What is the relationship between conceptual understanding and engineering language in the context of an engineering design task over the course of a semester?

These questions will provide insight into how engineering language influences conceptual understanding in an introductory materials science and engineering course.

Chapter 2

OVERVIEW OF RELEVANT LITERATURE

Introduction

This literature review outlines models for language development and mental models relevant to student learning in science and engineering classrooms. First, models for development of language are presented. These models provide a foundation for understanding how students acquire language in the classroom. Second, foundations of scientific literacy and scientific academic language are discussed. Third, models to develop scientific and academic language are presented with a focus on scientific language acquisition and development. Fourth, systemic functional linguistics and mental models are identified and discussed as dual conceptual frameworks for this study.

Language Development

To understand academic language and its acquisition, it is necessary to first examine literature in the area of language development. Yeung and Werker (2009) studied how young children learned sounds with relatively little instruction. They discussed that previous literature supported the claim that infants learned to distinguish sounds based on statistical frequency analysis of auditory input. However, in a series of three experiments, they found that learning to distinguish sounds was dependent not only on frequency of input, but also on visual cues provided during input (Yeung & Werker, 2009). This suggests that infants who are given clues to the functionality of sounds upon encoding are more likely to distinguish, or learn the sounds. This finding is consistent with cognition literature on memory. Patalano and Seifert (1997) identified the usefulness of predictive encoding. They found that at the time of goal setting, students are more likely to recognize opportunities to achieve their goals if they are presented with cues, or tools and strategies, to do so at the time of encoding. These two ideas show that in learning, students must not only be taught words, but also taught the meaning and utility of words upon their introduction. In an engineering classroom, for example, this requires that when teaching students about the measureable property, strength, students are not only told what it means, but are given opportunities to see how it is used to characterize materials, guide material selection, or test material failure conditions. However, though helpful to recognition, these functional cues alone do not ensure students understand word meaning.

Assumptions that learners draw from these functional cues may promote incorrect understandings of word meaning. Markman (1991) discussed three assumptions made by language learners that inhibit understanding of word meaning: the whole object, the taxonomic, and the mutual exclusivity assumptions. The whole object assumption, made by language learners, applies a word to the entire object rather than a category it exists in or as a descriptor of its individual parts. For example, if someone uses the word boat under whole object assumption, the language learner assumes that boat refers to the entire object. In this case, the assumption does not inhibit understanding of word meaning. However, if the language learner used the word deck, assuming it to reference the entire boat, the whole object assumption would hinder the understanding of word meaning. The taxonomic assumption causes language learners to apply a word to objects similar to the object the word describes. If the language leaner utilizes the taxonomic assumption they may assume that the word boat describes other large objects with similar properties that float on water. This assumption may hinder learning of word meaning because it treats words as categories rather than specific, isolated meanings. The mutual exclusivity assumption allows language learners to assign labels to parts of objects, or to objects that may not belong in general categories (Markman, 1991). For example, rather than call every object that floats in water a boat, a learner may learn to distinguish rafts, jet skis, or cruise ships. While these things all fulfill the general requirements of a boat, they are mutually exclusive of each other. This assumption may hinder word comprehension when language learners assume that words that describe categories of objects are intended for only specific items. If a student assumes the word vehicle applies to only a car, for example, the learner will not understand that vehicle can refer to any object that is used for transportation purposes. These three types of assumptions are also in use when students learn scientific language. During the learning process, students are exposed to many new terms. It is possible that students apply these assumptions as they learn and assimilate new scientific and engineering terms. Without feedback, students may compromise proper encoding processes, allowing these assumptions to hinder learning.

Language and Learning

While summarizing the role of language on learning, Halliday (1994) identified seven views of education from a language perspective. First, he suggested that learners always construct knowledge. This is consistent with constructivist perspectives on education. Constructivism is not representative of a single theory, but rather is a category that describes many theories of learning and cognition that operate under two general assumptions: that learners enter classrooms with prior knowledge and experience about how the world works and that learners construct new knowledge as it somehow interacts with prior knowledge and experience (Driscoll, 2005). Halliday (1994, p. 15) argued, however, that a result of this continuous knowledge construction is the perpetual need for "new dimensions of semantic space." Second, the learner adapts multiple perspectives about their experience: one perspective identifies experience as a process and another defines experience as an object. For example, consider a student experiencing, through observation, a tensile test in introductory engineering. The student perceives the experience both as an object and a process. The perceived object is the tensile test, itself, including the utility, components, and information gathered from the test. The perceived process is the actual conducting of the test, or the tensile testing. This includes the actions associated with the experience and an understanding that it occurred as a process. Third, the learner realizes that learning is a communicative process where the intended audience must be determined and that the audience influences how the internal meaning of knowledge is expressed. For example, the student expresses his knowledge about the tensile test experience differently to his friends than he does to an instructor. Fourth, learners understand written language and reinterpret it as their conceptual understandings improve in order to develop higher level knowledge. If our student from the previous example encountered text about tensile tests following his experience, the learner could utilize his experiences in order to construct more complex knowledge about tensile tests. Fifth, learners engage and communicate to others what they are internalizing in their minds. Sixth, learners create language from experience and synthesize experience from language in order to develop knowledge. For example, the tensile test experience likely allowed the learner to develop additional language terms. Additionally, his previous understanding of language provided tools for understanding and encoding the experience. Lastly, learners are "developing the metafunctional foundation on the basis of which knowledge itself is constructed (1994, p. 16)." In other words, as students learn, they are mimicking the construction of human knowledge as an entity. So, for our tensile test observer, the methods and ways he learns simulate those that were used by the original discoverers of knowledge about tensile tests and their functionalities. These relations between language and knowledge, according to Halliday, are required in order for students to learn and become literate in any knowledge area.

Language Proficiency for Scientific Literacy

Scientific literacy has been emphasized as a goal of science education, thus gaining attention from educational researchers. However, there are inconsistencies in the way in which scientific literacy is defined. Definitions of scientific literacy range from being able to understand science, to understanding what science is and include the ability to perform scientific tasks, calculations, and thought processes (Norris & Phillips, 2003). Norris and Phillips (2003), however, argued that these views of scientific literacy are restrictive. In an article striving to operationally define scientific literacy, they argued that scientific literacy has two discrete components. The first is the fundamental sense, reading proficiency, writing and language in the context of science and second is the derived sense, understanding the concepts and nature of science. They then described six reasons why written language is related to scientific thought as a justification for their duel view of scientific literacy. First, scientific literacy includes tools for allowing readers to understand scientific texts. This requires students to understand fundamental strategies for reading and interpreting scientific writing. Second, scientific literacy requires that readers realize that scientific texts are interpretative and require external knowledge to understand. Norris and Phillips (2003) suggested that this occurs by ridding the learner of an authoritarian view of texts and teaching the learner that the meaning of the text is dependent on external information. Third, scientific literacy includes understanding that text is essential in science because theory cannot develop without it since text is the primary record keeping tool of the field. Fourth, scientific literacy requires an understanding that the interpretations of texts change though the words themselves remain the same. Fifth, though interpretation and reinterpretation is possible, scientific literacy includes understanding the specific words, meanings, phrases, and data enough to understand the degree to which reinterpretation is possible. Sixth, scientific literacy includes an understanding that science as a body of knowledge is dependent on text, interpretation and reinterpretation and an understanding of the degree to which reinterpretation can occur over time. These six tenants of scientific literacy mix both a fundamental view of grammar in scientific writing and scientific content knowledge to justify that scientific literacy requires a solid foundation of written language.

However, written language is not the only facet of language needed for establishing scientific literacy. Yore and Bisanz (2003) stated that school science classes often describe mathematics as the language of science. However, Yore and Bisanz (2003) argued that written and oral forms of language are most prominent in science because scientists most often share research through writing and oral presentations. Lemke (1998) supported this idea, claiming that in order to do science one must manage the multiple representations associated with being a scientist including verbal discussion, scientific performance tasks, mathematical operations, and graphical and visual representations. In his book, *Talking Science: Language, Learning, and Values*, Lemke (1990) observed science classrooms to understand scientific discourse. He found that students in science classes are not often taught how to use verbal scientific language. In contrasting verbal scientific language to every day colloquial language, Lemke found that verbal scientific language often uses passive voice, abstract nouns, abstract verbs, analogies, rhetorical devices, and multiple modes of communication. These complex semantic structures, Lemke said, are often only implicitly taught to students, most through instructors modeling these verbal skills in the classroom. He argued that "the mastery of a specialized subject like science is in large part mastery of its specialized ways of using language" (Lemke, 1990, p. 21). These arguments establish the difference between scientific and colloquial language, the importance of language in scientific literacy, and stress the importance of paying attention to and providing instruction about written and verbal scientific language.

Developing Scientific Language

As discussed in the previous section, scientific language varies from colloquial language and requires emphasis throughout science and engineering education. But how do students develop scientific language? In some cases, there are parallels between primary language acquisition and science language acquisition. In primary language acquisition gestures preceded words aided with inferences (Garham & Kilbreath, 2007). Often, language learners could use gestures such as pointing prior to being able to say words such as “here” or “there”. Young children often reach for objects prior to being able to use words to describe them, or make frantic gestures when wanting more of something prior to being able to ask for more verbally. Roth (2000) observed similar phenomena in a science classroom when examining the language development of science students. He observed that students’ gestures in science preceded their utterances to describe scientific phenomena. Roth observed a class of middle school science students to examine how gestures and language influenced cognitive development of introductory physical science topics. He found that students first exhibited understanding of concepts such as relative position first by pointing and moving objects and then later by using language to describe phenomena. Initially, students used words such as “here” or “there” with their gestures. Only after using gestures repeatedly did they begin using terms more consistent with scientific norms. He found that, as students became more proficient in scientific language, gestures were used to support utterances. This, he claimed, provided evidence that scientific language is a second language (Roth, 2000).

How can scientific language fluency be determined or assessed? In his book, Lemke (1990) defined language fluency as the degree to which one can interact in the scientific community. He outlined four strategies for teaching students how to talk science. First, he argued that students need time to practice discussing science. This, he said, must occur in situations that allow for lengthy dialogues. Unfortunately, students are not currently given these opportunities. After observing thirty lessons across middle and high school science classrooms, Newton, Driver, and Osborne (1999) found that less than five percent of classroom practice was spent on discussion. In examining the role of group work on learning, Kemp and Ayob (1995) collected writing samples for performance tasks following group work where students were asked to interact with each other verbally. They found that forty percent of ideas reflected in student written responses were formulated during group discussions. Even students who did not verbally participate in the group benefitted from the group interactions (though less than active language users), suggesting that exposure alone to oral scientific language use was beneficial for student learning. Second, Lemke suggested that students are taught to use multiple science terms to form complex sentences through explicit semantic instruction in both verbal and written form. This instruction is necessary to guarantee that students receive the appropriate functional cues, contexts and examples to aid in the understanding of words’ functions in order to achieve proficiency (Ptalano & Seifert, 1997; Yeung & Werker, 2009). While scientific discussions may provide sufficient auditory cues for language acquisition, classroom instruction tends to provide more opportunities for written functional cues. Lemke suggested having students work through explicit teaching activities verbally and then finish with a written summary. These sorts of explicit instruction, Lemke (1990) argued, help students understand the flexibility of science language and construct scientific language in a way that promotes scientific literacy. Third, students must discuss their preconceptions for every topic addressed. Lemke (1990) argued that by comparing the way students talk about topics and the way science talks about topics is necessary for student understanding of science because it allows for students to accurately interpret the language being used for both explanations. This prevents them from dismissing a scientifically normative view of a concept purely because there was a misinterpretation of the language used to describe it. Lemke’s fourth and final recommendation for teaching students to gain fluency in scientific language is to teach students about the different genres of science. He described two different genres: the major genre including lab reports, articles, and texts; and the minor genre including descriptions, comparisons, and observations. As before, he claimed that explicit instruction in these areas is necessary and that each genre needs equal emphasis. This view is shared by Halliday and Martin (1993), as they decided it was necessary in order for students to learn the power and fluidity of science through texts. In describing the literacy events that college science students most often engage in, Parkinson (2000) found that students are most often asked to engage in experimental research and write ups, lab experiences including lab manuals, tutorial sessions and problem solving, lectures with lecture notes, tests, problems, calculations and essays. Of all these events, students engaged in writing summary-based lab reports 85% of the time (Braine, 1989). While writing descriptive lab reports may give students a variety of functional cues for scientific language, it neither provides the necessary auditory cues nor the explicit instruction about scientific writing and genre for understanding new scientific language. Consequently, based on Lemke (1990; 1998), and Yeung and Werker's (2009) recommendations, simply writing lab reports does not give students adequate opportunities to learn the language of science.

Lemke identified a strong barrier to learning scientific language as being "a lack of student realization that scientific language and colloquial language are not the same even though they both use English" (1990, p. 172). He provided two suggestions for helping students move comfortably from colloquial to scientific language. First, Lemke suggested that instructors frequently use and translate between colloquial and scientific language. He recommended explicit activities that require students to translate scientific language to colloquial language and vice versa. Second, Lemke suggested using a variety of linguistic styles when teaching science including humor, irony, metaphor, fiction and others as well. This is supported by Prain and Hand (1996) who stated that allowing students to write in multiple styles and genres supports a constructivist view of knowledge which is widely used throughout various educational fields. Lemke (1998; 1990) and Prain and Hand (1996) both emphasized the importance of teaching students when specific genres are appropriate and argued that students must identify when certain genres are required. Though Lemke (1990) established guidelines for learning and becoming proficient in scientific language, there are also additional and more substantial pedagogical models, such as the Cognitive Academic Language Learning Approach, that have been developed to support academic language acquisition.

Cognitive Academic Language Learning Approach (CALLA)

With diverse populations entering the classroom, there is a need to examine teaching language in the context of various academic areas. Recognizing the importance of teaching language in context, the Cognitive Academic Language Learning Approach (CALLA) was created (Chamot & O'Malley, 1987; 1996). CALLA incorporates theoretical frameworks for learning and cognition and adapts them to prepare second language learners for learning participation language in academic settings. The three principles of CALLA include a total emersion curriculum for learners, language development for specific content areas, and instruction about various learning strategies (Chamot & O'Malley, 1987; 1996). Though scientific language uses the same words as English, Lemke described the nature of learning scientific language for students:

> The language of science is not part of students' native language. It is a foreign "register" (specialized subset of language) within English and it sounds foreign and uncomfortable to most students until they have practiced using it for a long time. (1990, p. 172)

While CALLA was developed with non-English speakers in mind, based on Lemke's description of scientific language this model can ensure students acquire science or engineering language literacy by adapting it to this task. Total emersion gives opportunities for engineering students to gain exposure to and experience with engineering technical language. Language development specific to engineering and science application helps students understand engineering language in appropriate contexts and learn how and when to use particular engineering technical language. Also, teaching learning strategies helps students learn how to monitor the assumptions and definitions that they are creating about the new terms and words being introduced.

CALLA consists of a five part instructional cycle to allow teachers to best promote academic language development, though developers cautioned that these stages may not occur linearly as the learning process is iterative. The first stage is preparation. During this stage, students are asked to describe their prior knowledge about a particular topic. While in this stage, students are encouraged to use their conceptions from their original language and explain content as best as they can while using academic language. For development of scientific language, this pushes students to draw upon knowledge using colloquial English and express it to the best of their abilities in scientific English. For students who are learning when English is not their first language, additional intermediate steps may be required since using colloquial English is not a native language. In these cases initial expression is in their native language and later in colloquial English. At this point in the instructional cycle, the teacher is not to correct any language use, but to encourage students to engage as much as possible. Chamot and O'Malley (1996) argued that this allows students to see connections between their native and academic language. The second stage in the CALLA instructional cycle is presentation. In this stage, new information is transmitted to the student. Under the CALLA model, this new information is both content and language focused. New content is supplemented with new language and introduced with visual cues. Chamot and O'Malley (1996) suggested that the teacher models verbal and comprehension skills so that the students can understand what thought processes are necessary for verbal and written comprehension. For scientific language development, this requires using both colloquial and scientific terms and explicitly discussing their similarities and differences as well as modeling comprehension of scientific texts. The third stage in the CALLA instructional cycle is practice. In this stage students practice speaking, writing, and discussing the strategies they are implementing in order to use academic language. Often, Chamot and O'Malley (1996) concluded, this is done though group interactions. The fourth stage in the CALLA instructional cycle is evaluation. However, the emphasis is on student self-evaluation rather than on summative assessment. While instructors will gain knowledge on student progress, the purpose of this stage is to develop self-evaluation strategies. Chamot and O'Malley (1996) suggested that self-evaluation may take place in various areas of learning such as science content, language proficiency, strategies that helped acquire academic language or anything else students feel is influential for their learning. This metacognitive component was not part of Lemke's recommendations, but may have great impact on scientific language acquisition (Anderson, 2002). The final stage of the CALLA instructional cycle is expansion. In this stage, students are encouraged to find connections between the new information they have learned and their native language and culture. In the development of scientific language, this may mean finding connections between colloquial language and scientific language and knowledge or a connection between past experiences and scientific language and knowledge. Chamot and O'Malley (1996) also suggested that during this stage students should determine which learning strategies were most effective for them. Overall, the CALLA instructional cycle and Lemke's recommendations are similar. However, CALLA introduces components that are crucial for language development: metacognition and self-regulation.

The CALLA model for teaching academic language in science was implemented in the Arlington Public School System and examined over a five year period (Chamot, 1995). Chamot found that middle school aged students who participated in CALLA based instruction demonstrated higher achievement on both science performance tasks and grades in introductory high school science courses than those who did not participate in CALLA based instruction during middle school. Similar results were found in a sample of middle school English language learners by using a similar approach called the Cognitive Language Academic Proficiency (CLAP) approach to teach science skills (Klenk, et al., 2007). CLAP strategies, very similar to those in CALLA, were used to introduce students to an engineering design task about electrical conductivity. Student understanding was high when assessed through focus groups and content-based assessment. Utilizing similar methods as described by CALLA and CLAP, Parkinson outlined the implementation of a language course for science students (Parkinson, 2000). This course was developed in South Africa for a disadvantaged population. The course aimed to create experiences and opportunities for students to communicate as part of a scientific community with the intention of improving scientific language literacy. Students read papers and discussed them in groups, went on field trips and wrote and shared essays, examined and modeled data together, designed experiments and reported results as a community (Parkinson, 2000). After the course, students exhibited higher proficiency in scientific language. This study acts as a possible approach for strengthening student scientific language acquisition. These studies emphasized the apparent link between cognition and language, by showing that language acquisition requires emersion, instruction targeting language itself, and the teaching of strategies specific to learning language acquisition.

Pedagogical Implications for Teachers

Though this study will not explicitly incorporate the CALLA instructional cycle or Lemke’s (1990) recommendations for learning scientific language, it is necessary to understand them in order to explain and provide insight about student scientific language proficiency. Awareness of academic language allows teachers to develop and evaluate it. Achugar, Schleppegrell, and Oteiza (2007) engaged in three professional development activities for teachers to help them become aware of and understand how to better teach academic language in their classrooms. The first project, The California History Project, helped history teachers develop strategies to teach language through analysis of semantics and syntax of text passages. The project included teachers discussing why words were used in various situations and what the words meant or how the words could inform them about the historical context. Students in classrooms where teachers used this approach were more proficient in language and better able to construct thesis statements with strong supporting evidence (Achugar, Schleppegrell, & Oteiza, 2007). The second project, The Institute for Learning, took a group of history teachers and focused on reading historical texts and interpreting them through a rhetorical lens. The Institute for Learning required teachers to think about the relationships among words in sentences and the implications that each word had in terms of historical context and historical meaning. Workshop leaders also asked teachers to reflect and identify what and why certain sections of text are difficult for students not proficient in historical academic language. After the workshop, teacher reflections indicated that teachers felt more confident to use language explicitly to help students understand the nature of history and felt less pressured to decipher text for students (Achugar, Schleppegrell, & Oteiza, 2007). The third teacher workshop was held with pre-service Spanish teachers. To help students with academic writing, teachers were taught to have students focus on writing about themes and structure rather than experiences and grammar rules. This, they claimed, enables students and teachers to understand the impact of language on overarching meaning instead of focusing on superficial grammatical rules (Achugar, Schleppegrell, & Oteiza, 2007). Workshops such as these enable instructors to understand the importance of academic language in learning and enable them to develop and implement strategies for utilizing academic language to further their teaching goals.

Theoretical Framework

In a literature review of twenty-five years of research in scientific literacy and in the book *Language and literacy in Science Education*, authors reported that there has been little research on the relationship between verbal scientific language and science learning (Yore & Bisanz, 2003; Wellington & Osborne, 2001). Though both authors reported adequate literature with respect to verbal interactions, little was found relating to the specific interaction between this discourse and student learning.

In the present study, the relationship between academic language development and conceptual understanding was examined. To do so, a multifaceted conceptual framework was required. This framework was created by drawing from academic language development research as well as conceptual understanding literature. To understand academic language development, a systemic functional linguistics framework was adopted. For interpreting conceptual understanding, a mental models framework was used. Both are described in the following sections.

Mental Models

The goal of all science instruction is to move students towards a normative view of how the world works. Engineering classrooms aim to transition students towards understanding applications of these fundamental theories of the universe. “To comprehend what we are taught verbally, or what we read, or what we find out by watching a demonstration or doing an experiment, we must invent a model or explanation for it….” (Holliday, Yore, & Alvermann, 1994, p. 877). Students are often described as creating models of concepts to explain and predict phenomena. There are five different types of explanations: intentional, descriptive, interpretive, causative, and predictive (Gilbert, Boulter, & Rutherford, 1998). These explanations are defined in Table 1.

Table 1

Types of Explanations for a Functional Mental Model

Type of Explanation	Description of Explanation
Intentional	identifies importance and relevance
Descriptive	describes behavior or phenomena
Interpretive	identifies relationships such as categories, classifications, or comparisons
Causative	identifying cause of behavior or phenomena
Predictive	predicts similar situations or phenomena

Intentional explanations are those that provide justification of relevance and importance. An intentional explanation in science and engineering is created in response to a question like “Why are you doing that experiment?” or “Why are you choosing that material for the intended design?”. Gilbert, Boulter & Ritherford (1998) discussed that this occurs in science as students realize that choices are made intentionally, whether they are choosing a topic of study, a specific design, or experimental procedure. Descriptive explanations answer how the phenomenon behaves. In science and engineering, descriptive explanations are often produced over time. For example, over the course of scientific experimentation, descriptive explanations are produced before, during, and after some process. Often descriptive explanations are categorized and classified within students' frameworks of thinking by examining similarities of differences between them (Gilbert, Boulter, & Rutherford, 1998). Interpretive explanations enable these classifications and comparisons. They include understanding what various components of the observation are called, what they look like, and how they are organized. These skills allow for categorizing and classifying. Causative explanations describe what induces the specific phenomena. This requires the learner to develop a reason for why a particular phenomenon occurred. For example, if a student observed that a ceramic plate broke when hit with a hammer (a descriptive explanation), the causative explanation attempts to explain why the impact from the hammer caused the plate to break. Predictive explanations generate likely hypotheses about comparable situations or similar phenomena. In the hammer and plate example, a predictive explanation hypothesizes, for example, how other ceramics react when hit with a hammer. Of these five types of explanations, it is apparent that some are easier to produce than others. A descriptive explanation, for example, only involves reporting back observations. Creating an intentional explanation, however, requires contextual information. And, even more complex, interpretive, causative and predictive explanations require synthesis and application of other multiple experiences.

An explanation produced, regardless of type, is either acceptable or faulty. An acceptable explanation is one that promotes further discussion or questioning and is plausible, concise, generalizable, and fruitful (Gilbert, Boulter, & Rutherford, 1998). If an explanation is not plausible, it stifles further productive discussion because it causes confusion. Revisiting the hammer and plate example, if a student is asked to produce a causative explanation and then stated that the hammer broke the plate because there was an animal outside the door; this is a faulty explanation. It is improbable that the plate broke because there was an animal outside the door, so discussion of this is not productive. If an explanation is not concise, or specifically parsimonious, it also hinders productive discussion. If the same student explained that the plate broke because the hammer and the handle and the plate and the noise in the room and the person swinging it and the dent on the hammer all came together to cause the plate to break, then the discussion breaks down because the listener needs clarification of all of the concepts identified due to lack of parsimony. If an explanation is not generalizable, it is also considered faulty. An explanation that does not relate to anything else halts discussion rather than promoting thought and additional debate. For example, if the student claimed that the plate style 3345 broke because it was hit with hammer 4456, the situation is so specific there is no need for further discussion. Lastly, if an explanation is not fruitful, there is no discussion due to a lack of general interest or motivation. The degree of fruitfulness depends on the listener, which makes it important for the speaker to understand the intended audience. If an explanation remains plausible, parsimonious, generalizable, and fruitful to the listener, it is considered acceptable and, therefore, promotes discussion. But what creates these explanations?

Gilbert, Boulter, and Rutherford (1998) claimed that explanations are created from models which they defined as simplified viewpoints capable of producing many explanations for a particular phenomenon. They claimed that models can represent ideas, objects, events, or processes and can vary greatly in complexity. Model development occurs through analogical reasoning in which a learner identifies similarities between a previously held idea that is seen as similar to the actual phenomena, the source, and the actual phenomena, the target (Gilbert, Boulter, & Rutherford, 1998). The more connections are made to prior knowledge through the use of analogies, the stronger a model becomes. For example, if the student discussed previously had an understanding of how ceramics behave under stress, then when confronted with the hammer breaking the plate, that student draws conclusions between previous knowledge and phenomena allowing for model construction. A model is strengthened through the use of analogies comparing known information to new observations. However, even strong models have limitations. If a model, weak or strong, cannot offer each type of explanation, it is considered faulty. So each model, or viewpoint of the world, produces intentional, descriptive, interpretive, causative, and predictive explanations if it is a functioning model. Returning to the student-hammer-plate scenario let’s consider a possible model. Prior to the demonstration, the student has a model to describe why things break. This is constructed from analogical reasoning of prior experiences, formal education, or a combination of both. During the demonstration, the student watches the hammer hit the plate and sees the plate break. At this point, if the student has a functioning model to describe why things break, he produces each of the five explanations to describe the phenomenon. Consider a potential student response:

> We hit the plate with a hammer to see if it would break (intentional). When we did this, the plate broke (descriptive). The broken pieces of the plate all looked about the same (interpretive). This happened because the plate is rigid and the hammer is hard (causative). I bet if you hit other rigid things with a hammer, they'd break too (predictive).

If this description is produced, the student has a functioning model because each of the five explanations is created and acceptable, regardless of the level to which they are correct or normative. The degree to which a model is correct is determined by comparing it to a normative or consensus model. A consensus model is a "model which is subjected to testing by scientists and which is socially agreed upon by at least some of them as having merit for the time being" (Gilbert, Boulter, & Rutherford, 1998, p. 93). If a model is consistent with a consensus model, it is considered correct. Note, however, that a model's correctness and functionality are not mutually exclusive. A student may have a model that functions properly (provides the five types of acceptable explanations) but is incorrect (not consistent with the consensus model), or a model that is faulty (cannot provide all explanations) but is correct (is consistent with the consensus model). In order to assess the correctness and functionality of a student's model, they must communicate what is in their minds and express it with the outside world.

Language acts as a communicative tool allowing students to explain what knowledge exists in their minds. Mental models are personal representations of the target that occur in the mind, and are therefore only fully understood by the person by whom it has been constructed (Gilbert, Boulter, & Rutherford, 1998). However, if the model is explained by that student (through verbal, written, or kinesthetic communication), it becomes an expressed model (Gilbert, Boulter, & Rutherford, 1998). The expressed model can then be compared to the normative, or scientifically accepted, model. To understand student knowledge and conceptual understanding, this study adopted a mental models framework. However, without language, accessing students' mental models is incredibly challenging. Even with language, without a clear understanding of the student's fluency in academic language, it is difficult to determine the strength of their mental model. This makes it imperative to understand how students use academic language in context.

Language as Foundation and Meaning

Matthiessen, Slade, and Macken (1992) described the challenge of assessing student writing. They reported that it is difficult to assess student writing because reliable objective frameworks often only assess the student's written product, but subjective frameworks which assess the writing process and reveal its insights lack reliability. Essentially, reliable objective assessment misses much of the student's knowledge while more valid subjective assessment lacks the ability to provide repeatable, consistent results. The authors argued that this challenge is surmountable when utilizing a framework for language analysis that allows for objectivity and makes explicit connections between grammar, meaning, and context. Language is measured across two dimensions: actualization and stratification (Matthiessen, Slade, & Macken, 1992; Halliday, 1992).

Actualization refers to language as a tool, the thought process while constructing it, and the actual use of the language (Matthiessen, Slade, & Macken, 1992). This takes into consideration that language is a process, not just a product and has the potential to create meaning. Stratification, however, is much more fundamental and encompasses language use in terms of grammar, semantics and phonology (Matthiessen, Slade, & Macken, 1992). These linguistic devices incorporate word construction, sentence development, pronunciation, encoding and decoding of text. Matthiessen, Slade, and Macken (1992) described the necessity of these two dimensions:

> Linguistic processing is not a matter of spontaneous creation; it relies on a shared system. Similarly, communication is possible precisely because the levels of language-in-context interlock. Grammar expresses semantics and through semantics contexts of use and culture; these higher levels are created by grammar. These levels have evolved together. (p. 177)

To address this multidimensional perspective of language, the authors suggested a holistic framework: systemic-functional theory. The mental models framework will be used to analyze data for student conceptual understanding. However, to understand student academic language in this research, a systemic functional linguistics framework is used.

Systemic Functional Linguistics

Systemic functional linguistics (SFL), as described by Halliday and Matthiessen (2004), enables the researcher to examine the relationship between fundamental language use (stratification) and its context (actualization). This allows for understanding how particular words, intended audiences, and medium of communication used are related to the meanings, contexts, and situations that they are used for. In her book, *An Introduction to Systemic Functional* Linguistics, Suzanne Eggins (2004) described the primary purpose of SFL is to interpret the meaning of texts and the reasons they convey that meaning. Halliday explained SFL similarly:

> The aim has been to construct a grammar for purposes of text analysis: one that would make it possible to say sensible and useful things about any text, spoken or written, in modern English. (Halliday, 1994)

An SFL framework makes four theoretical claims about language. First, it claims that language is functional (Eggins, 2004). This assumes that language is intended to achieve specific purposes. Eggins (2004) described the functionality of language as being two-fold. She described that language is used for different functions and is structured in different ways dependent on the intended function. Second, SFL claims that the entire function of language is to create meaning (Eggins, 2004). This includes the different sorts of meaning made from language and how and why those meanings are different from each other. Third, SFL claims that the context of language and interaction influences the meaning of language (Eggins, 2004). Eggins explained that SFL attempts to describe exactly which aspects of context affect language and which facets of language are affected by these contexts. For example, in a discussion about the weather outside between two people, the current temperature conditions, intended audience, and location of discussion may all influence language. However, the color of the participants' socks or shoes does not have an impact on the language. SFL helps to describe which contextual cues are significant and how they influence language. Fourth, SFL claims that language is a semiotic system, or process of expressing appropriate units (words, sounds, symbols, structures) that are encoded to create a desired meaning (Eggins, 2004). Eggins used an example of a traffic light to illustrate the features of a semiotic system:

> To construct a semiotic system, we need to observe that each coloured light triggers different behaviors in the drivers who arrive at the intersection. When the light is red, drivers stop, when the light is green, they go, and when the light is amber, they prepare to stop. (Eggins, 2004, p. 13)

In the traffic light example, Eggins explained that the colored lights (red, amber, green) are expressive units, which are then encoded by the driver, to create specific meanings (stop, slow down, go). Together, the claims that language is intended for function, the primary function of language is for making meaning, context can influence meaning, and language is a semiotic system encompass a SFL view of language.

To better understand language as a semiotic system, SFL examines how foundational grammar units are influenced by context or, themselves, influence context and meaning. To understand the necessity of examining these relationships, consider the phrase, *I believe they are appropriate to bond*. This phrase has a variety of grammar units. However, the meaning of this phrase is not clear without context. First, the word *they* is unclear. We are unsure of what *they* is in reference to. Is it two people? If so, maybe *bond* refers to a relationship that they are entering. Is it two objects? In this case, *bond* might mean that they will physically stick together. In the context of science, this may refer to two elements where the word *bond* indicates a chemical bond. Without knowing the context, any one of these explanations is reasonable. However, the phrase is not limited to contextual ambiguity. It also has components that, regardless of context, are unclear. The verb *believe* has multiple meanings. Does the person think this statement is true? Is this statement something that the person thinks might happen? Is it something that the person hopes will happen? These subtleties have implications on meaning. For example, knowledge is culturally something that we are comfortable disputing or altering as long as there is appropriate evidence. However, if it is a belief, it is often not permissible to challenge it. SFL attempts to understand these ambiguities by further examining the relationships between grammatical components, context (referred to as register), and meaning.

This is done by examining various subcomponents of register (field, tenor, and mode), meaning (ideational, interpersonal, and textual), and how those components interact. These relationships are shown in Figure 1 and are explained in the following sections.

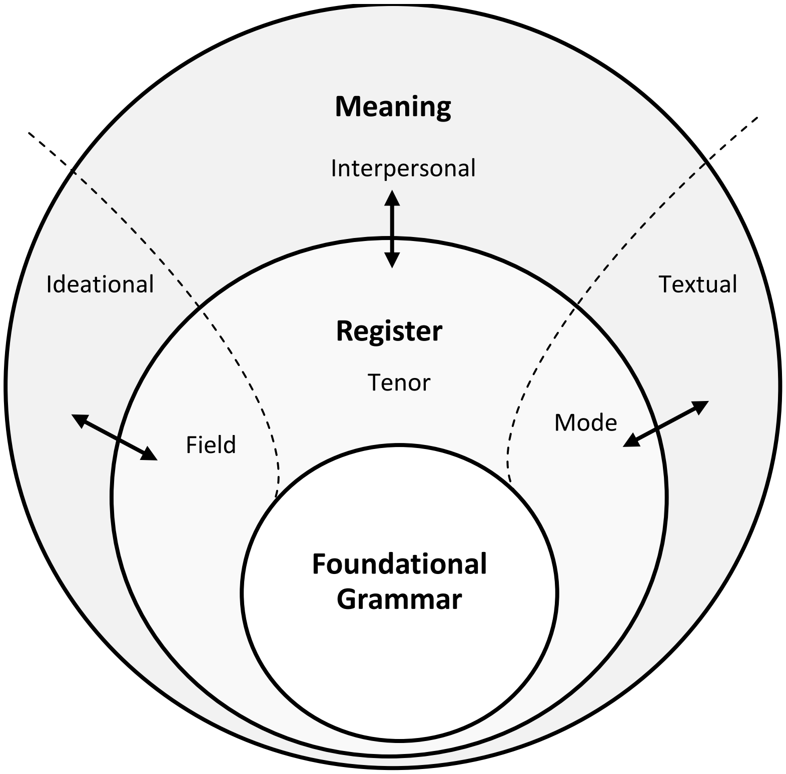

Figure 1. Components of Systemic Functional Linguistics. Adapted from the following: (Matthiessen, Slade, & Macken, 1992; Martin, 2009; Halliday & Matthiessen, An introduction to functional grammar, 2004)

Register. Register refers to the context or setting of the language. Lemke described differences in the languages of various school subjects such as literature, science, history, music, math and economics as registers: “These languages are all, of course, parts of English. They use the same grammatical and semantic resources, but they use them in different ways, for different purposes” (Lemke, 1990, p. 155). These different communication preferences and purposes comprise each subject’s register. In science and engineering, registers are comprised of technical vocabulary, specific intended audiences and explicit forms of verbal and written communication such as scientific presentations or lab reports. In engineering specifically, design proposals and language use in the form of actionable design and application are required. These characteristics make up a distinct engineering register. It is apparent that register is dependent on multiple subtleties within each language. To better understand the complexities of the register, Halliday and Matthiessen (2004) introduced three distinct subsets of the register.

Register is further divided into field, tenor, and mode as shown in Table 2. Eggins reported that Halliday chose these variables because “of all the things going on in a situation at a time of language use, only these three have a direct significant impact on the type of language that will be produced (2004, p. 90).”

Table 2

Variables of the Linguistic Register

Variable	Description	Engineering Example
Field	▪ subject matter context ▪ vocabulary ▪ subject specific concepts	▪ engineering design ▪ failure, deformation, stress, etc. ▪ engineering knowledge required
Tenor	▪ the intended audience ▪ the required mood	▪ a client or manufacturer ▪ professional, authoritative
Mode	▪ medium of communication ▪ textual structure	▪ a formal written brief ▪ complex explanatory structure

The first, field, refers to the subject matter context. For example, the specific topic or discipline for which the language is being used, like engineering. Field is constituted as the context or setting for the language. For example, if an engineer is examining information for the purpose of developing a design recommendation, then the context of the language is engineering design. Field also includes the technical vocabulary associated with the context (the specific engineering terminology) and the concepts required to communicate within the context (the prior knowledge and conceptual understanding of engineering concepts related to the context). Returning to the example above, if an engineer is evaluating information for the purpose of developing a design recommendation, the linguistic field is made up of engineering terminology, knowledge of engineering concepts, and the situational context of a design task. Eggins (2004) described two continuums of field including technical depth and taxonomic complexity. Technical depth consists of vocabulary use ranging from technical-specialized language use to commonsense-everyday language use. In the engineering field technical language includes the field specific vocabulary associated with engineering in contrast to common words used in everyday colloquial speak. Taxonomic complexity, she explained, shows the level to which terms and concepts are grouped into similar classifications. Shallow taxonomies have limited term and concept classification while deep taxonomies have complex classifications of concepts and terms. For example, an engineering student uses a variety of engineering terms though somewhat randomly and incoherently. Though the language is technical and specialized, it is not taxonomically deep. However, if an engineering professional uses technical terms appropriately such that there is evidence that he understands the relationships between those terms and their underlying concepts, there is a higher degree of taxonomic complexity.

The use of technical language and classification of it into taxonomies comprises the linguistic field.

The second variable of register, tenor, refers to audience context or to whom one communicates with. For engineering students this includes instructors, peers, engineers or the general population. For engineers this includes colleagues, superiors, clients or manufacturers. A subsection of tenor is the mood of the language communication. For example, if an engineering student is communicating in class with his or her peers, the mood is casual or inquisitive. In contrast, if an engineer is providing a design recommendation to a manufacturer, the mood is professional and authoritative. Eggins (2004) identified three features of tenor that influence language: power, contact, and affective involvement. Power describes the comparative social status of participants and ranges from equal to unequal. For example, an engineering student communicating with his peer has equal power. But an engineering student communicating with his professor has unequal power. Power exists on a continuum between highly informal and formal. Equal power, Eggins (2004) discussed, generally dictates an informal tone, while unequal power promotes formality. Contact describes the degree of familiarity between the participants. Participants that frequently interact have high contact while those who only occasionally interact have low contact. As expected, frequent contact often promotes an informal tone, while occasional contact suggests a more formal tone. Affective involvement describes the level to which the participants are emotionally committed. For example, spouses or close friends have a high level of affective involvement while strangers or coworkers have a lower level of affective involvement. The lower the level of affective involvement produced, the more formal the tone of language (Eggins, 2004). In an engineering course, students encounter many different combinations of power, contact, and affective involvement. Even the frequency of class meetings influences contact which has implications for the language used within the course.

The third variable of register, mode, refers to the medium of communication or how specifically one communicates. For example, communication occurs verbally or through writing. The in-class interactions between peers as described above suggest an informal verbal mode. However, the engineer's design recommendation suggests a formal written mode. Mode also includes how words are used and how sentences are structured, dictating, for example, if they are short and concise or long and complex. Eggins (2004) described two different components of mode, spatial distance and experiential distance, both describing how closely linked language is to the situation in which it is being used. Spatial distance refers to the possible feedback frequency that participants are exposed to. For example, this ranges from a published book, where there is a very low level of (if any at all) feedback between author and reader, to a face to face conversation, where there is a high level of visual, auditory, and kinesthetic feedback. Between the two extremes are situations where feedback varies in rate or type. Experiential distance describes the degree to which language is part of the experience of the participants. In some cases, language is just an action, accompanying other actions, however, in other situations it is the driving force influencing other actions. Eggins (2004) used the example of a card game and a fiction novel. In the card game, language is often just an action added to the others (selecting a card, making a bet, observing others). However, in a fiction novel, language is the only action and it is responsible for directing, constructing, and promoting other actions (Eggins, 2004). Each type of mode has a unique effect on language comprehension. Together, field, tenor and mode create the linguistic register.

Meaning. In addition to register, the other dimension of SFL is meaning. Meaning describes not the actual words and context as register does, but rather what those words represent. For example, as a student explains how to design an airplane the actual words used, the intended audience and the written medium make up the register. What the words mean based on the student's prior knowledge, how the student intends to communicate most effectively with the desired audience and how the words are written in order to communicate effectively comprise the meaning. To better explain meaning Halliday and Matthiessen introduced three subsets of meaning: ideational, interpersonal, and textual (2004) (Table 3).

Table 3

Metafunctions of Linguistic Meaning

Metafunction	Included strategies	Engineering Example
Ideational	▪ representation of building knowledge and explaining the world ▪ creating complex ideas	▪ supporting language claims with engineering knowledge ▪ fully explaining thoughts
Interpersonal	▪ social communication ▪ turn taking	▪ establish interactions ▪ questioning, commanding, denying, accepting, refuting, stating
Textual	▪ creating coherence ▪ determining importance and relevance	▪ making sure a design recommendation makes sense ▪ checking all content is relevant to intended design

Adapted from: (Halliday & Matthiessen, 2004; Martin, 2009)

The first metafunction, ideational meaning, includes language strategies that help create knowledge building and explanations of the natural world. For example, for an engineer developing a design recommendation, ideational meaning involves the engineer's ability to use prior knowledge and appropriate language to support his idea of a design recommendation. Halliday (2004) further divided ideational meaning into experiential and logical structures. Experiential structures help choose context and use appropriate grammar to represent the world. Eggins (2004) identified three components of experience that influence how the world is depicted: process type, participants, and circumstance. The process type (either material, mental, verbal, behavioral, existential, or rational) determines which process is implied from a statement. Eggins used the following example to illustrate the differences in process type (2004, pp. 213-214):

Diana gave some blood	[material]
Diana thought she should give blood	[mental]
Diana said that giving blood is easy	[verbal]
Diana dreamt of giving blood	[behavioral]
There is a reward for giving blood	[existential]
Diana is a blood donor	[relational]

Material processes involve action. Mental processes describe what is thought or felt. Verbal processes are similar to material processes although they involve actions directly requiring speech or verbal communication. Behavioral processes are described as “physical or psychological” behaviors that occur in the present tense and involve only one participant (Eggins, 2004). Existential processes describe that something has or does exist. Lastly, relational processes, like existential processes, explain that something exists while also describing its relation to other things. For every clause, at least one process type exists. As discussed in the previous section about the tenor of the linguistic register, the second component of experience, the participants, create situations of varying power, affective involvement, and contact. The third component of experience, circumstance, frames the context of the situation and is often shown through the use of adverbs or prepositional phrases (Eggins, 2004). For example, one refers to *next week* or *across the street* to indicate circumstance. Together, process type, participants, and circumstance form the experiential structure of ideational meaning. The logical structures of language include the ability to connect clauses appropriately in order to create desired meaning. Eggins (2004) described two systems of the logic structure: the tacit and logico-semantic systems. The tacit system refers to the relative importance or emphasis given to clauses. If clauses are given equal weight, they are parataxis. However, if clauses are not given equal weight (such as in the case of a list), they are considered hypotaxis. The logico-semantic system refers to how the meanings of clauses are related (Eggins, 2004). Either the clauses are related through projection (where one quotes or tells that an object did something) or expansion (where a clause explains or supports another clause). Examining logic and experiential structures together gives information about ideational meaning.

The second metafunction, interpersonal meaning, encompasses resources that allow for engaging in social interactions. For example, for the engineer creating a design recommendation this includes strategies to keep the reader's interest while maintaining confidence in the engineer. In the area of verbal communication, this includes an understanding of when to take turns speaking, when to question, when to explain, when to accept or when to refute. Interpersonal meaning relies heavily on a person's ability to interpret, respond to, create and maintain social interaction. Eggins (2004) identified two components of interpersonal meaning: mood and modality. The mood chooses from various speech functions and the subject that they are intended for. Some examples of speech functions are statements, commands, answers, acknowledgements, questions, offers, acceptances, and compliance (Eggins, 2004). Each of these dictates a different mood. For example, statements yield a declarative mood while questions dictate an interrogative mood. The modality is "the different ways in which a language user can intrude on her message, expressing attitudes and judgments of various kinds" (Eggins, 2004, p. 172). Modalities include arguing, asking, listening, or even showing facial expressions or gestures. Together, use of mood and modality determine interpersonal meaning.

The third metafunction, textual meaning, includes resources necessary for creating coherent and interpretable communications. While the interpersonal and ideational meaning remains the same, textual meaning reorganizes components of a clause or sentence to alter the purpose or meaning (Eggins, 2004). During the creation of the mentioned design recommendation, an engineer ensures that the recommendation is logical and coherent. In addition, the engineer checks that all language and content used is relevant to the design in question. Textual meaning is composed of theme and information structure. Theme offers "choices about what meanings to prioritize in text" (Eggins, 2004, p. 320), while information structure "is realized through intonation changes" (Eggins, 2004, p. 298). These functions, which monitor coherence and relevance, comprise textual meaning.

Together, the three meaning metafunctions (ideational, interpersonal and textual meaning) socially engage an audience with the use of the register and utilize field, achieve tenor, and determine mode. Together the two main aspects of SFL (register and meaning) including their six components (field, tenor, mode, ideational meaning, interpersonal meaning and textual meaning) describe how language context and meaning are related. The systemic functional lingustics framework is used in this study to understrand academic language proficiency while interpreting student writing samples.

Studies using Systemic Functional Linguistics (SFL). In order to understand how language influences the ability to communicate scientific concepts Hsu and Yang (2007) examined two commonly used textbooks using a SFL framework. Of the one hundred and thirty-two middle school students learning about moon phases, those reading the textbook designed with a SFL framework scored significantly higher on assessments than those engaged with traditional texts (gain score effect sizes of 1.11 and 0.54). In this case, SFL allowed Hsu and Yang to measure the degree to which context and meaning were related in texts by examining the structure of print, structure of images, and the structure of interactions between print and images. Their results suggest that the texts guided by the SFL framework (in terms of the discussed structures) are more helpful for student learning than traditional texts.

Zhihui Fang argued in a 2005 article that a functional linguistic perspective is needed in teaching science in order to maximize scientific literacy. Fang analyzed various sections of text from science journal articles and other scientific texts. Fang found that there are specific differences in the register and meaning of scientific texts that do not exist in colloquial language. Fang highlighted that scientific texts, when compared to everyday text, have increased informational density, higher levels of abstraction, greater technicality, and stronger authoritativeness. This, the author argues, provides evidence that a framework such as SFL that connects grammar, register and meaning is necessary when analyzing and teaching scientific language so that students understand the connections between foundational grammar and meaning-making.

In order to understand and interpret student academic language, a functional view of linguistics is used as a theoretical framework for interpreting language proficiency for this study. While traditional views of language focus primarily on grammar and sentence structure (Barry, 2008), a functional view of linguistics examines the relationships between the structural components of language and their contexts and meanings (Halliday & Matthiessen, 2004). After observing trends in science teaching, Mohan and Slater (2006) argued that SFL is the most appropriate way to analyze the relationship between language and concepts in science classrooms.

In the present study, SFL is used as a theoretical framework for understanding academic language by guiding analysis of student writing samples. For the present study, only field context and ideational meaning are examined. Mohan and Slater (2006) also exclusively used these two components when exploring language and understanding of magnetism. However, they remind us that even if only select components of register and meaning are examined, all three contexts and meanings are present in all language.

Summary

Language development occurs as a result of immersion and the use of appropriate functional cues about language use. Scientific language development occurs in very similar ways due to the nature of a unique register. Suggestions and models for academic and scientific language development exist and primarily involve allowing students to practice language, receive feedback about language use, make connections between colloquial and scientific language and, in some cases, develop metacognitive language monitoring strategies. To understand the relationship between academic language proficiency and conceptual understanding, a mental models framework along with a SFL framework are used in this study. By analyzing student mental models, one assesses the strength of the concepts and connections students make. If students provide ideational, descriptive, interpretative, causative and predictive explanations their mental model is functioning. Student language use is examined from a SFL perspective while focusing on their field context and ideational meaning to understand engineering language proficiency. Used together, student mental models and a SFL framework explore the relationship between engineering language proficiency and conceptual understanding.

Chapter 3

METHODOLOGY

Overview

The purpose of this study was to examine how engineering language development effects conceptual understanding of introductory materials science and engineering concepts. Students were observed for one semester. At the start, a demographic survey of participants was conducted in order to understand the researched population. Written engineering design tasks were administered multiple times throughout a one-semester course in order to understand progressions in student engineering language and conceptual development. Team observations were conducted multiple times to measure the frequency of student engagement with the engineering register during team tasks. The Materials Concept Inventory (MCI) was administered at the beginning and end of the course in order to provide a valid measure of conceptual development over the course of the semester. Data analysis was conducted to answer the following research questions:

1. How does exposure to engineering language through peer discussion during team tasks influence engineering language proficiency?
2. How does exposure to engineering language through peer discussion during team tasks influence conceptual understanding in the context of an engineering design task?

3. What is the relationship between conceptual understanding and engineering language when examined during an engineering design task over the course of a semester?

Participants

This study was conducted at a large university in the southwestern United States. A convenience sample of forty-one undergraduate students enrolled in an introductory materials science and engineering course was used. Participation was voluntary though research activities were integrated into the course. The fifteen-week semester course, containing the sample students, met for seventy-five minutes two times per week. This introductory engineering course was a required lower division course for materials, mechanical, aerospace, and chemical engineers and an elective course for all other engineering disciplines. The course had seven female and thirty four male students. The majority were juniors. Most students were mechanical engineering majors, though there were also students majoring in mathematics, aerospace, biomedical, chemical, and industrial engineering. Participant demographics are summarized in Table 4.

Table 4

Participant Demographics: Major and Class Level

	Class Level				
Major	Sophomore	Junior	Senior	Post-Bac	Total
Aerospace	--	--	1	--	1
Biomedical	--	--	--	1	1
Chemical	2	6	1	--	8
Industrial	--	3	--	--	3
Mechanical	6	12	7	--	25
Mathematics	--	--	2	--	2
Total	8	21	11	1	41

In order to determine additional sample characteristics, a demographic survey (Appendix A) was administered at the beginning of the semester. The six question survey asked students to report how many languages they are fluent in, if English is his/her first language, how confident they are in their ability to learn a new language, how many engineering and chemistry courses were previously taken, and how important they felt learning engineering vocabulary was for learning engineering concepts. Results are summarized in Table 5.

Table 5

Summary of Demographic Survey (N=41)

Demographic Characteristics	Descriptive Statistics	
	Mean	Standard Deviation
Number of Fluent Languages	1.27	.45
College Engineering Courses Taken	3.78	2.52
College Chemistry Courses Taken	1.98	1.08
Confidence in Learning Language	3.85*	.94
Importance of Vocabulary for Learning Engineering	4.49+	.68

* From a Likert Scale where 1=Not at all confident and 5=Very confident

+ From a Likert Scale where 1=Not important and 5=Very important

From the sample of forty one students enrolled in the course, thirty (73%) reported fluency in one language while eleven (27%) reported to be fluent in two languages. Of the eleven students who reported being fluent in two languages four students said that English was not the language learned first. The remaining thirty seven students in the sample said that English was their first language learned. There were some differences in the number of college engineering courses students had taken (Figure 2). As shown, the majority of students had taken one or two engineering courses prior to enrolling in the current course. However, there were many students that had taken additional courses. These differences are consistent with the differences in grade levels and programs of the students in the course.

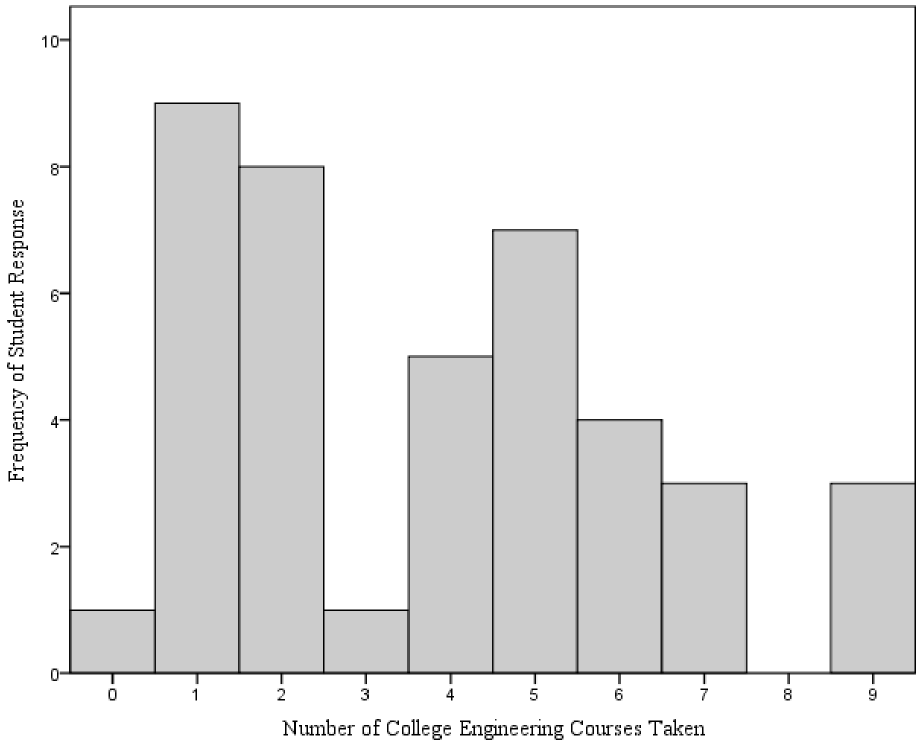

Figure 2. Number of college engineering courses students reported taking previously.

Differences were not observed when examining the number of college chemistry courses students had taken (Figure 3). The majority (83%) of students had taken only one or two college chemistry courses. The remaining 17% of students had taken three or more chemistry courses. This is consistent with a sample of 19% chemical engineering majors, who often are required to take additional chemistry courses near the beginning of their studies.

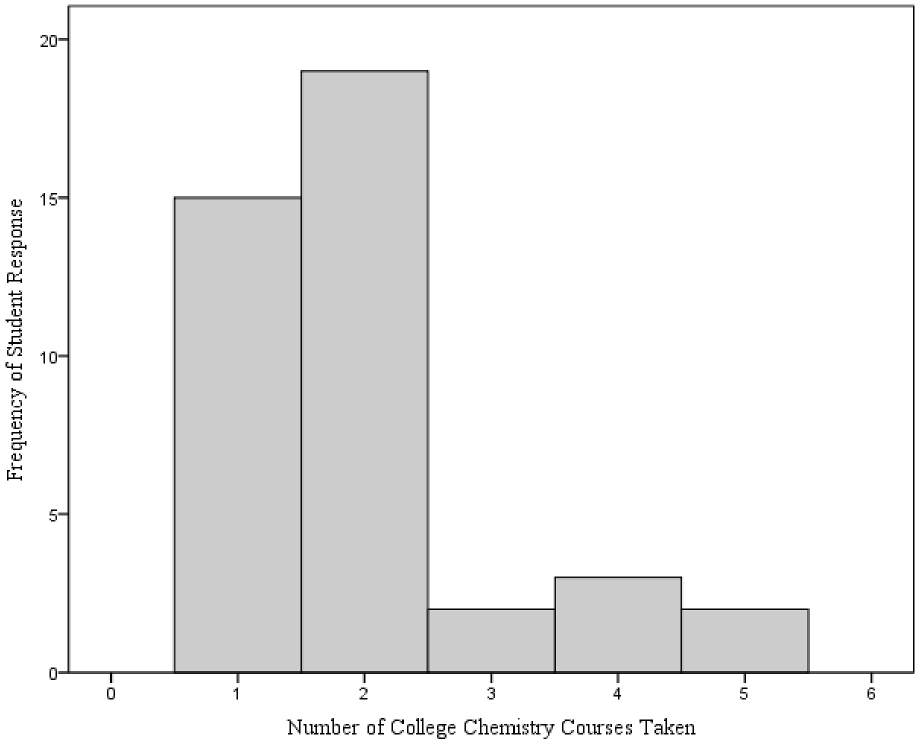

Figure 3. Number of college chemistry courses students reported taking previously.

Students were asked how important they felt learning engineering vocabulary is for learning engineering concepts. As show in Figure 4, student responses ranged from neutral to very important. Many students (59%) reported that learning engineering vocabulary was very important for learning engineering concepts.

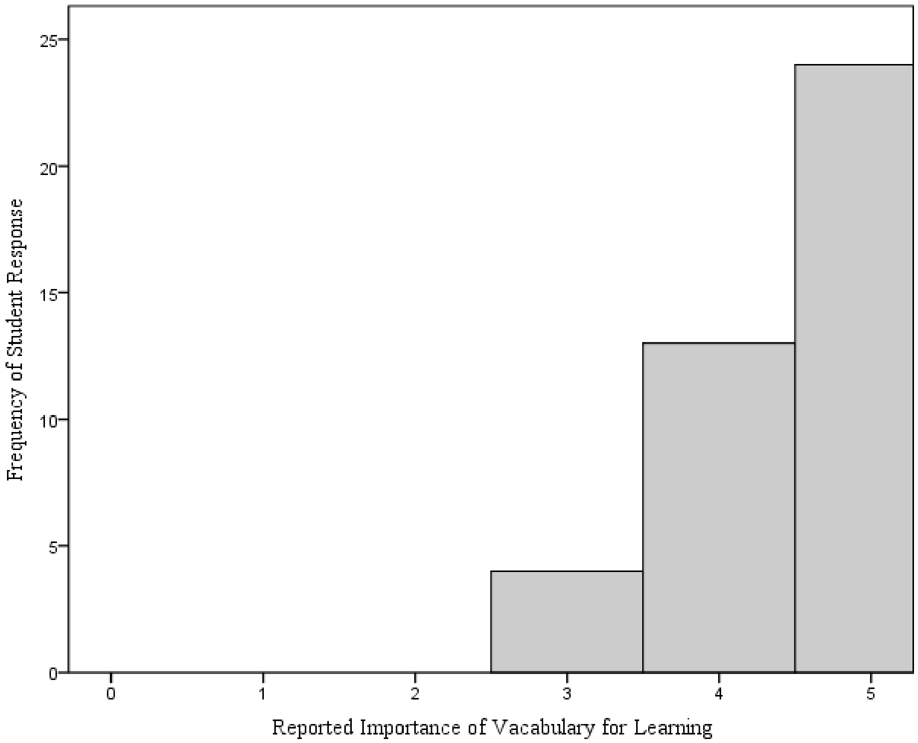

Figure 4. Student rankings of how important learning engineering vocabulary is for learning engineering concepts.

Classroom Context

The course was taught by a professor with over thirty years of teaching experiences who was invested in engineering education research. Instruction consisted of various materials and strategies that allowed for frequent formative feedback and student interaction. Class lecture notes were contextualized and comprised of mini lectures, team activities, a metacognitive reflection, contextualized homework, concept maps, and a combination of written, graphical, and mathematical representations of content. A sample of the class lectures notes can be found in Appendix B. Pre and post assessments were given before and after each content module to understand student learning progressions and gain the necessary feedback to maximize student learning. At the end of each class, a metacognitive reflection comprised of a Point of Interest, Muddiest Point, and Valuable Point, was given to students asking them to reflect on various pieces from each class. The response to the Point of Interest allowed for students to think about and convey the parts of the content that they found interesting and intriguing. The response to the Muddiest Point gave students opportunities to identify the content topics which they had trouble understanding. The Valuable Point asked students to identify the content, skill, or piece of knowledge from the class with the most value. After each class the instructor read student responses to the Points of Reflection and prepared the Points of Clarification which was shared with students at the start of the following class. The Points of Clarification acknowledged common Muddy Points and promoted further discussion or redirection to aid student learning.

Students were grouped in self-selected teams of four to six during team based activities. They worked together in teams on a variety of tasks assigned by the instructor. Most team activities lasted approximately ten minutes. Following an activity, teams were asked to self-select a representative to report their findings to the class. While teams reported their agreed upon answer to the class, the instructor probed for explanations. After all teams had reported answers and the instructor felt an appropriate consensus was reached, the team activity ended. A typical class meeting consisted of a Points of Clarification (7 minutes, 10%), two mini lectures (30 minutes, 40%), two team based activities (30 minutes, 40%), one worked analytical problem or example (4 minutes, 5%), and a student metacognitive reflection (4 minutes, 5%). Students, at all times, were encouraged to ask questions and participate in the course.

Procedure

This study utilized a quantitative, quasi-experimental, repeated measures design. The effects of the independent variable, exposure to engineering language through team interactions during group activities, on the dependent variables, engineering language and conceptual understanding, were examined. Students were assessed throughout the course of the semester in various ways. Pre and post assessments were administered. Additionally, a repeated measures assessment was deployed four different times throughout the semester. Group observations were also conducted biweekly. Students were arranged into nine groups of four to six participants. These groupings were determined and limited by the configuration of the classroom in which there were nine hexagonal tables available for students to sit in teams of four to six. Since all participants were enrolled in the same section of the course, all events occurring within the course were consistent across participants. Repeated measure written engineering design tasks were open ended such that students were unable to rely on previous assessment experiences to superficially increase scores while completing assessments.

Measures

In order to gain access to the variables of interest, a variety of assessments were utilized including the Materials Concept Inventory, Engineering Design

Task Writing Prompts, and Team Language Use Observations. A timeline of the assessment plan is summarized in Table 6. After which, each of the assessments is discussed in further detail.

Table 6

Summary of Assessment Timeline

Variable Being Assessed	Assessment	Administered (Week)
Initial conceptual understanding	Materials Concept Inventory: Pre	1
	Engineering Design Task	1, 6, 12, 16
Conceptual understanding	Conceptual Score	
Engineering language proficiency	Language Score	
Design task contextual dependency	Engineering Design Task Control	5
Student engagement and exposure to engineering register (frequency and uniqueness)	Team Observations	
	Observation 1	Within 2-3
	Observation 2	Within 3-5
	Observation 3	Within 5-6
	Observation 4	Within 6-8
	Observation 5	Within 8-9
	Observation 6	Within 10-11
	Observation 7	Within 12-13
	Observation 8	Within 13-15
Final conceptual understanding and conceptual gains	Materials Concept Inventory: Post	16

Conceptual Development: Materials Concept Inventory (MCI)

To access student conceptual development, the MCI was administered both before and after instruction. The MCI was used for answering research questions one and two to control for variations between groups. The MCI was developed with the goal of revealing students’ conceptual frameworks and tracking conceptual development in an introductory materials science and engineering course (Krause, Decker, Niska, & Alford, 2002).

Validity. The topics represented on the MCI were initially determined by grouping topics from course syllabi and surveying commonly used introductory materials science and engineering textbooks (Krause, 2007). Distracters were originally developed from student misconceptions elicited by open ended student responses, focus groups, and developers' experiences with difficulties students faced throughout an introductory materials science and engineering. Due to the multidisciplinary nature of materials science and engineering, many of the topics chosen (phase diagrams and solutions, atomic bonding, electronic structure, atomic arrangement and crystal structure, defects and microstructure, solubility, and macroscopic properties) may have been presented to students in other core classes prior to their enrollment in introductory materials science and engineering (Krause, 2007; Krause et al., 2002; Corkins, 2009).

To establish the measure's predictive validity, Corkins (2009) examined data where the MCI was given as a pretest two days prior to any instruction to three-hundred and three undergraduate engineering students from six classes over three years who were enrolled in a materials engineering course. He found that the pretest was able to predict the final course grade ($r = .30$, $p < .001$). Corkins also found that the MCI demonstrated adequate reliability ($\alpha = .73$) and strong discriminatory power (Ferguson's delta , $\delta = 0.96$). Additionally, he found that he post-test MCI scores showed significant correlation to final course grade ($r = .50$, $p < .001$) establishing the convergent validity of the MCI.

Reliability. To establish the internal consistency reliability of the MCI, Corkins (2009) computed Cronbach's coefficient alpha claiming that all measures over .70 are considered adequate. When the MCI was deployed after instruction to a sample of two hundred and thirty one students, the assessment was determined adequately reliable ($\alpha = .73$). When the MCI was deployed prior to instruction to a sample of three hundred and four students, the assessment was also determined adequately reliable ($\alpha = .71$). These results establish that the MCI is a reliable instrument for assessing student understanding before and after instruction.

For the sample of students from this study, test-retest reliability was determined by finding the correlation between pre and post MCI scores. The MCI for this sample was determined reliable ($r = .74$, $p < .001$).

Administering the MCI. For this study, the MCI was administered in class but did not count for part of the students' grades. Students were given twenty minutes to complete the assessment. The MCI is a thirty question multiple-choice test and is available in Appendix C. All questions have one correct answer. Students were given one point for every question answered correctly. There was no penalty for questions answered incorrectly. By administering the assessment in weeks one and sixteen, student conceptual understandings before instruction, after instruction, and conceptual gains over the course of the semester were measured.

Student Engineering Language and Conceptual Understanding: Writing Prompts

In order to assess students' engineering language proficiency and conceptual understanding, student writing samples were collected four times over the course of the semester. This assessment was used to answer research questions one, two, and three. To do so, a written Engineering Design Task (Appendix D) was administered as part of the course as a homework assignment and was deployed before instruction at week one, during instruction at weeks six and twelve, and after instruction at week sixteen. These writing samples allowed for tracking student changes in engineering language proficiency and conceptual understanding as the semester progressed. The writing prompt was as follows:

> Using as much of the vocabulary and concepts of materials engineering as you can, describe how you would engage in the materials selection process for deciding what materials should make up the various parts of a bicycle. Be sure to explain what engineering information you are using and how you are using it to make your decision.

This provided insight to how students used the engineering register in order to complete an engineering design task. Independent of language, conceptual understanding was measured by evaluating the actual concepts that students wrote about and their consistency with normative engineering ideas.

To score the writing prompt for engineering language proficiency, a SFL approach to assessing student writing as outlined by Matthiessen, Slade, and

Macken (1992) was used. Writing samples were scored for the register variables of field and ideational meaning as the semester progressed. Field provided insight about how students interacted with the engineering context and language. Ideational meaning examined how students chose to express their ideas through semantic choices. The rubric used for assessing writing samples is shown in Table 7.

Table 7

Engineering Language Rubric for Writing Sample

Linguistic Feature	Specific Objective	Characteristics	Requirements for Each Score			
			3	2	1	0
Meaning: Ideational	Experiential: Engages in materials selection process as engineer	Engineering context	x	x	x	--
		References bicycle	x	x	x	--
		Selects materials	x	x	--	--
		Explains thinking	x	--	--	--
	Logical: Making meaning with clauses	Uses projections to articulate choices	x	x	x	--
		Weights clauses appropriately - taxies	x	x	--	--
		Uses expansions to support claims	x	--	--	--
Register: Field	Technical Depth: Frequency of term use	Uses technical terms when appropriate	Most of the time	About ½ the time	Rarely	Never
	Taxonomic Complexity: Organization of technical terms within register	Groups like terms Shows evidence of knowing term associations	Most of the time	About ½ the time	Rarely	Never

Students were able to achieve a maximum score of twelve and a minimum score of zero. Their writing samples were scored for ideational meaning and field register. The ideational meaning assessed students' ability to utilize experiential and logical structures. Experiential structures assessed students' ability to choose appropriate processes, participants, and circumstances. In the context of an engineering design task, this required acknowledging an engineering context, the design task of bicycle design, material selection, and an explanation of design choices. Logical structures assessed students' ability to create appropriate clauses including knowledge of when certain clauses should be emphasized, and use of appropriate projections (isolated statements) and explanations (supports for statements). A score of three represented a student who fulfilled all requirements of the prompt, while a score of zero represented a student who ignored the prompt. Field register was scored for technical depth and taxonomic complexity. Technical depth assessed students' abilities to use engineering technical vocabulary at all appropriate opportunities. This is different from the correct use of engineering terms which was not explored through this rubric. So a student could have used many terms incorrectly but still scored high for technical depth. However, incorrect use of terms may influence students' scores on taxonomic complexity. Taxonomic complexity assessed students' abilities to classify like terms and examined the connections students made between various concepts within the field. So students may have used two concepts like atomic bonding and macroscopic properties, and then drew connections between them to generate an idea. This could show evidence of some taxonomic complexity. It is, however, important to remember that while student engagement with the engineering field and meaning was being examined for engineering language proficiency, conceptual correctness was ignored. So, it was possible that students' scored very high on engineering language (as determined by the rubric) due to using substantial technical language and making many complex connections, yet not be conceptually "correct" in any of the language use or complex connections. To ensure precision in measurement, only one rater was used to score engineering design tasks.

To assess student conceptual understanding, writing samples were scored using an understanding of mental and expressed models as described by Gilbert et al. (1998). Writing samples were scored for the five requirements of a functional mental model. Changes in these scores were monitored over the course of the semester. The rubric for assessing writing samples is shown in Table 8.

Students were able to achieve a maximum conceptual understanding score of fifteen and a minimum score of zero. Their writing samples were scored for usefulness of their expressed model. Intentional explanations were used to assess students' abilities to understand the relevance of the design task. Descriptive explanations were scored to assess student ability to describe and explain phenomena. Interpretive explanations were used to understand student ability to develop classifications or patterns in data. Causative explanations were scored to

Table 8

Conceptual Understanding Rubric for Writing Sample

Type of Explanation	Characteristics	Requirements for Each Score			
		3	2	1	0
Intentional explanations – justifying relevance and importance	Identifies connections between concepts and engineering design	x	x	x	--
	Correctly identifies the challenges and affordances of design	x	x	--	--
	Recognizes implications of materials selection process	x	--	--	--
Descriptive explanations – describing phenomena behavior	Explains material behavior	x	x	x	--
	Describes how behavior changes in varying conditions	x	x	--	--
	Discusses how macroscopic material behavior influences design choices	x	--	--	--
Interpretive explanations – comparing and classifying similar cases	Identifies families of materials appropriate for materials selection	x	x	x	--
	Discusses features of classifications of materials that are important in design task	x	x	--	--
	Shows evidence of recognizing these materials as similar in behavior	x	--	--	--
Causative explanations – describing cause of phenomena	Makes connections between microscopic and macroscopic behavior or materials	x	x	--	--
	Explains why choices are appropriate to design requirements most of the time	x	--	--	--
	Explains why choices are appropriate to design requirements sometimes		x	x	--
Predictive explanations – predicting in similar situations	Foresees design limitations	x	x	x	--
	Predicts how materials will behave in different operating conditions	x	x	--	--
	Student identifies varying material recommendations to address different operating conditions or design modifications	x	--	--	--

see if students could justify the reason for their choices or causes for material behavior. Predictive explanations showed if students could predict future situations within the design task. Students were assessed on their ability to justify the relevance of the design task, describe material phenomena, compare and classify similar materials, describe the microscopic behavior of materials, and make predictions within the context of the design task.

By scoring writing samples for engineering language proficiency and conceptual understanding using the two rubrics discussed, students obtained a score for engineering language proficiency and a score for conceptual understanding. Because the writing prompt was administered four times throughout the semester, this provided opportunities to see how engineering language and conceptual understanding changed throughout the course.

In order to see if the topic of the design task influenced students' engagement with the engineering register, an additional Written Engineering Design Task (Appendix E) was administered at week five asking students to design the components of an airplane rather than a bicycle. The prompt read:

> Using as much of the vocabulary and concepts of materials engineering as you can, describe how you would engage in the materials selection process for deciding what materials should make up the various parts of an airplane. Be sure to explain what engineering information you are using and how you are using it to make your decision

This allowed for examining if the topic of the design task influenced students' ability to engage with the engineering register. Statistical analysis was completed to see if there were differences between scores on design tasks for the bicycle and airplane.

All student writing samples were scored by only one rater. As a result, no inter rater reliability can be assessed. While this ensures that samples are scored consistently, it does not control for potential bias in scores and limits the results of the study.

Frequency and Breadth of Language Use in Class: Group Class Observations

In order to understand how students engaged in engineering language throughout the learning process, group observations were made approximately once every other week for each group over the course of the semester. This was used to answer research questions one and two. Each group observation was approximately four minutes in length. Some variation in observation length occurred due to the instructor ending the activity time or groups claiming to have completed the entire activity. Though group observations were conducted each class period, due to the number of groups, only about one quarter of the groups were observed each class period. Each group was observed a total of eight times, with the exception of one group in which all group members were absent for a full week due to illness. Engineering language terms used within those four minutes were tallied on the group observation sheets (Appendix F). To determine which words would be considered engineering language, class lecture notes were examined for each class. Engineering language included all terms in the engineering register that had been introduced to students up to the time of the each observation in the semester. For example, for observations conducted during the third class of the semester, all technical words introduced in the lecture notes from class one, two, and three were considered engineering language. As such, for each date there was an updated observation sheet with new terms added from prior classes. The observations provided two pieces of information from each date observed. First, frequency of engineering language (E_f) use for the group was calculated. This was done by calculating engineering language use per minute. In this calculation, each time an engineering term was used by a group member it was tallied, even if the same word was used previously by either someone else or that same group member. The total number of engineering terms used in the observation time were then summed and divided by the length of the observation in minutes. This provided a rate of engineering language use in the units of words per minute as shown below.

$$E_f = \frac{number\ of\ engineering\ speak\ terms\ used}{time\ of\ observation\ in\ minutes} \qquad (1)$$

Additionally, the uniqueness of engineering terms used was examined. This was calculated by examining unique engineering language (E_u) use per minute. In this calculation, only the number of unique engineering terms were considered. Each time a unique engineering term was used by a group member it was tallied. If the same word was used again, it was ignored. The total number of unique engineering terms used in the observation time were then summed and divided by the length of the observation in minutes. This provided a rate of unique engineering language use in the units of words per minute as shown below. This provided a measure of the richness or diversity of the engineering language that occurred within the group.

$$E_u = \frac{number\ of\ unique\ engineering\ speak\ terms\ used}{time\ of\ observation\ in\ minutes} \tag{2}$$

By examining the use of these terms, further insight can be gained about the language that is used and developed in the context of the learning environment. There was one observer conducting group observations, so inter observer reliability cannot be assessed. While this controls for consistency among observations, it does not control for bias and may limit the results of the study.

Summary

To answer the research questions about engineering language proficiency, a convenience sample of forty-one undergraduate students in an introductory materials science and engineering course was used. All data collected was integrated with the course. Measures included the MCI, a written engineering design task, and group observations. Both SFL and mental models frameworks were utilized to interpret data and guide analysis. Research question one was answered by regression analysis using group observations and engineering language scores from the written design task. Research question two was answered by regression analysis using group observations and conceptual understanding scores from the written design task. Research question three was answered by correlation analysis using engineering language scores and conceptual understanding scores from the written design task. MCI scores and demographics were used to control for differences between groups in research questions one and two.

Chapter 4

DATA ANALYSIS AND RESULTS

Overview

To understand the trends measured from each of the assessments, first they were considered individually over the course of the semester. Then, to answer the research questions, multiple assessments were used to conduct linear regressions at various times throughout the semester. Last, a summary of findings was discussed.

Relationships within the Sample Population

A demographic survey was administered at the beginning of the semester. The six question survey asked students to report how many languages they are fluent in, if English is their first language, how confident they are in their ability to learn a new language, how many engineering and chemistry courses they have taken, and how important learning engineering vocabulary was for learning engineering concepts. There was a statistically significant correlation between students' perceived importance of vocabulary for learning and the number of chemistry courses taken (r=.324, p=.039). Though this was not the focus of the study, the relationship should be kept in mind as it could suggest that students taking more chemistry courses may influence their academic language acquisition.

Group Observations throughout the Semester

To understand how group language use changed over the course of the semester, for each observation two variables were computed for each group. First, frequency of engineering language (E_f) use was calculated. The total number of engineering terms used in the observation time were then summed and divided by the length of the observation in minutes. This provided a rate of engineering language use in the units of words per minute. Second, the uniqueness of engineering terms used was examined. This was calculated by examining unique engineering language (E_u) use per minute. The total number of unique engineering terms used in the observation time were then summed and divided by the length of the observation in minutes. This provided a rate of unique engineering language use in the units of words per minute. The calculated rates for each group are shown in Table 9.

Table 9

Group Engineering Language Use

	Observation							
	1	2	3	4	5	6	7	8
Group	E_f/E_u	E_f/E_u	E_f/E_u	E_f/E_u	E_f/E_u	E_f/E_u	E_f/E_u	E_f/E_u
1	.8/.8	2.4/.8	4/2.3	5.5/3	3.8/1	7.1/2.6	6.8/2.8	5.8/.8
2	2.8/1.8	5/2.8	11.5/4.8	11/2	3/1.3	1.3/1	10.3/2.5	7.2/4
3	.8/.5	2.6/.6	4/2.5	2.3/1	3/1	.6/.6	0/0	12.1/2.8
4	8/2	2/1	1.8/.8	6.3/1.8	5/.5	12.3/2.5	9.5/4.5	10.5/5.3
5	3.5/2	1.8/.4	2.5/1.5	2.8/1	11.5/2.3	8.5/2.5	11.7/3.1	8.8/2
6	3.5/1.3	3/.8	3.5/1.5	1.3/1	9.3/2	4.5/2.5	2.5/1.8	8/3.1
7	2.3/.8	1.5/1	4.3/1.3	3/1.3	0/0	3.3/1	12.5/4.5	-- / --
8	2.8/.8	.8/.5	13.8/2.3	12.3/2.3	8.3/2.5	11.3/2.5	.5/.5	5/2.25
9	5.7/3.7	2.8/1.8	10.5/3	4.5/2	6.5/2.5	12.3/3.3	9.7/4.6	16.8/4.3

To better understand and observe these trends over the semester, the average group scores for each observation were calculated. Figure 5 shows these trends.

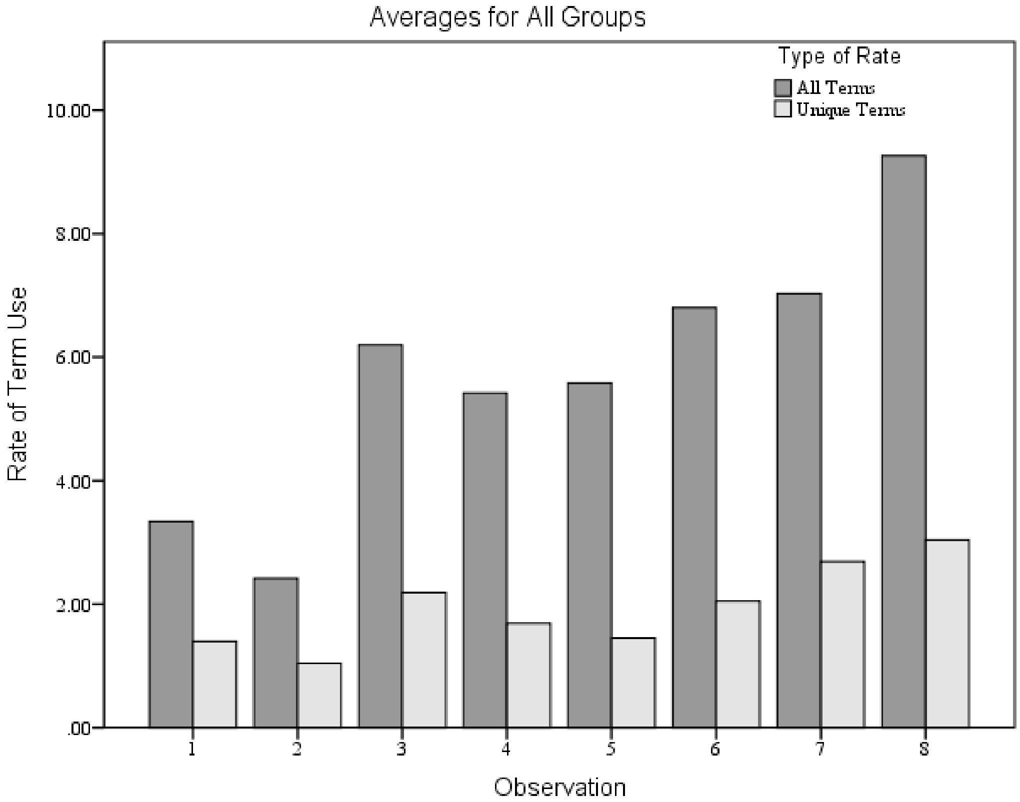

Figure 5. Average group E_f and E_u scores across all observations.

As the semester progressed, most groups tended to use more engineering terms and though only a slightly larger variety of engineering terms. This trend of averages was consistent within all groups with the exception of group eight. Group eight, as shown in Figure 6, used more academic language during the middle of the semester, with little language use near the beginning and ends of the semester.

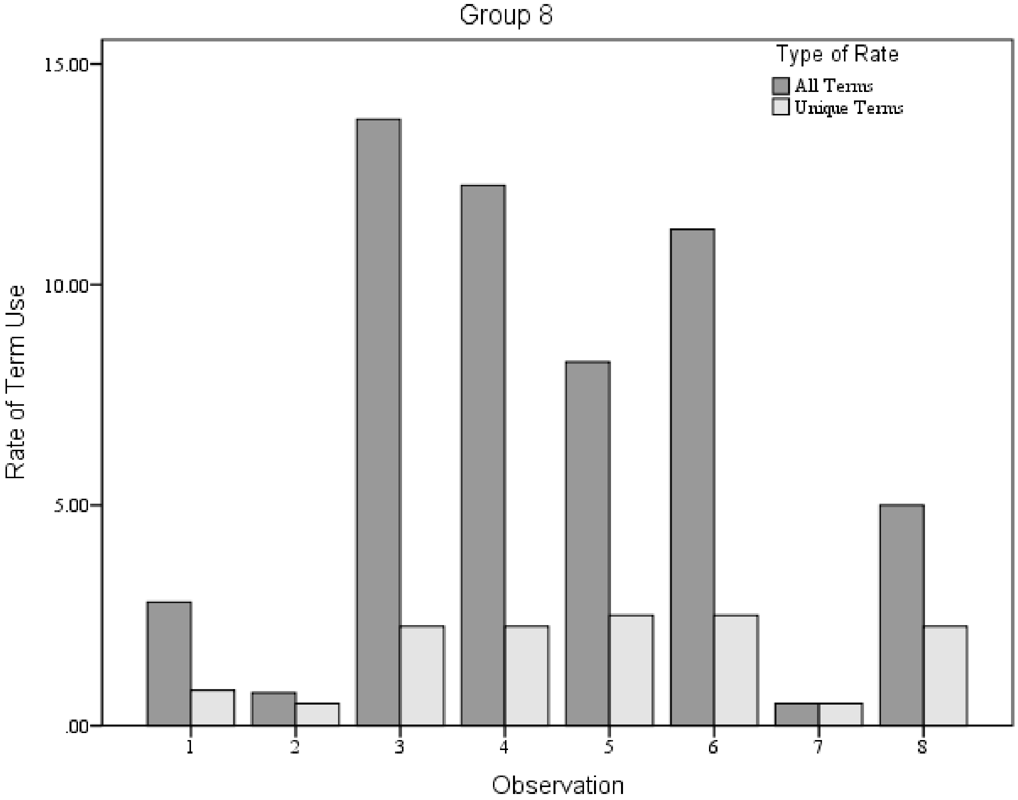

Figure 6. Group eight E_f and E_u scores across all observations.

Group members in this group began to use academic language purposefully during the middle of the semester as they noticed an observer. This was apparent from group members asking “How many [words] did we use that time?” This only occurred for a few observations after which they returned to doing activities while ignoring the presence of the observer.

Performance on Materials Concept Inventory

To understand student conceptual gains over the course of the semester, a dependent samples *t*-test was conducted and tested at $\alpha=0.5$. The means scores following instruction ($M=17.32$, $SD=4.23$) were significantly greater than the mean scores prior to instruction ($M=12.36$, $SD=3.50$), $t(27)=9.18$, $p<.01$. The 95%

confidence interval for the mean difference between pre and post scores was 3.85 to 6.07, indicating a high level of confidence that the mean differences were nonzero and positive. A distribution of student scores is shown in Figure 7. Students not only improved following instruction, but varied over a similar range when compared to scores prior to instruction.

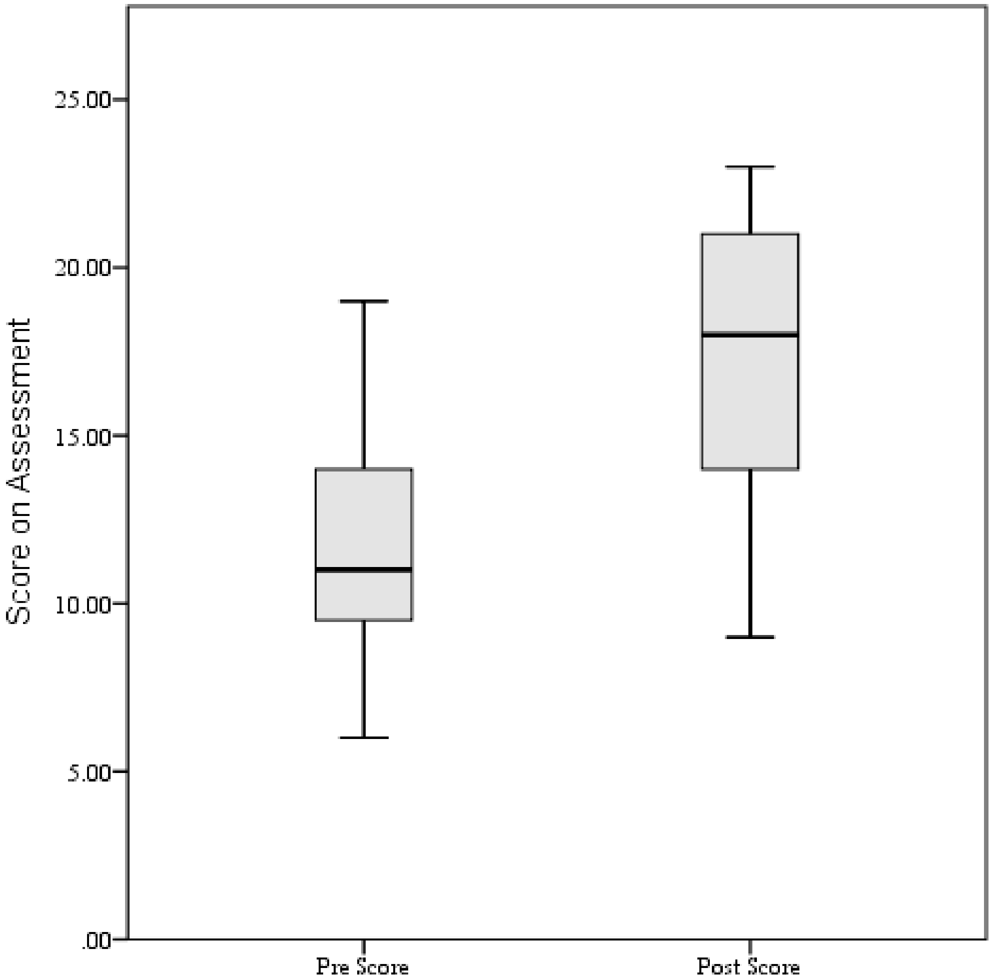

Figure 7. Distributions of scores on the MCI before and after instruction.

A one-way analysis of variance was conducted to evaluate the relationship between pre and post MCI scores between groups. The independent variable, the group, included nine levels: one for each group in the class. The dependent variable was the change in MCI scores from pre to post test. The ANOVA was not significant, $F(8,19)=1.37$, $p=.27$. These results indicated that no statistically significant differences in MCI gains among groups.

Design Task Context Dependency

To understand if the context of the design task influenced student performance, two design tasks were administered within one week. One asked students to consider the design for a bicycle and the other an airplane. To test for differences among scores, a dependent samples *t*-test was conducted on both conceptual understanding and language proficiency scores. The mean conceptual understanding scores on the bicycle design task ($M=5.78$, $SD=3.61$) were not significantly different than the mean conceptual understanding scores on the airplane design task ($M=5.95$, $SD=2.62$), $t(17)= -.225$, $p=.83$. The 95% confidence interval for the mean difference between the conceptual understanding scores was -1.73 to 1.40, indicating that the mean score differences were likely low and possibly zero. These results suggest that conceptual understanding was independent of design context when comparing airplane and bicycle designs.

The same analysis was conducted with language proficiency scores. The mean language proficiency scores on the bicycle design task ($M=6.39$, $SD=1.97$) were not significantly different than the mean language proficiency scores on the airplane design task ($M=5.50$, $SD=2.00$), $t(17)= 1.76$, $p=.10$. The 95% confidence interval for the mean difference between the language proficiency scores was -.175 to 1.95, indicating that the mean score differences were likely low and possibly zero. These results suggest that language proficiency, like conceptual understanding, is independent of design context when comparing airplane and bicycle design.

Research Question One

The first research question asked how exposure to engineering language through peer discussion during team tasks influenced engineering language proficiency. To answer this question, regression analysis was conducted for each group at four different intervals throughout the semester. These intervals were determined by the collection of each engineering design task. Group level data was examined by considering mean group scores for observation data and language proficiency as measured by design task data. Observation data included frequency of term use and uniqueness of term use.

A series of multiple regression analyses were conducted to evaluate how well group engineering language use predicted language proficiency. The predictors were the frequency of language use and uniqueness of language use while the criterion variable was the mean group language proficiency scores on the engineering design task. Group level data was used thus, the sample size for these analyses was only N=9. This suggests that the study may have been underpowered, making it difficult to infer results to the population. For this reason, effect sizes will be discussed in more detail than inferential statistics.

Predicting Engineering Design Task 1

For the first time interval, the linear combination of group language use was not significantly related to language proficiency, $F(2,6)=3.97$, $p=.08$. The sample multiple correlation coefficient was .76, indicating that approximately 57% of the variance of language proficiency can be accounted for by the linear combination of group engineering term use. While the relationship was not able to be inferred to the population, the effect size was high, R^2=.57, adjR^2=.43. This suggested that the relationship was very strong in the present sample. To understand the relative strengths of the predictors, bivariate and partial correlations were examined. These are shown in Table 10.

Table 10

Bivariate and Partial Correlations of the Predictors with Language Proficiency: Design Task 1

Predictors	Correlation between each predictor and language proficiency	Correlation between each predictor and language proficiency controlling for other predictors
Frequency of Term Use	-.75	-.51
Uniqueness of Term Use	-.64	-.071

All the bivariate correlations were moderate and negative, though not statistically significant, making it difficult to make claims about the relationship between term use and language proficiency in the broad population. However, it was still possible to understand the relationship of the variables in the sample for this study. The bivariate correlations suggested that, in the study sample, group engineering term use was inversely related to academic proficiency on the design task. In other words, the more terms students in the study sample used in their group discussion, the less proficient they were on the engineering design task.

This relationship cannot be generalized past the study sample. Frequency of term use, for the study sample, was moderately correlated to language proficiency when controlling for the effects of unique term use. This suggested that the frequency students in the study sample used engineering terms was moderately, and inversely, related to their language proficiency. However, the variety of different terms used during team interactions was not strongly related to language proficiency when controlling for frequency of term use in the study sample. It is important to mention that the frequency of engineering term use and uniqueness of engineering term use during team activities were strongly correlated, $r=.82$, $p<.01$. Since the two predictors were correlated, it becomes difficult to understand the true relative importance of each in predicting academic language proficiency.

Predicting Engineering Design Task 2

For the second time interval, the linear combination of group language use was not significantly related to language proficiency, $F(2,6)=.93$, $p=.44$. The sample multiple correlation coefficient was .49, indicating that approximately 24% of the variance of language proficiency can be accounted for by the linear combination of group engineering term use. The relationship was not able to be inferred to the population and the effect size was moderate to low, $R^2=.24$, adj$R^2=.02$. This suggested that the relationship was weak in the present sample. To understand the relative strengths of the predictors, bivariate and partial correlations were examined. These are shown in Table 11.

Table 11

Bivariate and Partial Correlations of the Predictors with Language Proficiency: Design Task 2

Predictors	Correlation between each predictor and language proficiency	Correlation between each predictor and language proficiency controlling for other predictors
Frequency of Term Use	-.46	-.44
Uniqueness of Term Use	-.24	-.17

All the bivariate correlations were negative, though not statistically significant, making it difficult to make claims about the relationship between term use and language proficiency in the broad population. However, it was still possible to understand the relationship of the variables in the sample for this study. For the study sample, the bivariate correlations suggested that group engineering term use was, again, inversely related to academic proficiency on the design task. In other words, the more terms students in the study sample used in their group discussion, the less proficient they were on the engineering design task, though the relationship was weaker than Design Task 1. Frequency of term use for the study sample was weakly correlated to language proficiency when controlling for the effects of unique term use. However, the variety of different terms used during team interactions was not related to language proficiency in the study sample when controlling for frequency of term use. It is important to mention that the frequency of engineering term use and uniqueness of engineering term use during team activities were, again, strongly correlated, r=.74, p=.01. Due to the correlation of these two predictors, it was difficult to understand the true relative importance of each in predicting academic language proficiency.

Predicting Engineering Design Task 3

For the third time interval, the linear combination of group language use was not significantly related to language proficiency, $F(2,5)=1.37$, $p=.88$. The sample multiple correlation coefficient was .23, indicating that approximately 5% of the variance of language proficiency was accounted for by the linear combination of group engineering term use. The relationship cannot be used to infer to the population and was not a large effect size, $R^2=.05$, adj$R^2= -.32$. This suggested that the predictors do not predict academic language proficiency. To understand if the predictors had individual effects, bivariate and partial correlations were examined. These are shown in Table 12.

Table 12

Bivariate and Partial Correlations of the Predictors with Language Proficiency: Design Task 3

Predictors	Correlation between each predictor and language proficiency	Correlation between each predictor and language proficiency controlling for other predictors
Frequency of Term Use	.13	-.11
Uniqueness of Term Use	.20	.19

Bivariate correlations were small and not statistically significant. This suggested that even within the sample, there was not a meaningful relationship between group language use and language proficiency. In other words, the amount of terms students used in their group discussion was not related to how proficient they were on the engineering design task.

Predicting Engineering Design Task 4

For the fourth time interval, the linear combination of group language use was not significantly related to language proficiency, $F(2,4)=.47$, $p=.66$. The sample multiple correlation coefficient was .44, indicating that approximately 19% of the variance of language proficiency was accounted for by the linear combination of group engineering term use. The relationship was not able to be inferred to the population and the effect size was low, $R^2=.19$, adj$R^2= -.21$. This suggested that the relationship may not be present in the sample. To understand if the predictors had individual effects, bivariate and partial correlations were examined. These are shown in Table 13.

Table 13

Bivariate and Partial Correlations of the Predictors with Language Proficiency: Design Task 4

Predictors	Correlation between each predictor and language proficiency	Correlation between each predictor and language proficiency controlling for other predictors
Frequency of Term Use	.43	.29
Uniqueness of Term Use	.34	-.08

Bivariate correlations were small and not statistically significant. This suggested that even within the sample, there was not a meaningful relationship between group language use and language proficiency. In other words, the amount of terms students used in their group discussion was not related to how proficient they were on the engineering design task.

Summary

In all four cases, the linear combination of group language use was not significantly related to language proficiency. However, the effect sizes (R^2=.57, .24, .05, .19) were able to provide insight towards the phenomena within the small sample. For the first engineering design task, the amount of group term use was inversely and strongly related to engineering language proficiency. This relationship then became weaker for design tasks two and three. By design task four, group term use was directly and weakly related to engineering language proficiency. Near the beginning of the semester, the more terms used in the group suggested a low level of language proficiency in the sample. By the end of the semester, the more words used in groups suggested higher levels of language proficiency. For the study sample, it seems that the influence of exposure to engineering language during team tasks on engineering language proficiency varies throughout the semester. To answer the research question, however, the relationship between exposure to engineering language during team tasks on engineering language proficiency cannot be inferred.

Research Question Two

The second research question asked how exposure to engineering language through peer discussion during team tasks influenced conceptual understanding in the context of an engineering design task. To answer this question, regression analysis was conducted for each group at four different intervals throughout the semester. These intervals were determined by the collection of each engineering design task. Group level data was examined by considering mean group scores for observation data and conceptual understanding as measured by design task data. Observation data included frequency of term use and uniqueness of term use.

A series of multiple regression analyses were conducted to evaluate how well group engineering language use predicted conceptual understanding. The predictors were the frequency of language use and uniqueness of language use while the criterion variable was the mean group conceptual understanding score on the engineering design task. Since group level data was used, the sample size for these analyses was only N=9. This suggests that the study may have been underpowered, making it difficult to infer results to the population. For this reason, effect sizes will be discussed in more detail than inferential statistics.

Predicting Engineering Design Task 1

For the first time interval, the linear combination of group language use was not significantly related to conceptual understanding, $F(2,6)=.69$, $p=.54$. The sample multiple correlation coefficient suggested by the model was .43, indicating that approximately 19% of the variance of conceptual understanding can be accounted for by the linear combination of group engineering term use. The relationship was not able to be inferred to the population and the effect size was small, $R^2=.19$, adj$R^2= -.09$. This suggested that the predictors do not predict conceptual understanding. To understand the relative strengths of the predictors, bivariate and partial correlations were examined. These are shown in Table 14.

Table 14

Bivariate and Partial Correlations of the Predictors with Conceptual Understanding: Design Task 1

Predictors	Correlation between each predictor and conceptual understanding	Correlation between each predictor and conceptual understanding controlling for other predictors
Frequency of Term Use	.20	.43
Uniqueness of Term Use	-.06	-.39

Correlations were not statistically significant. This suggested that group engineering term use was not related to conceptual understanding on the design task. In other words, the amount of terms students used in their group discussion was not related to their conceptual understanding on the engineering design task.

Predicting Engineering Design Task 2

For the second time interval, the linear combination of group language use was not significantly related to conceptual understanding, $F(2,6)=3.21$, $p=.11$. The sample multiple correlation coefficient was .72, indicating that approximately 52% of the variance of conceptual understanding can be accounted for by the linear combination of group engineering term use. While the relationship was not able to be inferred to the population, the effect size was large, $R^2=.52$, adj$R^2=.36$. This suggested that the relationship was strong in the present sample. To understand the relative strengths of the predictors, bivariate and partial correlations were examined. These are shown in Table 15.

Table 15

Bivariate and Partial Correlations of the Predictors with Conceptual Understanding: Design Task 2

Predictors	Correlation between each predictor and conceptual understanding	Correlation between each predictor and conceptual understanding controlling for other predictors
Frequency of Term Use	-.70	-.64
Uniqueness of Term Use	-.42	.21

All the bivariate correlations were moderate, though not statistically significant, making it difficult to make claims about the relationship between term use and conceptual understanding in the broad population. However, it was still possible to understand the relationship of the variables in the sample for this study. The bivariate correlations suggested that, in the study sample, group engineering term use was inversely related to conceptual understanding on the design task. In other words, the more terms students in the study sample used in their group discussion, the less conceptual understanding they exhibited on the engineering design task. This relationship cannot be generalized past the study sample.

Predicting Engineering Design Task 3

For the third time interval, the linear combination of group language use was not significantly related to conceptual understanding, *F*(2,5)=.17, *p*=.85. The sample multiple correlation coefficient was .25 indicating that approximately 6%

of the variance of conceptual understanding can be accounted for by the linear combination of group engineering term use. The relationship was not able to be inferred to the population and was not a large effect size, R^2=.06, adjR^2= -.31. This suggested that the predictors did not predict conceptual understanding. To understand if the predictors had individual effects, bivariate and partial correlations were examined. These are shown in Table 16.

Table 16

Bivariate and Partial Correlations of the Predictors with Conceptual Understanding: Design Task 3

Predictors	Correlation between each predictor and conceptual understanding	Correlation between each predictor and conceptual understanding controlling for other predictors
Frequency of Term Use	.23	.20
Uniqueness of Term Use	.15	-.11

Correlations were small and not statistically significant. This suggested that there was not a meaningful relationship between group language use and conceptual understanding. In other words, the amount of terms students used in their group discussion was not related to their conceptual understanding on the engineering design task.

Predicting Engineering Design Task 4

For the fourth time interval, the linear combination of group language use was not significantly related to conceptual understanding, $F(2,4)$=.29, p=.77. The sample multiple correlation coefficient was .35 indicating that approximately 13%

of the variance of conceptual understanding can be accounted for by the linear combination of group engineering term use. The relationship was not able to be inferred to the population and the effect size was small, R^2=.13, adjR^2= -.31. This suggested that the relationship was not apparent in the present sample. To understand the relative strengths of the predictors, bivariate and partial correlations were examined. These are shown in Table 17.

Table 17

Bivariate and Partial Correlations of the Predictors with Conceptual Understanding: Design Task 4

Predictors	Correlation between each predictor and conceptual understanding	Correlation between each predictor and conceptual understanding controlling for other predictors
Frequency of Term Use	.33	.05
Uniqueness of Term Use	.35	.14

Correlations were weak and not statistically significant. This suggested that group engineering term use was not related to conceptual understanding on the design task.

Summary

In all four cases, the linear combination of group language use was not significantly related to conceptual. However, the effect sizes (R^2=.19, .52, .06, .13) were able to provide insight towards the phenomena within the small sample. For the first engineering design task, the amount of group term use was not related to engineering conceptual understanding. This relationship then became strong for design task two. The trend showed that the more terms students in the study sample used, the less they were likely to understand. By design task three and four, the amount of group term use was not related to engineering conceptual understanding. For the study sample, it seems that the influence of exposure to engineering language during team tasks on conceptual understanding has minimal effect. To answer the research question, the relationship between exposure to engineering language during team tasks on engineering conceptual understanding cannot be inferred.

Research Question Three

The third research question asked what the relationship between conceptual understanding and engineering language was when examined during an engineering design task over the course of a semester. To answer this question, regression analysis was conducted at four different intervals throughout the semester. These intervals were determined by the collection of each engineering design task.

A series of multiple regression analyses were conducted to evaluate how well engineering language proficiency predicted conceptual understanding. The predictors were language proficiency on the engineering design task while the criterion variable was conceptual understanding scores on the engineering design task.

Predicting Engineering Design Task 1

For the first time interval, the linear combination of language proficiency was significantly related to conceptual understanding, $F(1,34)=19.30$, $p<.01$. The sample multiple correlation coefficient was .60, indicating that approximately 36% of the variance of conceptual understanding can be accounted for by engineering language proficiency, R^2=.36, Adj R^2=.34. The effect size was moderate to high. To understand the strength of the predictor, the bivariate correlation was examined and both were statistically significant and strong, r=.60, p<.01. This suggested that as student proficiency increased, so did conceptual understanding, making engineering language proficiency a good predictor of engineering conceptual understanding.

To ensure that initial conceptual understanding was not influencing the relationship, a second analysis was done predicting conceptual understanding from pre MCI score and language proficiency. The second model did not produce any statistically significant increases, ΔR^2=.00, p=.98. This suggested that by adding the initial MCI score to the model, no greater prediction in conceptual understanding scores could be made.

Predicting Engineering Design Task 2

For the second time interval, the linear combination of language proficiency was significantly related to conceptual understanding, $F(1,21)$=20.00, p<.01. The sample multiple correlation coefficient was .70 indicating that approximately 49% of the variance of conceptual understanding can be accounted for by engineering language proficiency, R^2=.49, Adj R^2=.46. The effect size was high. To understand the strength of the predictor, the bivariate correlation was examined and both were statistically significant and strong, r=.70, p<.01. This suggested that as student proficiency increased, so did conceptual understanding, making engineering language proficiency a strong predictor of engineering conceptual understanding.

To ensure that initial conceptual understanding was not influencing the relationship, a second analysis was conducted predicting conceptual understanding from pre MCI scores and language proficiency. The second model had statistically significant increases, *F*(1,20)=5.60. *p*=.03. An additional 11% of the variance in conceptual understanding scores could be accounted for when adding pre MCI scores as predictors, ΔR^2=.11. To understand the relative strengths of the predictors, bivariate and partial correlations were examined. These are shown in Table 18.

Table 18

Bivariate and Partial Correlations of Language Proficiency with Conceptual Understanding

Predictors	Correlation between each predictor and conceptual understanding	Correlation between each predictor and conceptual understanding controlling for other predictors
Language Proficiency	.70**	.73**
Pre MCI Score	.39*	.47*

**p*<.05, ***p*<.01

All the bivariate correlations were large and positive. This suggested that both language proficiency and initial MCI scores were directly related to conceptual understanding on the design task. In other words, the more proficient students were in engineering language and the higher they scored on the MCI prior to instruction, the higher conceptual understanding they showed on the engineering design task. Engineering language proficiency was strongly correlated to conceptual understanding when controlling for the effects of the pre MCI. This suggested that language proficiency was a greater predictor of conceptual understanding than the initial MCI score.

Predicting Engineering Design Task 3

For the third time interval, the linear combination of language proficiency was significantly related to conceptual understanding, $F(1,17)=11.48$, $p<.01$. The sample multiple correlation coefficient was .64, indicating that approximately 40% of the variance of conceptual understanding can be accounted for by engineering language proficiency, $R^2=.40$, Adj $R^2=.37$. The effect size was moderate to high. To understand the strength of the predictor, the bivariate correlation was examined and both statistically significant and strong, $r=.63$, $p<.01$. This suggested that as student proficiency increased, so did conceptual understanding, making engineering language proficiency a good predictor of engineering conceptual understanding.

To ensure that initial conceptual understanding was not influencing the relationship, a second analysis was conducted predicting conceptual understanding from pre MCI scores and language proficiency. The second model did not produce any statistically significant increases$\Delta R^2=.00$, $p=.91$. This suggested that the prediction of conceptual understanding scores was unaffected by the addition of initial MCI scores.

Predicting Engineering Design Task 4

For the fourth time interval, the linear combination of language proficiency was significantly related to conceptual understanding, $F(1,10)=15.97$, $p<.01$. The sample multiple correlation coefficient was .78, indicating that approximately 62% of the variance of conceptual understanding can be accounted for by engineering language proficiency. The effect size was high, $R^2=.62$, adj $R^2=.57$. To understand the strength of the predictor, the bivariate correlation was examined and both were statistically significant and strong, $r=.78$, $p<.01$. This suggested that as student proficiency increased, so did conceptual understanding, making engineering language proficiency a very strong predictor of engineering conceptual understanding.

To ensure that initial conceptual understanding was not influencing the relationship, a second analysis was conducted predicting conceptual understanding from pre MCI scores and language proficiency. The second model did not produce any statistically significant increases, $\Delta R^2=.00$, $p=.97$. This suggested that the initial MCI scores had no effect on the model's predictions of conceptual understanding scores.

Summary

In all four cases, the linear regression of engineering language proficiency was significantly related to conceptual understanding. The effect sizes ($R^2=.36$, .49, .40, .62) ranged from moderately high to high, indicating that language proficiency was a powerful predictor of conceptual understanding throughout the semester and the most powerful predictor near the end of the semester. For the second engineering design task, initial MCI scores were also able to predict conceptual understanding scores. However, this was not the case at any other time; adding the pre MCI to the regression model did not increase the variance accounted for by language proficiency alone. To answer the research question, engineering language proficiency and conceptual understanding are directly related and this relationship may strengthen over time.

Engineering Language Proficiency

Student engineering language use during team activities did not produce any statistically significant impacts on engineering language proficiency on design tasks. This may be a result of an underpowered study as there were some high effect sizes. Even effect sizes provide inconsistent insights as, in the study sample, group language use inversely affected language proficiency near the beginning of the semester but then directly influenced it towards the end. These results suggest that team interactions may not have a consistent or desired effect of helping students achieve engineering language proficiency. However, developing engineering language proficiency is important because results suggest that it was directly related to engineering conceptual understanding. Engineering language proficiency has a high effect on conceptual understanding, strengthening over the course of the semester.

Chapter 5

DISCUSSION

Engineering Language Proficiency

This study examined how engineering language proficiency influenced conceptual understanding of introductory materials science and engineering concepts. Three research questions guided this dissertation:

1. How does exposure to engineering language through peer discussion during team tasks influence engineering language proficiency?
2. How does exposure to engineering language through peer discussion during team tasks influence conceptual understanding in the context of an engineering design task?
3. What is the relationship between conceptual understanding and engineering language when examined during an engineering design task over the course of a semester?

Exposure to Engineering Term Use and Language Proficiency

Using regression analysis student engineering term use during team activities did not produce any statistically significant predictions about language proficiency as measured by the design tasks. However, it is important to point out that statistical significance only determines if the findings are generalizable to the desired population. It does not influence the reported effects that existed in the study sample. In the study sample, engineering term use was strongly and inversely correlated to language proficiency in the beginning of the semester. As the semester progressed, this relationship became weaker and by the end of the semester, engineering term use was moderately correlated to language proficiency. This suggests that in the study sample, there were relationships between engineering term use and language proficiency though those relationships changed throughout the semester. These findings could not be inferred to the population.

The lack of relationship may have been a result of the small sample size. However, even in the study sample, the relationship between engineering term use and language proficiency was not clear. Providing students with opportunities to use engineering language is not enough to ensure that they become proficient in language (Lemke, 1990; Ptalano & Seifert, 1997; Yeung & Werker, 2009). Lemke (1990) discussed that explicit instruction about scientific language is required for students to become proficient in science language. In order for students to understand engineering language, they must be given information about the utility and functionality of words when they are introduced (Yeung & Werker, 2009). While participants in the study were given many opportunities to use engineering language, there was minimal time devoted to explicit instruction of engineering language. However, giving students opportunities to self-reflect about their language use helps with developing language proficiency (Chamot & O'Malley, 1996; Anderson, 2002). In this study, these strategies were not used to help students acquire engineering language. The current study suggests that, even with repeated engineering term use, students do not acquire engineering language proficiency when explicit language instruction and self-reflection about language use are not implemented.

Exposure to Engineering Term Use and Conceptual Understanding

Student engineering term use during team activities did not produce any statistically significant predictions of conceptual understanding as measured by regression analysis during the design tasks. In the study sample, engineering term use was weakly correlated to conceptual understanding at the start of the semester. This suggested that, initially, there was a negligible relationship. However, by the second assessment, student term use was strongly and inversely correlated to conceptual understanding. The more students used terms, the less likely they were to understand concepts. By the third and fourth assessments, the relationship became moderate and direct, making student term use directly related to conceptual understanding. This suggests that, in this sample, engineering term use was initially unimportant to conceptual understanding, then hindered conceptual understanding, and later predicted it. These findings could not be inferred to the population.

The lack of relationship may have been a result of the small sample size. However, even in the study sample, the relationship between engineering term use and conceptual understanding was not clear. Norris and Phillips (2003) claimed that in order for students to become proficient in science, they must be able to interpret and understand written text. While engineering term use gave students practice using engineering verbal language, it did not provide opportunities to become proficient in engineering written language. Roth (2000) found that students repeated use simultaneous terms and gestures led to student understanding of the normative ideas associated with those terms. Student gestures were not observed as part of this study. However, students rarely were engaged in engineering tasks while using engineering terms. This limited their ability to use appropriate engineering gestures while speaking. For example, when discussing engineering tensile tests, students were not able to be in the laboratory with a set up tensile test which would have allowed them to point and interact with something tangible. Examination of engineering written language and gesture use were not used to help students make connections between language and conceptual understanding. The current study suggests that, even with repeated engineering term use, students do not acquire conceptual understanding when the discussed strategies are not implemented.

Conceptual Understanding and Engineering Language Proficiency

Through a regression analysis of conceptual understanding and engineering language proficiency, engineering language proficiency predicted conceptual understanding as measured by engineering design tasks. These results were statistically significant indicating that not only did they exist in the study sample, but they can be inferred to the population from which the sample was drawn. As the semester progressed, this relationship was strengthened. These results suggest that engineering language proficiency is very important and becomes even more important for conceptual understanding over time.

Previous Research

Previous research addressed how students develop scientific language during classroom instruction. Lemke (1990) argued that students need practice discussing science, explicit instruction about scientific language, and instruction about genres of communication in science. The findings in this study showed that by only giving students opportunities to engage in engineering academic language, there was no measurable influence on their engineering language proficiency. This suggests that a multiple step approach, like the one that Lemke proposed may be necessary. Students might need explicit instruction over and above opportunities to use language. These findings, however, are inconsistent with conclusions drawn by Kemp and Avob (1995) that suggested that exposure to oral scientific language influenced student performance on writing samples. Due to the small sample size associated with the present study, additional research is required to provide insights to the true relationship. Additional research linking scientific or engineering academic language to conceptual understanding is sparse, suggesting that the relationship still requires further exploration in order to be understood.

Limitations of the Dissertation Study

One limitation of this study is the use of a convenience sample of students in an introductory materials science and engineering course at a university in the southwestern United States. This class was limited in the number of students, so a large sample of students from varying locations and backgrounds was not obtained. Additionally, groups were not randomly assigned within the sample, making it impossible to control for characteristics that may have brought students together to choose to be in a group. Since group level data was used, the small sample size limited the ability to infer results to a larger population. A larger sample size would be desirable.

The convenience sample was made up of an actual classroom unit that spanned over a fifteen week semester. As a result, student attendance could not be controlled. Additionally, students who did not complete assignments could not be assessed. As the rigor of the course increased over the semester, collecting student data became increasingly difficult. Ideally, a more controlled setting would be used to control for the challenges that occur in common classrooms.

All engineering design tasks were scored by the researcher. As a result, no inter rater reliability could be calculated. Additionally, it is possible that, because the rater was the researcher, that observations could have been biased. The use of multiple external raters could control for these discussed challenges of reliability and bias.

Group observations were conducted over time intervals. This meant that each group had their first observation within a two week time frame, a second observation within the next two week time frame, and so on. This observation scheduled assumed that within the two week observation interval all groups had the same experiences and had made the same progress in the course. However, since there were two class meetings per week, observations for each group could have been as much as three classes apart from one another. As a result, students may have been in varying places in their learning. This limitation was imposed because the researcher could not conduct all nine observations in one class period based on the structure of the course and time allotted to team activities. Multiple observers conducting simultaneous observations on all groups would be best.

Recommendations

Increased Frequency of Group Observations

There were over three hundred new engineering terms introduced to students over the course of the semester. As a result, students were being exposed to many new terms each class. This suggests that team interactions should be observed more frequently in order to be able to determine how student interactions are influenced by the constantly growing vocabulary. Rather than observing groups every two weeks, they should be observed daily and simultaneously. This would ensure that all groups have been introduced to the same amount of vocabulary and are being asked to do the same task at the time of observation.

Increased Variety of Design Task Contexts

In this study, engineering design tasks were framed in airplane and bicycle design. To ensure that the studied relationships occur across all types of engineering design, additional design contexts must be explored. While conceptual understanding and language proficiency were independent of the two design task contexts used in the study, it may differ in substantially different contexts. For example, students may exhibit varying levels of conceptual understanding and language proficiency when designing for medical purposes or sustainability. These avenues need to be explored.

Increased Variety of Communication Mediums

Engineering language proficiency was only examined through writing samples in this study. However, language also permeates verbal interactions. To understand engineering language proficiency as a whole, it should be assessed verbally as well. It is possible that students exhibit differing levels of language proficiency when communicating verbally rather than through writing. By assessing verbal communication, this relationship could be explored.

Influence of Teaching Practice

In this study, students were examined independent of the classroom environment. However, it is possible that the relationship between engineering language proficiency and conceptual understanding varies with each classroom environment. By examining students from different classroom settings, these varying environments could be controlled for during statistical analysis. The current study was conducted in a classroom that valued student communication and team tasks. In order to understand if the relationship between engineering language proficiency and conceptual understanding is the same for all students, students from different types of classrooms must be observed.

Future Directions

The first step in continuing the study is to expand the sample size. This would allow for the sample trends to be inferred to a broader population of introductory materials engineering students. In doing so, students from varying types of materials engineering classroom environments should also be examined to determine if the relationships found were independent of classroom setting.

Another extension of the study is to add additional assessments that provide a more holistic view of student engineering language proficiency. This would include assessing student verbal language in addition to written language. By doing this, the intricacies between modes of communication can be examined.

After the previous trends have been explored, the mechanism for engineering language development should be examined. Though it is helpful to understand that engineering language proficiency predicts conceptual understanding, it does not answer why it influences conceptual understanding or how it is developed. Insights about how engineers acquire academic language could yield implications about how to better educate engineers.

The ability to speak the language of a culture helps one feel like a part of that culture. Proficiency in engineering language may contribute to a student’s sense of belonging and identity within the engineering culture. This may lead to understanding what factors cause students to choose to study or pursue careers in engineering. The potential link between engineering language proficiency and engineering identity is one that needs to be explored in order to help recruit future engineers.

Conclusions

Students may use the technical engineering terms without knowing what these words mean. This creates a language barrier in engineering that influences student learning. Previous research has been conducted to characterize the difference between colloquial and scientific language. Since this research had not yet been applied explicitly to engineering, conclusions from the area of science education were used instead. Various researchers outlined strategies for helping students acquire scientific language. However, few examined and quantified the relationship it had on student learning. The goal of engineering education is to educate students such that they enter the engineering field and address societal needs. Consequently, it becomes imperative that the relationship between language proficiency and conceptual understanding of engineering concepts be explored in order to inform practitioners how to best prepare future engineers. A SFL framework was adopted for this dissertation which is a framework that has not previously been used in engineering education research. However, educational researchers from varying disciplines stressed that SFL is necessary when examining links between language and meaning.

Engineering academic language proficiency was found to be strongly linked to conceptual understanding in the context of introductory materials engineering courses. As the semester progressed, this relationship became even stronger. The more engineering concepts students are expected to learn, the more important it is that they are proficient in engineering language. However, exposure to engineering terms did not influence engineering language proficiency.

These results stress the importance of engineering language proficiency for learning, but warn that simply exposing students to engineering terms does not promote engineering language proficiency. In order to better prepare students to become engineers it is clear that language matters. Additional research is required to understand how to best foster student engineering language proficiency.

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APPENDIX A

DEMOGRAPHIC SURVEY

Identification Code: ____________

Date: ____________

Student Survey

For each of the questions below, circle the answer that best represents your choice.

1. *How many languages are you fluent in?*	1	2	3	4	5+				
2. *Is English your first language?*	*yes*	*no*							
3. *How confident are you in your ability to learn another language?*	1 *Not at all Confident*	2	3 *neutral*	4	5 *very confident*				
4. *How many college level engineering courses have you taken so far?*	1	2	3	4	5	6	7	8	9+
5. *How many college level chemistry courses have you taken so far?*	1	2	3	4	5	6	7	8	9+
6. *In your opinion, how important is knowledge of engineering vocabulary for understanding engineering concepts?*	1 *Not at all important*	2	3 *neutral*	4	5 *very important*				

APPENDIX B

SAMPLE CLASS LECTURE NOTES

Ch. 2: Atomic Structure & Interatomic Bonding II: Relationship to Material Properties

ISSUES TO ADDRESS...

- What macroscopic properties are affected by the *bond strength* in metals, ceramics, & polymers?
- How does bonding affect physical properties of Elastic Modulus (stiffness) and Coefficient of Thermal Expansion?
- How are Melting Point, Coefficient of Thermal Expansion, and Modulus related to a material's atomic bonding potential well?

Class 3 – Chapter 2: Bonding & Material Properties Topic #1.2

Bond Strength → Macroscopic Properties

Bond strength is related to three macroscopic properties:

–Modulus (stiffness) E

Will a given force deform a more strongly bonded material more or less?

–Melting Temperature Tm

Will it take more or less thermal energy to melt a more strongly bonded material?

–Coefficient of Thermal Expansion α

Will material's atoms vibrate with greater or lesser amplitude in a more strongly bonded when temperature is raised?

Thomas Young
(1773-1829)

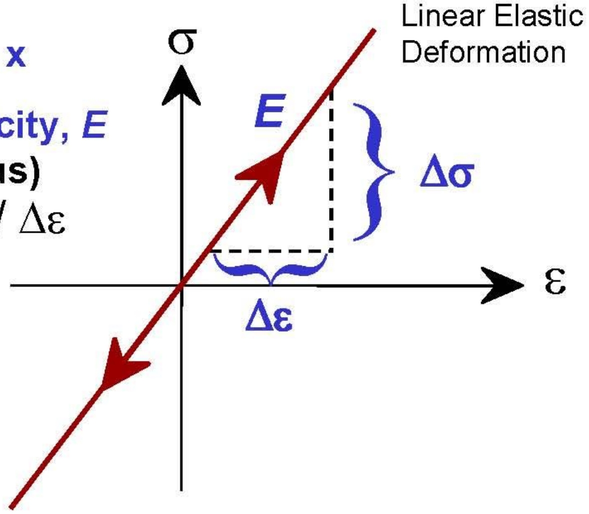
English genius – physicist who created Young's Modulus, a physician who discovered eye focusing mechanism, linguist who translated Rosetta Stone

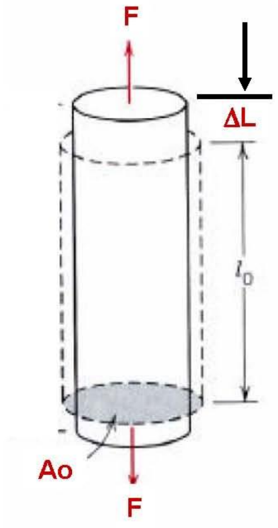
How Do Materials Behave When Stressed?

stress σ = Normalized force (F/Ao) vs.
strain ε = Normalized elongation (ΔL/Lo)

Hooke's Law F = k x

- **Modulus of Elasticity, *E***
  (Young's modulus)
  $E = \sigma / \varepsilon = \Delta\sigma / \Delta\varepsilon$

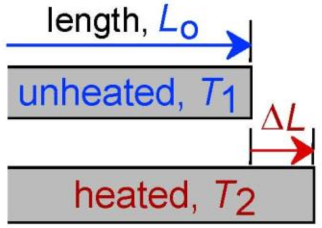




What is Coefficient of Thermal Expanision α?

It is elongation of a material in response to higher temperature

- Coefficient of thermal expansion, $\boldsymbol{\alpha}$



coeff. thermal expansion $\boldsymbol{\alpha}$

$$\frac{\Delta L}{L_o} = \alpha\,(T_2 - T_1)$$

Atomic Bonding Forces in Equilibrium

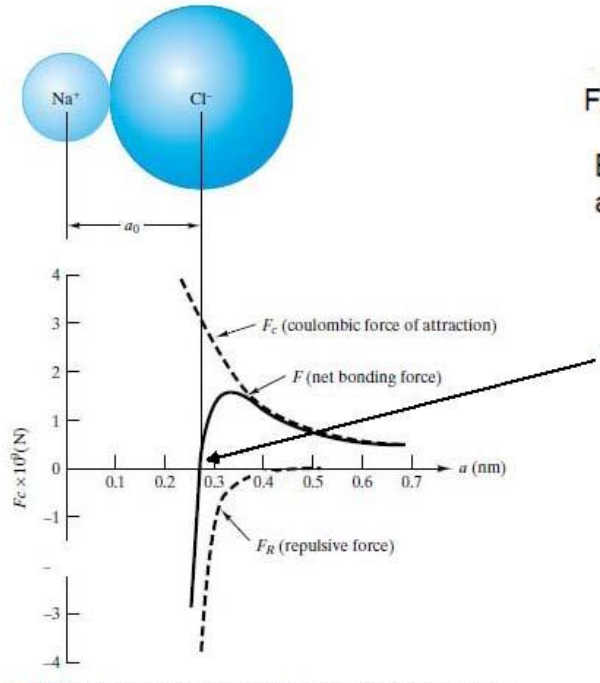


Figure 2-7 *Net bonding force curve for a* Na^+-Cl^- *pair showing an equilibrium bond length of* $a_0 = 0.28$ *nm.*

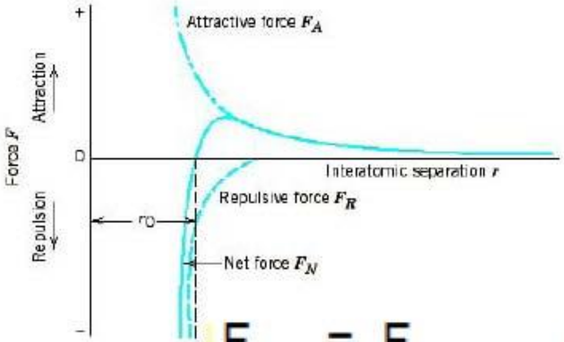
$F_{Net} = F_{Attractive} + F_{Repulsive}$

Balance between repulsive and attractive forces of atoms

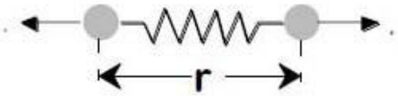
Zero force = lowest energy

$F_{attractive} = F_{repulsive}$

Bonding Forces and Energy

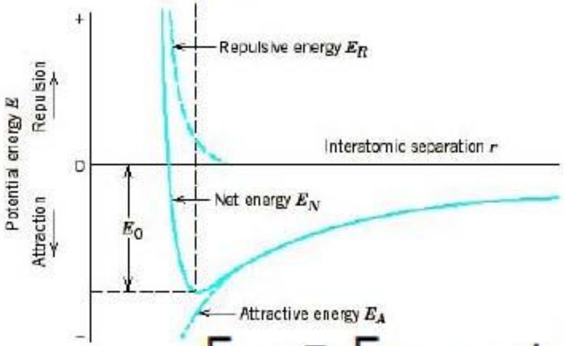


Bond length, r



Net force is given by the **sum** of an **attractive** force and a **repulsive** force

$$F_{Net} = F_{Attractive} + F_{Repulsive}$$



Potential is given by the integral of the net force curve with respect to distance:

$$E = \int F \bullet dr$$

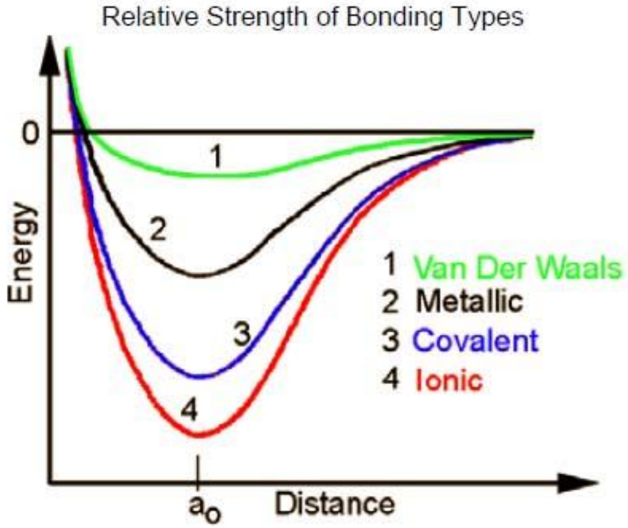
Note: *equilibrium separation occurs where the net force = 0*

$$E_{Net} = E_{Attractive} + E_{Repulsive}$$

Bond Strength → Macroscopic Properties

Bond strength is related to three macroscopic properties:

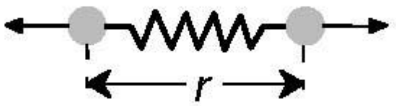
- –Modulus (stiffness)
- –Temperature of melting
- –Coeff. of Thermal Expansion



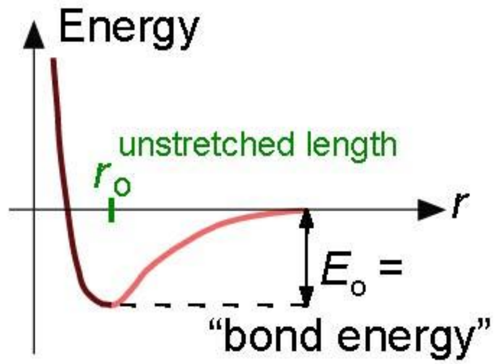
Deeper well depth = stronger bonding

Property Related to *Bond Strength*: T_m

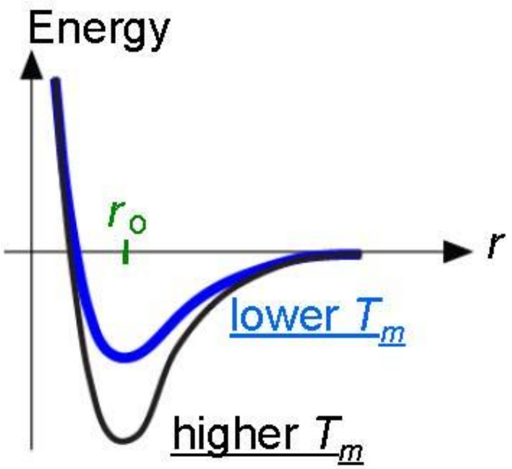
- Bond length, r



- Bond energy, E_o



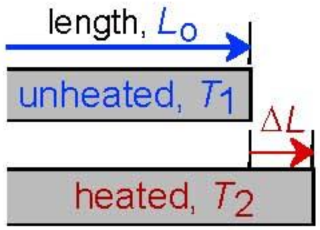
- Melting Temperature, T_m



T_m is larger if E_o is larger.

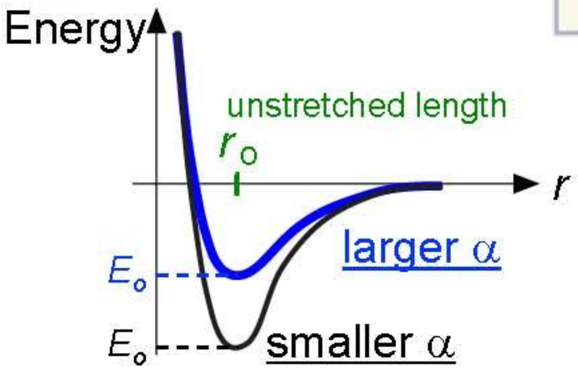
Property Related to *Bond Strength*: α

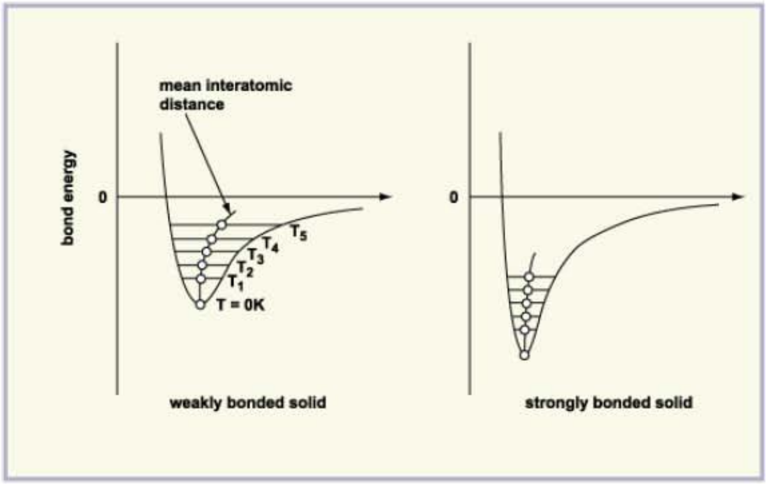
- Coefficient of thermal expansion, α



coeff. thermal expansion α

$$\frac{\Delta L}{L_o} = \alpha\,(T_2 - T_1)$$

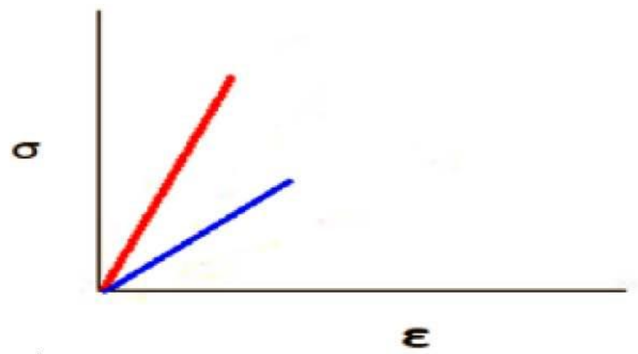




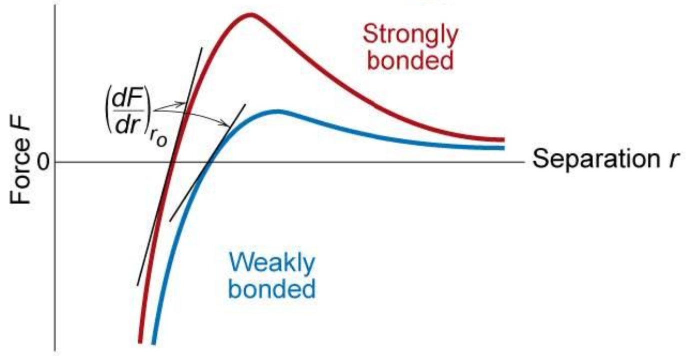
α is larger if E_o is smaller.

Property Related to *Bond Strength* - Elastic Modulus

E = elastic modulus = σ / ε



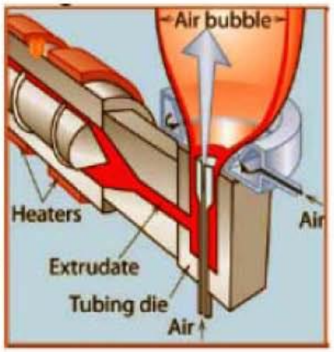
Slope of stress strain curve is the elastic modulus E which correlates to atomic level rate of change in atomic spacing as force is changing



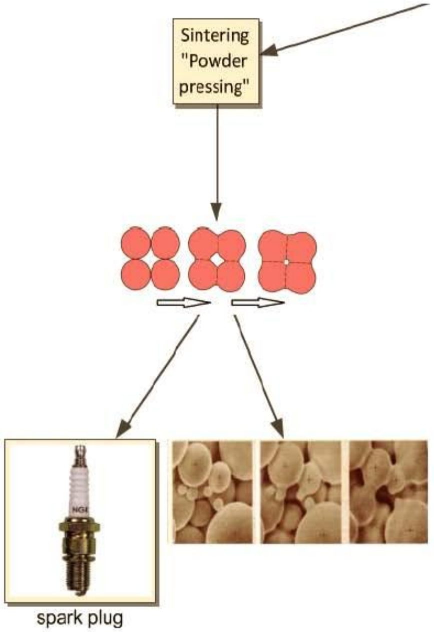
Surface residual stress in a deformed metal can be measured with X-ray diffraction that gives the change in crystal unit cell lattice spacing

Effect of Bonding on Temperature of Processing

Polymer Film Blowing Low Tm

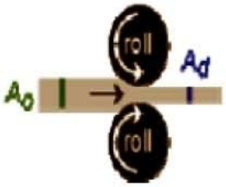


Ceramic Sintering High Tm

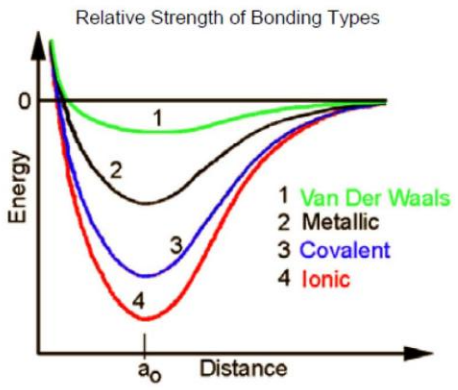


Metal Cold Rolling Moderately High Tm

- **Rolling (Hot or Cold Rolling)**
  (I-beams, rails, sheet & plate)



Bond Types in Engineering Materials

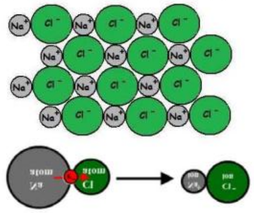


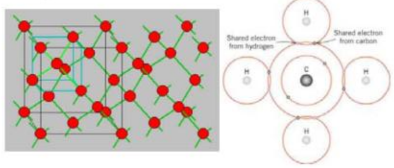
Deeper well depth = stronger bonding

Ceramics - Ionic and/or Covalent Bonding

Ionic bond solid **3-D Covalent bonded solid**

Transfer of electrons **Sharing of electrons**

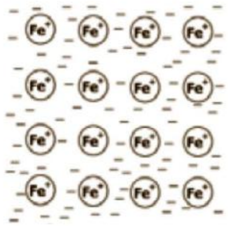




Metals - Metallic Bonding

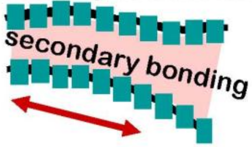
Metallic bonded solid -

Cation metal cores bound by delocalized sea of e's



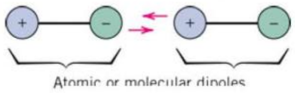
Polymers

1-D covalently bonded chain + vanDW between chains

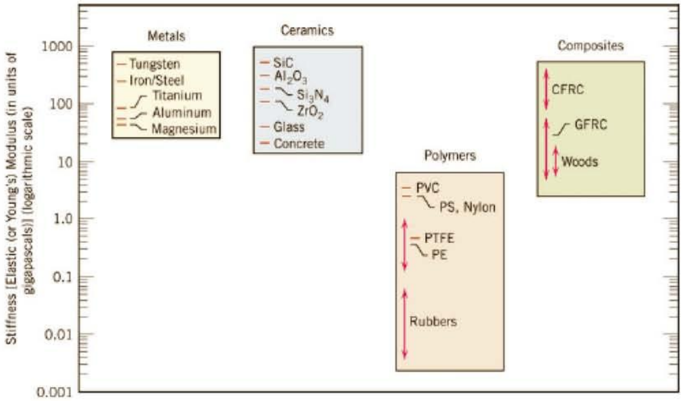


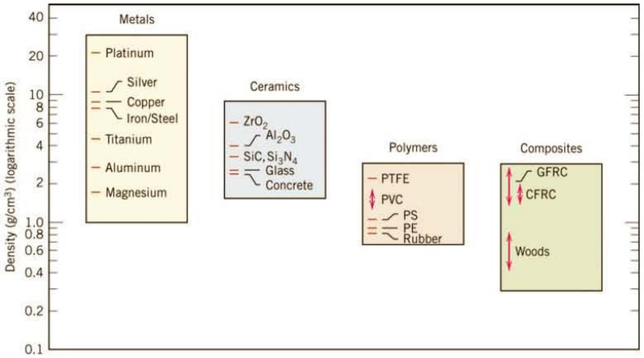
-C-C-C- covalent bonds along chain

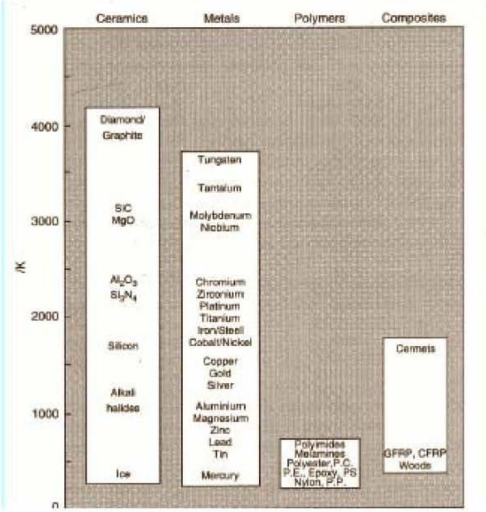
Temporary Dipole



Property Ranges for Families of Materials







Melting or softening temperatures

Activity - Bonding & Macroscopic Properties Worksheet

Color Concept Connecting Activity – Connecting Atomic Bonding and Physical Properties

I. Characteristics of 2 pure metals, Metal A and Metal B, are pictured below in each of the four figures.
What characteristic is shown in each Figure (i.e. what info does it give you) what does Figure say about differences of A vs B?

Figure 1 ____________________

Figure 2 ____________________

Figure 3 ____________________

Figure 4 ____________________

E = elastic modulus = σ / ε

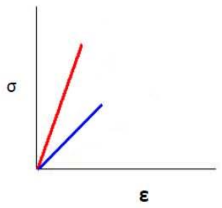
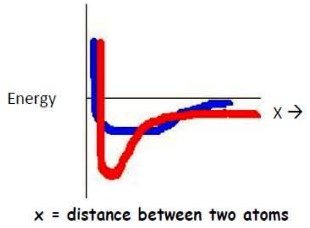


Figure 1



x = distance between two atoms

Figure 2

T_m = melting point

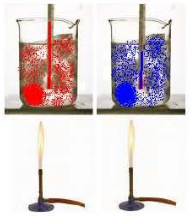


Figure 3

α = coefficient of thermal expansion

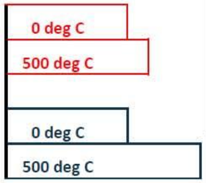


Figure 4

II. Fill in blanks below with **greater than** (**>**) or **less than** (**<**) comparing values of Metal A vs. Metal B from Figures .

? Explain your reasoning in 12 words or less:

E_A _____ E_B ____________________

α_A _____ α_B ____________________

$T_{m,A}$ _____ $T_{m,B}$ ____________________

Bond strength $_A$ _____ Bond strength $_B$ ____________________

III. From the list of these metals select four possible metal pairs of **A & B**: **Cu**; **Al**; **W**; **Fe**

i) Metal A___ vs B___; ii) Metal A___ vs B___; iii) Metal A___ vs B___; iv) Metal A___ vs B___

IV. Match III metals & items

Al pan

W filament

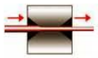
Cu kettle

Fe bridge

V.**Processing**

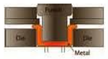
a) Cast

b) Wire drawn



c) Hammered

d) Deep drawn



Property Units for Bond Related Properties

Bond strength and type are strongly related to some important macroscopic properties:

- E - Elastic modulus (stiffness) = σ / ε (Gpa or msi)
- α - Coefficient of Thermal Expansion Δcm/cm-K
- Tm - Melting Temperature (^{o}C)

Many other features of materials besides bonding need study to show effects on properties.

- How do materials permanently deform or break?
- Why are some materials strong and others weak?
- Why do materials fail when it is too hot, too cold, or have too many stress cycles?

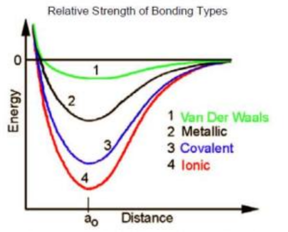
Summary of Bonding Property Relations in Materials

Ceramics

(Ionic & 3-D covalent bonding):

High bond strength

high T_m
high E
low α



Deeper well depth = stronger bonding

Metals

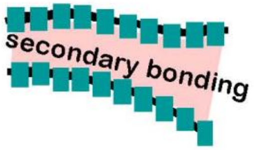
(Metallic bonding):

Moderately high bond strength

moderately high T_m
moderately high E
high α

Polymers

(1-D Covalent & Secondary):



Lower bond strength

Secondary bond. dominates unoriented poly.

small T_m
small E
large α

1-D covalent bond dominates oriented poly.

Activity - Materials Selection

Choose the most likely property, material, bonding, and process for these motorcycle items

	property	material	bonding	processing
i) motorcycle fender	______	________	________	________
ii) headlight lens	______	________	________	________
iii) motorcycle seat	______	________	________	________
iv) headlight filament	______	________	________	________
v) spark plug insulator	______	________	________	________

PROPERTIES	MATERIAL	BONDING	PROCESSING
I. transparent and impact resistant	1. tungsten - W	A. covalent	a. vacuum warm forming
II. stiff and ductile	2. polyvinylchloride	B. ionic	b. calendaring
III. flexible and tough	3. polycarbonate	C. metallic	c. wire drawing
IV thermal & electrical resistance	4. aluminum oxide (Al_2O_3)	D. van der Waals	d. metal stamping
V. thermally stable electrical conductor	5. steel – Fe + .2%C	E. covalent & van der Waals	e. sintering

Activity Instructions & Processing Definitions

Activity Information

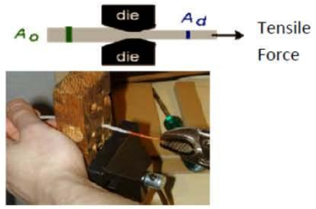
Learning Objectives and Outcomes

Learning Objective: Demonstrate the relationships between properties of a material and its atomic bonding and its and processing method and its performance application. These are some of the most important factors that come into play in the materials selection activity of the design process.
Learning Outcome: After completing this worksheet you will be able to look at an object and its important properties and identify the type of mat
atomic bonding, and processing method used to make that object.

Directions:
1. Use all the answers from the Properties, Material, Bonding, and Processing boxes to fill in each column with one answer from the corresponding answers from each box should be used at least once, except for the Bonding Box where each choice which may be used more than once or not at al
2. Household Item -

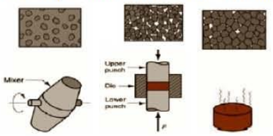
Materials Processing Methods

Drawing-Pulling a material through a reducing die with a tensile strength force applied to the emerging material.



vacuum thermoforming- softened thermoplastic sheet is placed on top of a mold and a vacuum pulls the sheet tightly over the mold allowing it to harden into the shape of the mold.

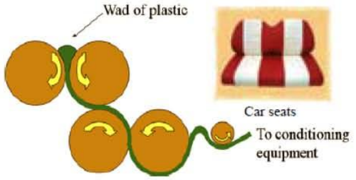
Sintering- Pressing diffused powdered aggregate into shape and then firing it at an elevated temperature.



a)Blending b)Compressing c)Sintering

metal sheet stamping- cold working a metal sheet where a stamping press pushes a die into the metal creating a complex shape.

calendar rolling- molten plastic is fed through a set of rollers that flatten the plastic into sheets



Homework # 3 Topic 1.2 Bonding & Macroscopic Properties

1. Callister 2.20- The purpose of this problem is to understand the relationship between melting temperature and bond energy.

   The purpose of solving and giving explanations to the correct choices for questions in this set of multiple choice problems is to apply your knowledge of bonding and property relationships for the three different family of materials.

2. For each question below select the most appropriate answer and explain your reasoning for selecting that answer.
   a. In materials engineering, the aspect of bonding that a material has that is most important to understand is
      a. the shape and location of electron shells and orbitals
      b. the different polar nature of each type of bonding
      c. the effect of each type of bonding on a material's properties
      d. the angle of bonds relative to parent atoms
      e. the quantum level energies of the elctrons
   b. Which type of bonding would most likely be present in a gold ring?
      a. Ionic
      b. Covalent
      c. Metallic
      d. van der Waals
      e. Covalent and van der Waals

   c. As a recycling expert, a town wants to know whether containers made of plastic or metal or glass would consume less energy for equal weight. You tell them that, to consume the <u>least amount of energy</u> in recycling by melting and then cooling, the type of bonding for the material you advise is:
      a. Ionic
      b. Covalent
      c. Metallic
      d. van der Waals
      e. Covalent and van der Waals



   d. The town also wants to know if the containers were recycled by breaking them into fine particles for composite filler, whether containers made of plastic or metal or glass would consume less energy for equal weight. You tell them that, to consume the <u>least amount of energy</u> in recycling breaking into fine particles, the type of bonding for the material you advise is:
      a. Ionic
      b. Covalent
      c. Metallic
      d. Van der Waals
      e. Covalent and van der Waals

3. The purpose of solving this problem is to connect atomic bonding concepts to physical properties, applications, and processing of a material. See the following page to solve problem

Homework #2 – Problem 4

4 Materials Selection Choose the most likely property, material, bonding, and process for these items **(20 pts)**

	property	material	bonding	processing
i) airplane wing	______	________	________	________
ii) airplane seat arm rest	______	________	________	________
iii) airplane cockpit window	______	________	________	________
iv) airplane landing gear tire	______	________	________	________
v) turbine blade thermal coating	______	________	________	________





PROPERTIES (one choice per item)	**MATERIAL** (one choice)	**BONDING** (may use more than once)	**PROCESSING** (1 choice)
I. transparent	1. aluminum - Al	A. covalent	a. sheet rolling
II. stiff and ductile	2. polyvinylchloride (PVC)	B. ionic	b. float on molten tin
III. flexible and tough	3. SiO2 – silicon dioxide	C. metallic	c. hot mold vulcanizing
IV high thermal resistance stability	4. zirconium dioxide (ZrO2)	D. van der Waals	d. sheet form + heat treat
V. rubbery and tough	5. rubber (polybutadiene)	E. covalent & van der Waals	e. high T thermal spray

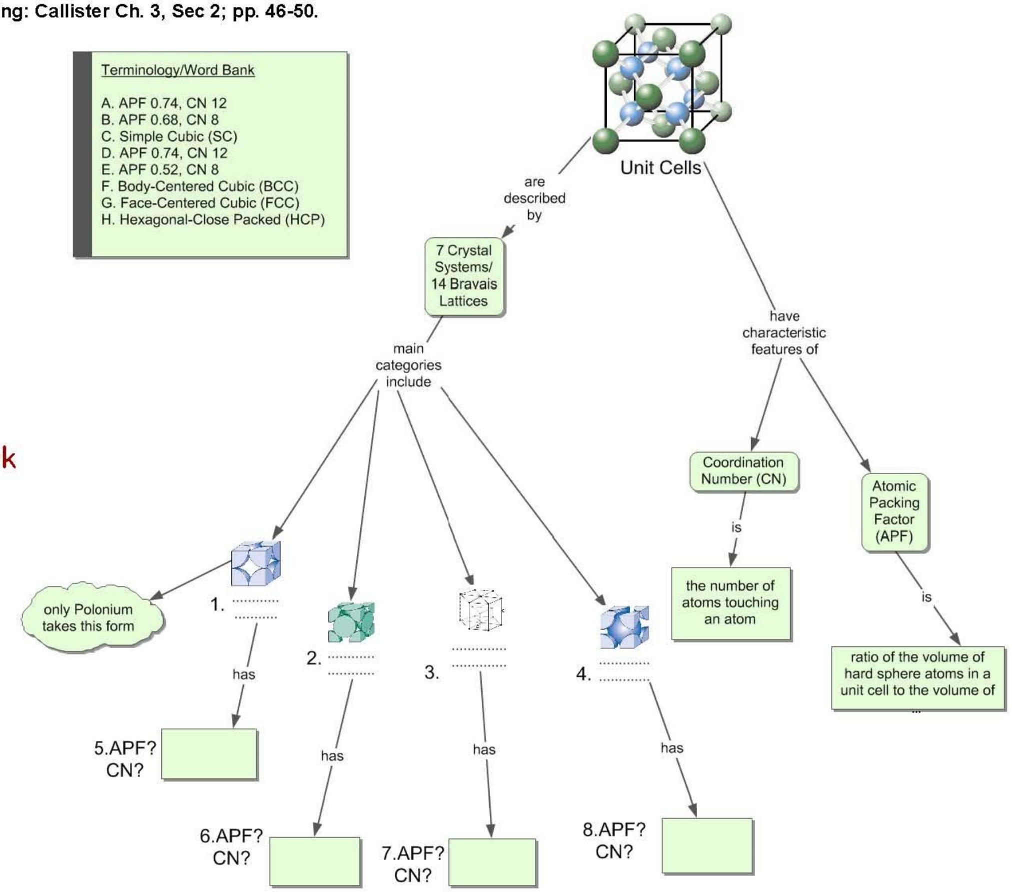
HW #3 - Problem #5. JiTT Preview Problem – Unit Cell Crystal Structures

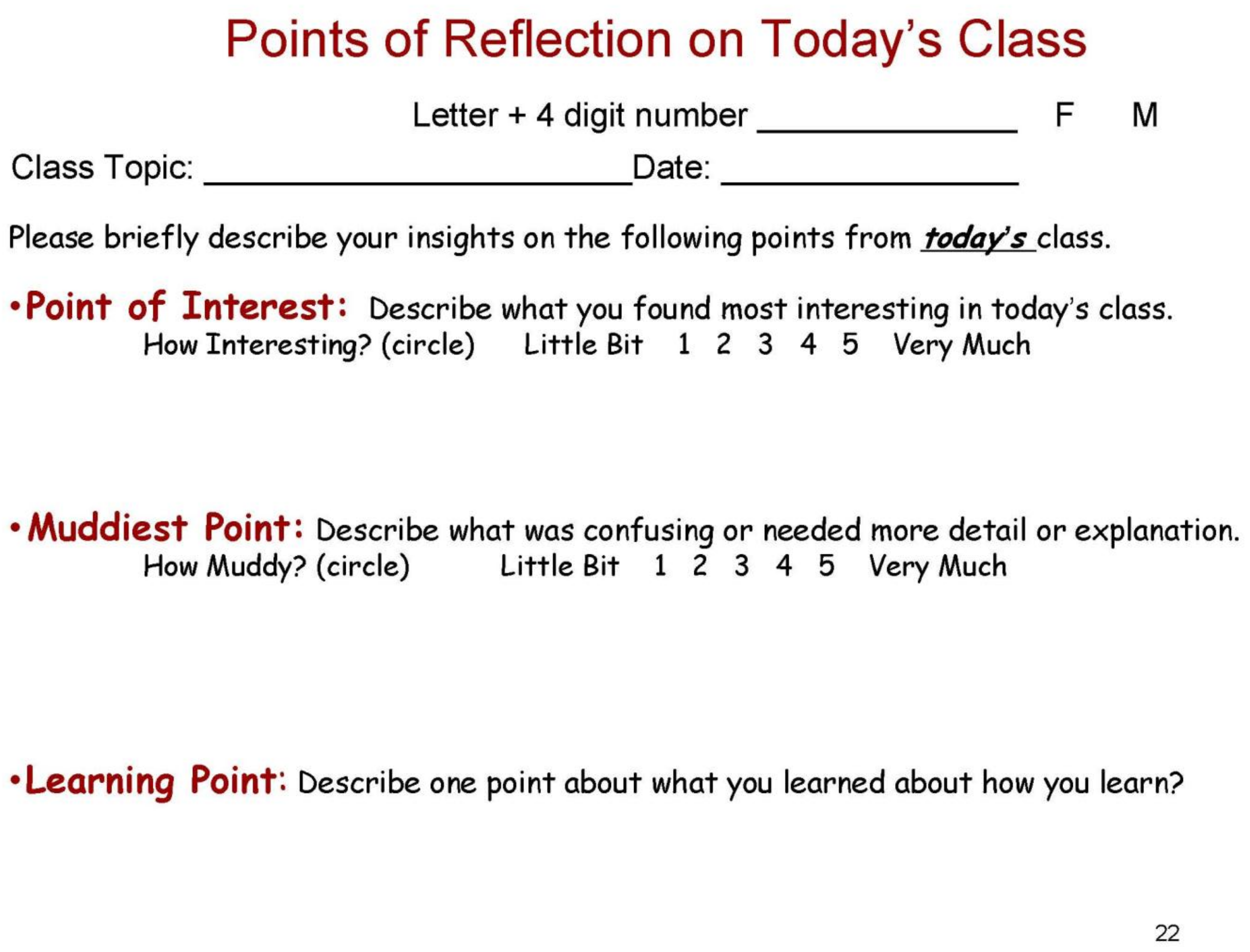
Instructions – Fill in the empty blanks on the concept map with the best choice from the word selection bank.
Focused reading: Callister Ch. 3, Sec 2; pp. 46-50.

Terminology/Word Bank

A. APF 0.74, CN 12
B. APF 0.68, CN 8
C. Simple Cubic (SC)
D. APF 0.74, CN 12
E. APF 0.52, CN 8
F. Body-Centered Cubic (BCC)
G. Face-Centered Cubic (FCC)
H. Hexagonal-Close Packed (HCP)

Homework





Points of Reflection on Today's Class

Letter + 4 digit number ______________ F M

Class Topic: _______________________Date: ________________

Please briefly describe your insights on the following points from ***today's*** class.

- **Point of Interest:** Describe what you found most interesting in today's class.
  How Interesting? (circle) Little Bit 1 2 3 4 5 Very Much

- **Muddiest Point:** Describe what was confusing or needed more detail or explanation.
  How Muddy? (circle) Little Bit 1 2 3 4 5 Very Much

- **Learning Point:** Describe one point about what you learned about how you learn?

APPENDIX C

MATERIALS CONCEPT INVENTORY (MCI)

Student Unique Identifier:________________________

Materials Concepts Inventory

Answer
(choose only one)

1. Atoms in a solid: _______
    - a) Cannot move, only electrons can
    - b) May move through vacancies in a crystal lattice
    - c) May move in the spaces between atoms in a crystal lattice
    - d) Can move through both vacancies and in the spaces between atoms in a crystal lattice
    - e) None of the above

2. If atomic bonding in metal A is weaker than metal B, then metal A has: _______
    - a) lower melting point
    - b) lower brittleness
    - c) lower electrical conductivity
    - d) lower thermal expansion coefficient
    - e) lower density

3. Compared to one mole of iron atoms, one mole of oxygen molecules has: _______
    - a) the same number of atoms
    - b) more atoms
    - c) less atoms

4. Nickel can exist as: _______
    - a) solid only
    - b) liquid only
    - c) gas only
    - d) liquid or solid only
    - e) liquid or solid or gas

5. The melting points of most plastics are lower than most metals because: _______
    - a) covalent bonds are weaker than metallic bonds
    - b) ionic bonds are weaker than metallic bonds
    - c) Van der Waals bonds are weaker than metallic bonds
    - d) covalent and Van der Waals bonds are weaker than metallic bonds
    - e) ionic and Van der Waals bonds are weaker than metallic bonds

6. Glass transmits light because: _______
    - a) it is very brittle
    - b) it has low crystallinity
    - c) it has high crystallinity
    - d) it doesn't interact with electrons in the glass

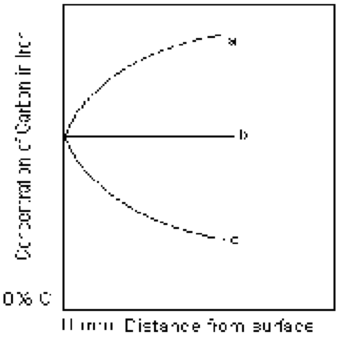
7. Marble feels colder than wood: _______
    a) because its temperature is lower
    b) marble is a better thermal conductor
    c) atoms are more tightly bonded in wood than marble
    d) wood is a better thermal conductor
    e) the water in wood holds in the heat

8. In comparing amorphous SiO2 (glass) to crystalline SiO2, the amorphous SiO2 has: _______
    a) higher thermal conductivity
    b) higher density
    c) higher coefficient of thermal expansion
    d) higher stiffness
    e) all of the above

9. The number of lines that connect opposite corners of a cube through its center is: _______
    a) 2
    b) 4
    c) 6
    d) 8
    e) 12

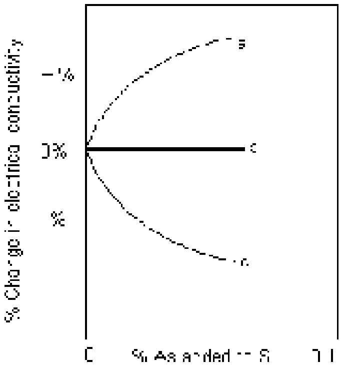
10. In a cube there are *** sides and *** edges. _______
    a) 4 and 6
    b) 4 and 8
    c) 6 and 8
    d) 6 and 12
    e) 8 and 12

11. If a slab of carbon is placed on a clean surface of iron at a high temperature, the carbon will diffuse into the iron. After a short time the profile of the carbon concentration versus length of diffusion into the iron looks like: _______



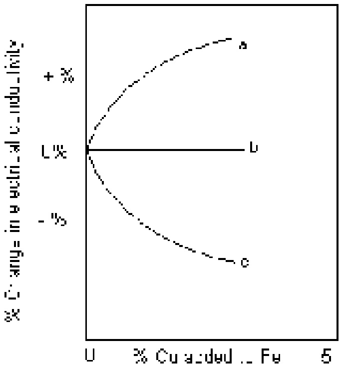
12. In a galvanic cell found in the corrosion process: _______
    a) electrons move in the electrolyte by being attracted to the protons in solution
    b) electrons and protons flow in opposite directions in the electrolyte
    c) electrons flow through the electrolyte from the anode to the cathode
    d) electrons are drained from the cathode resulting in a lower concentration there
    e) electrons move from anode to cathode through an electrically conductive connection

13. Addition of a very small amount of impurity such as arsenic to a pure semiconductor such as silicon will cause a change in conductivity as shown in the graph. _______

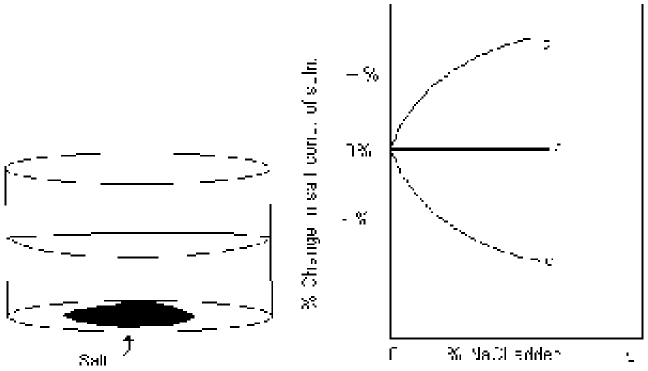


14. Aluminum is a better electrical conductor than is glass because aluminum: _______
    a) has more total electrons per volume
    b) has more conducting electrons per volume
    c) has electrons which move faster
    d) has which move slower
    e) has more conducting electrons per volume and they move faster than those in glass

15. If a small amount of copper is added to iron the electrical conductivity will change as shown:



16. When three tablespoons of salt are mixed into a glass of water and stirred, about a teaspoon of water-saturated salt remains on the bottom. If a small % of salt is slowly added to the glass while stirring the solution, the change in concentration of the salt in the solution is given by curve:



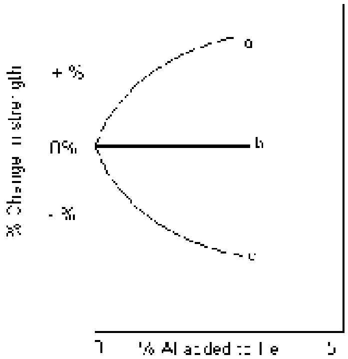
17. If the melting point of metal A is greater than metal B, then when a few % of metal A is added to metal B, the melting point could be given by:

a) may increase
b) may decrease
c) can increase or decrease

18. After a piece of copper wire from a hardware store is heated it becomes softer. This is because: ______
    - a) the bonds have been weakened
    - b) it has fewer atomic level defects
    - c) it has more atomic level defects
    - d) the density is lower
    - e) there is more space inside the crystal lattice

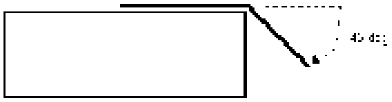
19. If a rod of metal is pulled through a tapered hole smaller than the diameter of the rod, the strength of the metal in the rod increases. This is because: ______
    - a) the density has increased
    - b) there are more atomic level defects present
    - c) there are less atomic level defects present
    - d) the bonds have been strengthened
    - e) the bonds have been compressed

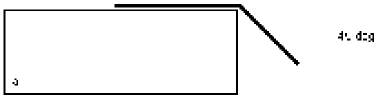
20. The addition of a few % of aluminum to iron will change the strength of the material as shown below: ______

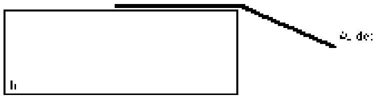


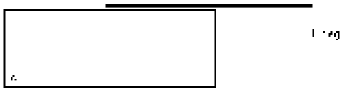
21. If a pure metal has mixed in 1% by volume of spherical particles of a different, harder material, then the resulting material would be hardest if the particles had a size of: ______
    - a) 100 microns
    - b) 10 microns
    - c) 1 micron
    - d) 0.1 microns
    - e) 0.01 microns

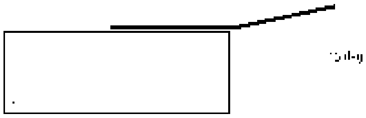
22. If a small steel rod, 4 inches long and 1/16 inch in diameter is rigidly attached to a block and a force is applied to the end of the rod that causes the rod to deflect to an angle of 45 degrees, the final position of the rod after the force is released is given by the shape in figure: _______







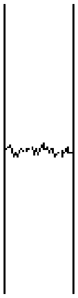


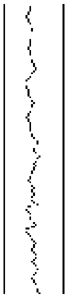


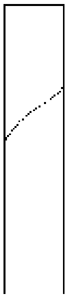
23. Materials which have significantly different strengths in tension and compression are: _______
   - a) metals
   - b) ceramics
   - c) polymers
   - d) metals and ceramics
   - e) metals and ceramics and polymers

24. Why does copper dent when hit with a hammer whereas glass breaks? _______
   - a) copper has higher density
   - b) copper has stronger bonding
   - c) copper is more crystalline
   - d) coppers atomic level defects move more easily
   - e) copper has weaker bonding

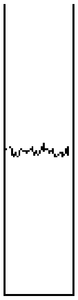
25. When a rod of ductile material like a metal is pulled in tension, the pieces after fracturing will look like: ______

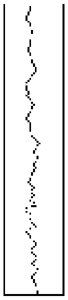

A

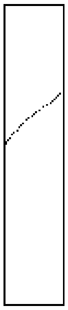

B


C

26. When a rod of brittle material like a ceramic is pulled in tension, the pieces after fracturing will look like: ______


A


B


C

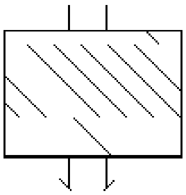
27. When two molecules react in the formation of a polymer: ______
    a) There is a net amount of heat absorbed by the reaction
    b) There is a net amount of heat given off by the reaction
    c) There is no net heat absorbed or given off by the reaction

28. The following materials are polymers: ______
    a) human skin
    b) vinyl car seat
    c) tree limb
    d) all of the above
    e) a) and b) above

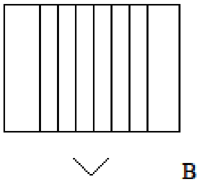
29. A polymer rubber band can stretch more than a metal paper clip because: _______

a) Covalent bonds along polymer chains can stretch and rotate
b) Covalent bonds along polymer chains can rotate and the Van der Waals bonds between chains allow chain slippage
c) Covalent bonds along polymer chains can break and the Van der Waals bonds between chains allow chain slippage
d) Covalent bonds along polymer chains can stretch and the Van der Waals bonds between chains allow chain slippage
e) Covalent bonds along polymer chains can rotate and break

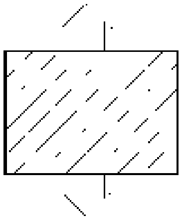
30. In the figures shown below the same force is applied to a composite which is reinforced with fibers running in different directions. The composite that deforms the least is: _______



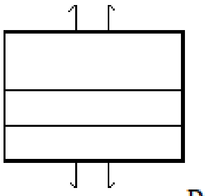
A



B



C



D

APPENDIX D

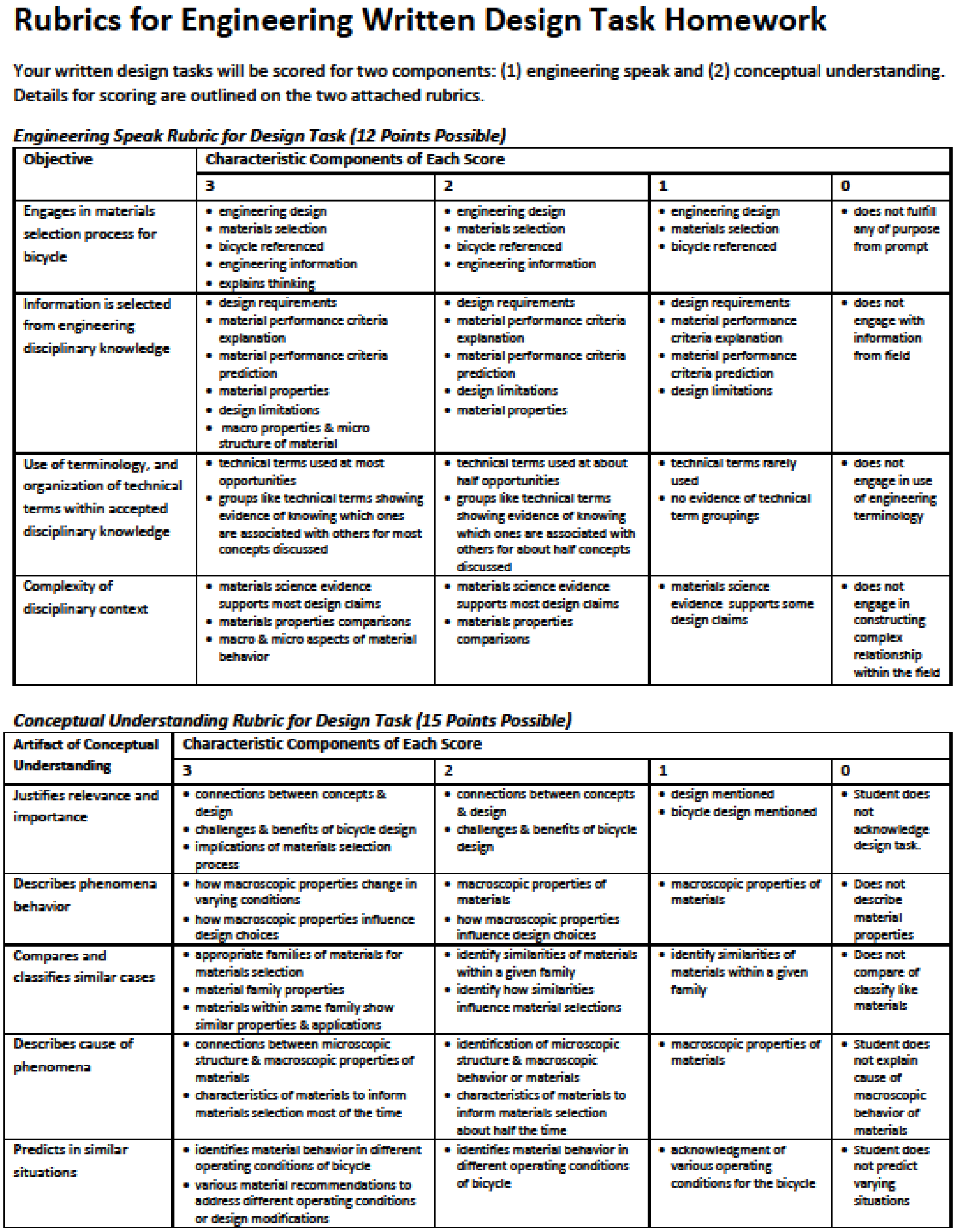
WRITTEN ENGINEERNG DESIGN TASK

Name: ________________________

Date:________________

Engineering Written Design Task 1 Homework

Using as much of the vocabulary and concepts of materials engineering as you can, describe how you would engage in the materials selection process for deciding what materials should make up the various parts of a bicycle. Be sure to explain what engineering information you are using and how you are using it to make your decision.



Rubrics for Engineering Written Design Task Homework

Your written design tasks will be scored for two components: (1) engineering speak and (2) conceptual understanding. Details for scoring are outlined on the two attached rubrics.

Engineering Speak Rubric for Design Task (12 Points Possible)

Objective	Characteristic Components of Each Score			
	3	2	1	0
Engages in materials selection process for bicycle	• engineering design • materials selection • bicycle referenced • engineering information • explains thinking	• engineering design • materials selection • bicycle referenced • engineering information	• engineering design • materials selection • bicycle referenced	• does not fulfill any of purpose from prompt
Information is selected from engineering disciplinary knowledge	• design requirements • material performance criteria explanation • material performance criteria prediction • material properties • design limitations • macro properties & micro structure of material	• design requirements • material performance criteria explanation • material performance criteria prediction • design limitations • material properties	• design requirements • material performance criteria explanation • material performance criteria prediction • design limitations	• does not engage with information from field
Use of terminology, and organization of technical terms within accepted disciplinary knowledge	• technical terms used at most opportunities • groups like technical terms showing evidence of knowing which ones are associated with others for most concepts discussed	• technical terms used at about half opportunities • groups like technical terms showing evidence of knowing which ones are associated with others for about half concepts discussed	• technical terms rarely used • no evidence of technical term groupings	• does not engage in use of engineering terminology
Complexity of disciplinary context	• materials science evidence supports most design claims • materials properties comparisons • macro & micro aspects of material behavior	• materials science evidence supports most design claims • materials properties comparisons	• materials science evidence supports some design claims	• does not engage in constructing complex relationship within the field

Conceptual Understanding Rubric for Design Task (15 Points Possible)

Artifact of Conceptual Understanding	Characteristic Components of Each Score			
	3	2	1	0
Justifies relevance and importance	• connections between concepts & design • challenges & benefits of bicycle design • implications of materials selection process	• connections between concepts & design • challenges & benefits of bicycle design	• design mentioned • bicycle design mentioned	• Student does not acknowledge design task.
Describes phenomena behavior	• how macroscopic properties change in varying conditions • how macroscopic properties influence design choices	• macroscopic properties of materials • how macroscopic properties influence design choices	• macroscopic properties of materials	• Does not describe material properties
Compares and classifies similar cases	• appropriate families of materials for materials selection • material family properties • materials within same family show similar properties & applications	• identify similarities of materials within a given family • identify how similarities influence material selections	• identify similarities of materials within a given family	• Does not compare of classify like materials
Describes cause of phenomena	• connections between microscopic structure & macroscopic properties of materials • characteristics of materials to inform materials selection most of the time	• identification of microscopic structure & macroscopic behavior or materials • characteristics of materials to inform materials selection about half the time	• macroscopic properties of materials	• Student does not explain cause of macroscopic behavior of materials
Predicts in similar situations	• identifies material behavior in different operating conditions of bicycle • various material recommendations to address different operating conditions or design modifications	• identifies material behavior in different operating conditions of bicycle	• acknowledgment of various operating conditions for the bicycle	• Student does not predict varying situations

APPENDIX E

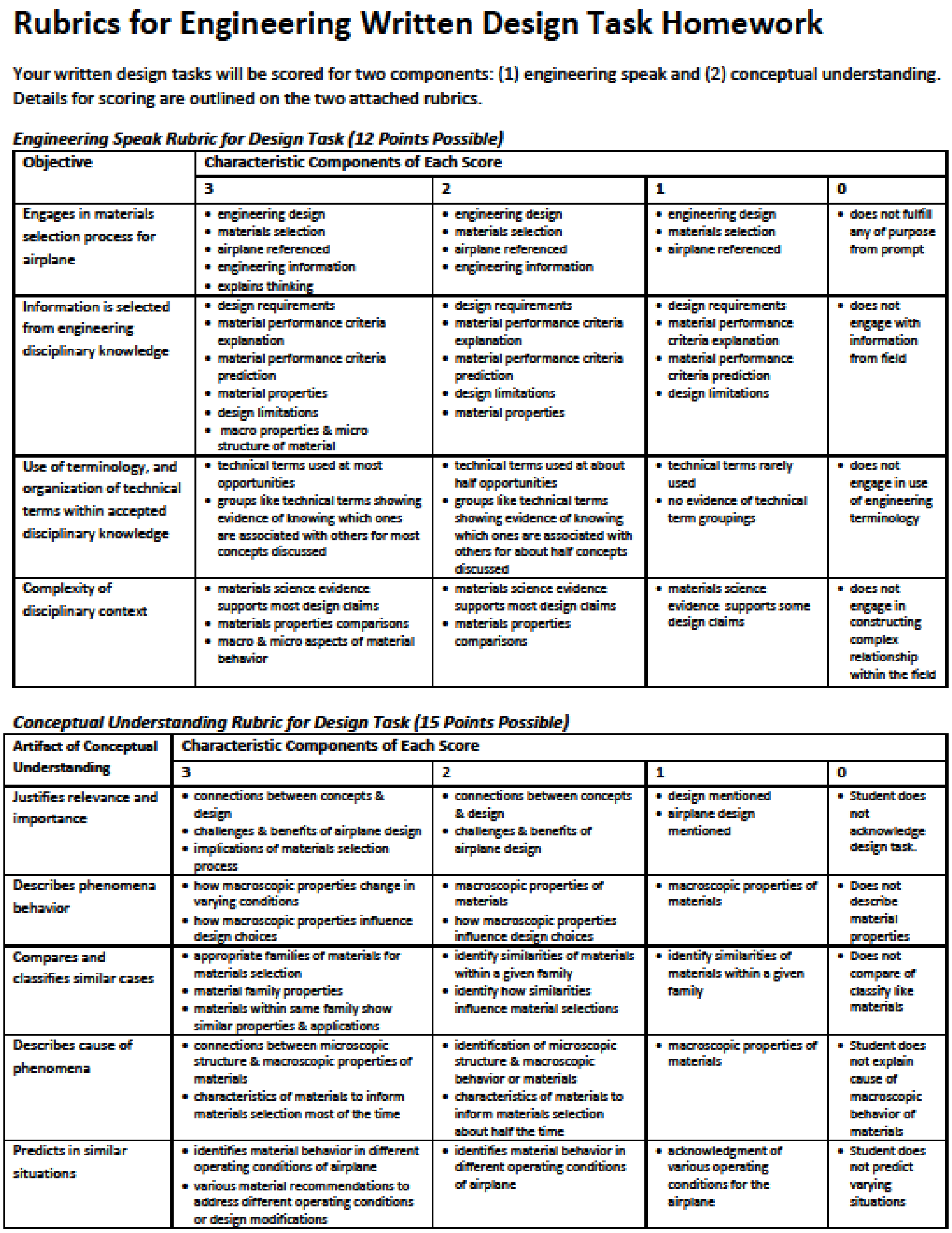
WRITTEN ENGINEERING DESIGN TASK: AIRPLANE

Name: ________________________

Date:________________

Engineering Written Design Task Homework

Using as much of the vocabulary and concepts of materials engineering as you can, describe how you would engage in the materials selection process for deciding what materials should make up the various parts of an airplane. Be sure to explain what engineering information you are using and how you are using it to make your decision.



Rubrics for Engineering Written Design Task Homework

Your written design tasks will be scored for two components: (1) engineering speak and (2) conceptual understanding. Details for scoring are outlined on the two attached rubrics.

Engineering Speak Rubric for Design Task (12 Points Possible)

Objective	**Characteristic Components of Each Score**			
	3	**2**	**1**	**0**
Engages in materials selection process for airplane	▪ engineering design ▪ materials selection ▪ airplane referenced ▪ engineering information ▪ explains thinking	▪ engineering design ▪ materials selection ▪ airplane referenced ▪ engineering information	▪ engineering design ▪ materials selection ▪ airplane referenced	▪ does not fulfill any of purpose from prompt
Information is selected from engineering disciplinary knowledge	▪ design requirements ▪ material performance criteria explanation ▪ material performance criteria prediction ▪ material properties ▪ design limitations ▪ macro properties & micro structure of material	▪ design requirements ▪ material performance criteria explanation ▪ material performance criteria prediction ▪ design limitations ▪ material properties	▪ design requirements ▪ material performance criteria explanation ▪ material performance criteria prediction ▪ design limitations	▪ does not engage with information from field
Use of terminology, and organization of technical terms within accepted disciplinary knowledge	▪ technical terms used at most opportunities ▪ groups like technical terms showing evidence of knowing which ones are associated with others for most concepts discussed	▪ technical terms used at about half opportunities ▪ groups like technical terms showing evidence of knowing which ones are associated with others for about half concepts discussed	▪ technical terms rarely used ▪ no evidence of technical term groupings	▪ does not engage in use of engineering terminology
Complexity of disciplinary context	▪ materials science evidence supports most design claims ▪ materials properties comparisons ▪ macro & micro aspects of material behavior	▪ materials science evidence supports most design claims ▪ materials properties comparisons	▪ materials science evidence supports some design claims	▪ does not engage in constructing complex relationship within the field

Conceptual Understanding Rubric for Design Task (15 Points Possible)

Artifact of Conceptual Understanding	**Characteristic Components of Each Score**			
	3	**2**	**1**	**0**
Justifies relevance and importance	▪ connections between concepts & design ▪ challenges & benefits of airplane design ▪ implications of materials selection process	▪ connections between concepts & design ▪ challenges & benefits of airplane design	▪ design mentioned ▪ airplane design mentioned	▪ Student does not acknowledge design task.
Describes phenomena behavior	▪ how macroscopic properties change in varying conditions ▪ how macroscopic properties influence design choices	▪ macroscopic properties of materials ▪ how macroscopic properties influence design choices	▪ macroscopic properties of materials	▪ Does not describe material properties
Compares and classifies similar cases	▪ appropriate families of materials for materials selection ▪ material family properties ▪ materials within same family show similar properties & applications	▪ identify similarities of materials within a given family ▪ identify how similarities influence material selections	▪ identify similarities of materials within a given family	▪ Does not compare of classify like materials
Describes cause of phenomena	▪ connections between microscopic structure & macroscopic properties of materials ▪ characteristics of materials to inform materials selection most of the time	▪ identification of microscopic structure & macroscopic behavior or materials ▪ characteristics of materials to inform materials selection about half the time	▪ macroscopic properties of materials	▪ Student does not explain cause of macroscopic behavior of materials
Predicts in similar situations	▪ identifies material behavior in different operating conditions of airplane ▪ various material recommendations to address different operating conditions or design modifications	▪ identifies material behavior in different operating conditions of airplane	▪ acknowledgment of various operating conditions for the airplane	▪ Student does not predict varying situations

APPENDIX F

GROUP OBSERVATION SHEET

Table Number __________ Date: 12/1/2011

Topic: Review (Class 25)

Start Time: __________

End Time: __________

Group Member ID: ____________________

Group Member ID: ____________________

Group Member ID: ____________________

Group Member ID: ____________________

Group Member ID: ____________________

Group Member ID: ____________________

Ceramics

- abrasives
- advanced cements
- anneling point
- cementation
- cements
- clay products
- compression
- crack tip
- die blanks
- glass
- glass forming
- glasses
- glassy
- modifier
- network
- particle forming
- polymorphic
- refractories
- sensors
- sinterng
- softening point
- strain point
- stress concentation
- stress concentration factor
- tension
- working point

electrical

- AC
- alternating current
- avalanche diode
- band gap
- band structure
- bipolar junction transitor
- charge
- charge carriers
- circuit
- conduction
- conduction band
- conductivity
- conductor
- current
- current flow
- current flow
- DC
- direct current
- dope
- electric field
- electrical
- energy band
- equilibrium
- extrinsic
- forward bias
- holes
- Insulator
- Interatomic seperation

- intrinsic
- junction
- light emiting diod
- metal oxide semiconductor field effect transistor
- migration
- mobility
- Ohm
- p-n junction
- p-type
- P/N diode
- path length
- potential
- rectifier
- rectifying junction
- resistance
- resistivity
- reverse bias
- state
- substrate
- valence band
- velocity
- voltage
- wafer
- semiconductor
- substrate
- transistor

bonding

- 0-D (covalent)
- 1-D (covalent)
- 3-D (covalent)
- acquire (electron)
- atom
- atomic mass unit
- atomic number
- atomic weight
- attractive force
- bond
- bond length
- bond strength
- bonidng
- cation
- chains
- coefficient of thermal expansion
- covalent
- delocalized electrons
- dipoles
- electron cloud
- electronegativity
- electronic configuration
- electrons
- elements
- energy (bond)
- equilibrium
- give up (electron)

- Hooke's law
- Ionic
- Ions
- melting temperature
- metallic
- mixed bonding
- neutrons
- nonmetal
- orbitals
- periodic table
- potential (energy bonding)
- potential well
- primary bond
- protons
- repulsive force
- sea of electrons
- secondary bond
- sharing (electrons)
- stable
- transfer (electron)
- unstable
- valance electron
- van der Waals

Polymers

- 1-D
- 3-D
- addition
- amorphous
- chain
- condensation
- crosslink
- diene
- elastomer
- free radical
- glass transition temperature
- heat set
- Initation
- linear
- linkage
- mer
- molecular weight
- monomer
- morphology
- non-linear
- normal
- nylons
- oriented
- particulate
- phenolics
- polyamids
- polymerization
- propogation
- reinforced
- semicrystalline
- stepwise
- synthetic

- termination
- thermoplastic
- thermoset
- unoriented
- unreinforced
- vinyl
- vinylidene

tensile test

- compression
- ductility
- elastic deformation
- elastic modulus
- elongation
- grain boundary
- load
- plastic deformation
- strain
- stress
- stress-strain curve
- tensile test
- tension
- toughness
- yield strength
- Young's modulus

general

- ANY Processing Mech
- ANY Specific Material
- ceramic
- metal
- phoenomena
- polymer

Phase diagrams

- age hardening
- alloy
- alpha
- austinite
- bainite
- beta
- cementite
- chemical composition
- concentration
- eutectic
- eutectic composition
- eutectic reaction
- eutecttic temperature
- eutectoid
- ferrite
- gamma
- heat treratment
- hypereutectic
- hypoeutectic composition
- isothermal
- liquid

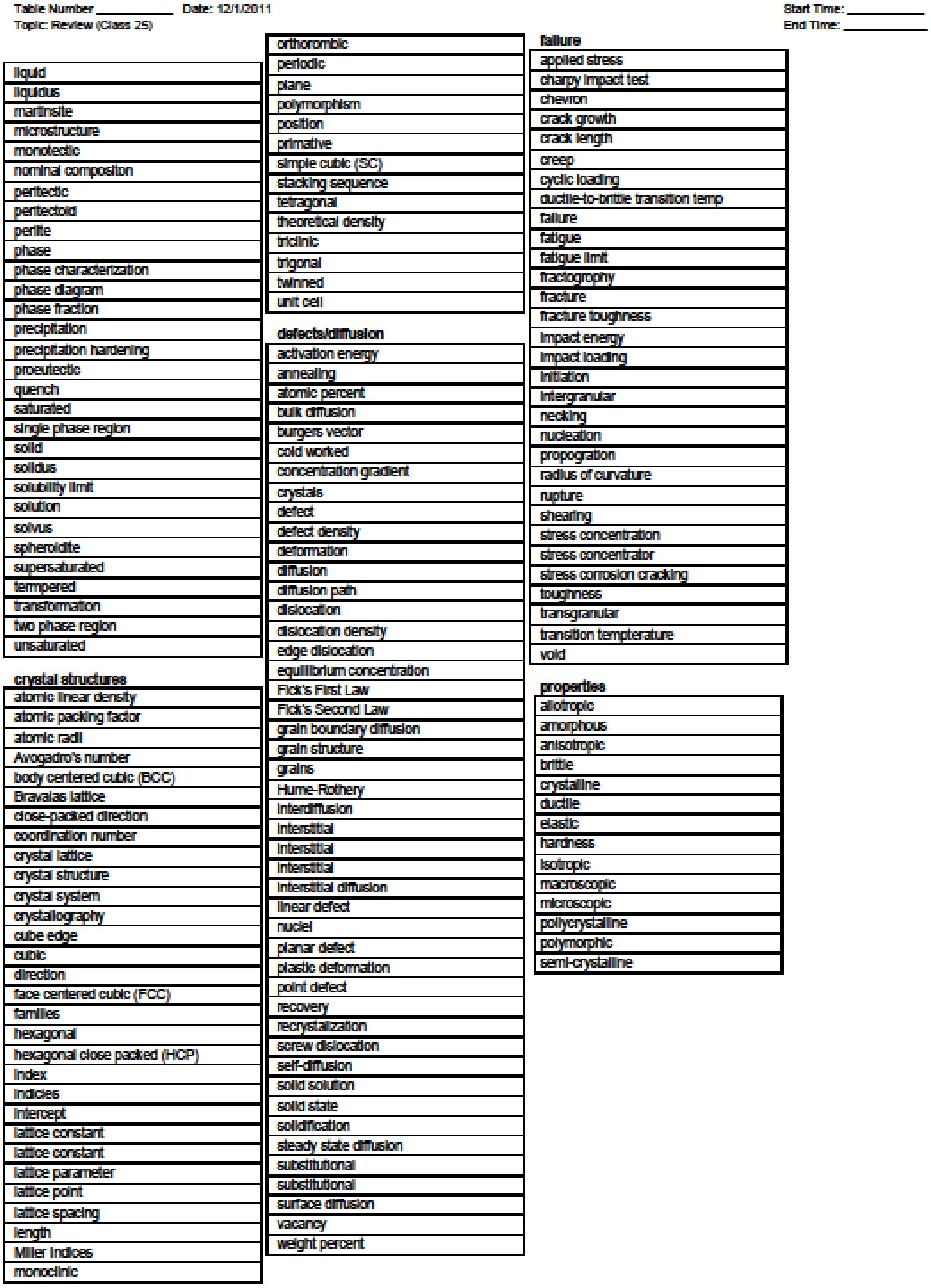


Table Number ____________ Date: 12/1/2011
Topic: Review (Class 25)

Start Time: ____________
End Time: ____________

liquid
liquidus
martinsite
microstructure
monotectic
nominal compositon
peritectic
peritectoid
perlite
phase
phase characterization
phase diagram
phase fraction
precipitation
precipitation hardening
proeutectic
quench
saturated
single phase region
solid
solidus
solubility limit
solution
solvus
spheroidite
supersaturated
tempered
transformation
two phase region
unsaturated

crystal structures

atomic linear density
atomic packing factor
atomic radii
Avogadro's number
body centered cubic (BCC)
Bravaias lattice
close-packed direction
coordination number
crystal lattice
crystal structure
crystal system
crystallography
cube edge
cubic
direction
face centered cubic (FCC)
families
hexagonal
hexagonal close packed (HCP)
Index
Indicies
Intercept
lattice constant
lattice constant
lattice parameter
lattice point
lattice spacing
length
Miller Indices
monoclinic

orthorombic
periodic
plane
polymorphism
position
primative
simple cubic (SC)
stacking sequence
tetragonal
theoretical density
triclinic
trigonal
twinned
unit cell

defects/diffusion

activation energy
annealing
atomic percent
bulk diffusion
burgers vector
cold worked
concentration gradient
crystals
defect
defect density
deformation
diffusion
diffusion path
dislocation
dislocation density
edge dislocation
equilibrium concentration
Fick's First Law
Fick's Second Law
grain boundary diffusion
grain structure
grains
Hume-Rothery
Interdiffusion
Interstitial
Interstitial
Interstitial
Interstitial diffusion
linear defect
nuclei
planar defect
plastic deformation
point defect
recovery
recrystallization
screw dislocation
self-diffusion
solid solution
solid state
solidification
steady state diffusion
substitutional
substitutional
surface diffusion
vacancy
weight percent

failure

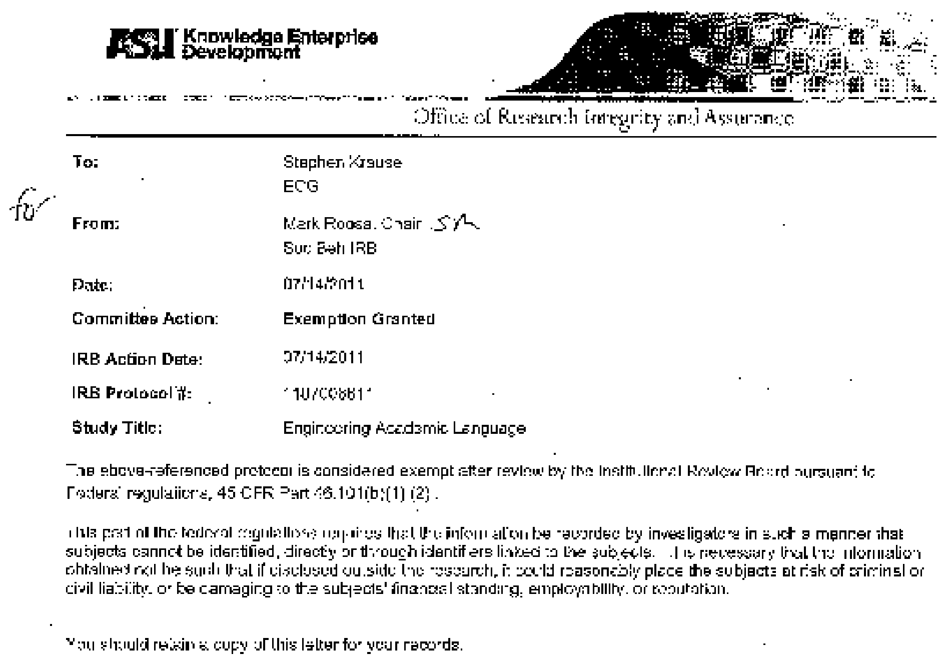
applied stress
charpy impact test
chevron
crack growth
crack length
creep
cyclic loading
ductile-to-brittle transition temp
failure
fatigue
fatigue limit
fractogrophy
fracture
fracture toughness
Impact energy
Impact loading
Initiation
Intergranular
necking
nucleation
propogration
radius of curvature
rupture
shearing
stress concentration
stress concentrator
stress corrosion cracking
toughness
transgranular
transition tempterature
void

properties

allotropic
amorphous
anisotropic
brittle
crystalline
ductile
elastic
hardness
Isotropic
macroscopic
microscopic
pollycrystalline
polymorphic
semi-crystalline

APPENDIX G

IRB APPROVAL LETTER



ASU Knowledge Enterprise Development

Office of Research Integrity and Assurance

To:	Stephen Krause ECG
for **From:**	Mark Roosa, Chair SK Soc Beh IRB
Date:	07/14/2011
Committee Action:	**Exemption Granted**
IRB Action Date:	07/14/2011
IRB Protocol #:	1107006811
Study Title:	Engineering Academic Language

The above-referenced protocol is considered exempt after review by the Institutional Review Board pursuant to Federal regulations, 45 CFR Part 46.101(b)(1) (2).

This part of the federal regulations requires that the information be recorded by investigators in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects. It is necessary that the information obtained not be such that if disclosed outside the research, it could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation.

You should retain a copy of this letter for your records.