AC 2011-1096: PREDICTING CONCEPTUAL GAIN IN AN ATOMIC BONDING MODULE

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Predicting Conceptual Gain in an Atomic Bonding Module from Proficiency in "Engineering Speak"

Abstract

Engineering education has focused on understanding student conceptual development with a variety of assessment methods. Much research is focused on developing strategies, pedagogies, or interventions to promote effective conceptual development. However, results are dependent on the ability to accurately, efficiently, and easily measure the effect of different strategies on differences in conceptual gains. At this time, the Materials Concept Inventory (MCI)[1] is the only validated pre-post course assessment tool for measuring student conceptual gain in introductory materials courses. But, because such courses are often broad in scope, topics may differ from those found on the MCI and can be difficult to assess. Developing alternative assessment tools that effectively elicit student misconceptions and measure conceptual change may take time, resources, and significant numbers of students. In this study we seek to answer the question, “What kind of model is there that can be constructed to predict conceptual change using student understanding which is easy to use for acquisition and analysis of data.?” One method for doing this, which is reported in this research literature, is to code the student responses to the various questions on a given topic with a quantitative rubric as a measure of the level of quality of technical “engineering speak”. The model also has the potential to track the impact of teaching and learning materials on student progress in learning of topical content for different engineering disciplines. In this research we report on the correlation between "engineering speak" and conceptual gain for the topic of atomic bonding in an introductory materials class.

Introduction

Language is a medium by which people communicate. It allows us to understand others and express our responses. In the classroom, language has been the primary tool for distributing, discussing, interpreting, and building knowledge despite it is through transmission, social constructivism, or situated cognition. Because of this importance, it is imperative to understand how students use and develop language in the classroom.

But language in the context of a science or engineering classroom is not necessarily consistent with everyday, colloquial speak. Vygotsky illustrated this point by distinguishing between everyday concepts and scientific concepts[2]. He argued that, in order for students to create formal, scientific concepts, it is necessary to create rich contextual and social environments. So, in terms of an engineering or science course, for students to “speak science” or “speak engineering”, we must treat language as a concept and explicitly teach students the languages of science or engineering. Work on this topic in the context of science is limited and in engineering is scarce. To further understand this claim and its implications, models of language structure and acquisition will be applied from two papers from the cognitive sciences.

Learning and Distinguishing Sounds

Yeung and Werker[3] examined how young children learned sounds with relatively little teaching. They discussed how 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[2]. This suggested that infants who were given clues to the functionality of sounds upon encoding were more likely to be able to distinguish, or learn the sounds. This finding is consistent with cognition literature on memory and goal setting. Patalano & Seifert[4] identified the usefulness of predictive encoding. They found that, at the time of goal setting, students were more likely to recognize opportunities to achieve their goals if they were presented with cues, or tools and strategies, to do so at the time of encoding.

Scientific language varies from everyday language. But how can we tell if someone is fluent in scientific language? In his book, *Talking science: Language, Learning and Values*, Lemke classifies it as the degree to which one can interact in the scientific community. According to him, scientific language is acquired through interaction with this community[5]. However, according to Yeung & Werker[2] and Patalano & Seifert[3], immersion may not be enough. Immersion in the scientific community would surely allow students opportunities to receive sufficient auditory input to be able to statistically analyze frequency of sounds; however, it may not guarantee that students receive the appropriate functional cues to achieve proficiency. Parkinson described a variety of “literacy events” that college science students are asked to engage in. These included experimental research and write ups, lab experiences including lab manuals, tutorial sessions and problem solving, lectures with lecture notes, tests, problems and calculations, and essays[6]. Of these described literacy events, students were found to engage in writing summary-based lab reports 85% of the time[7]. While this may give students a variety of functional cues for scientific language, it does not provide ample input so that students can statistically analyze the frequency of auditory input necessary for understanding new language. In order for students to best learn engineering or scientific language, according to this model, engineering and science instruction should provide ample opportunities for both immersion and literacy events as defined above.

Classroom teachers must be explicit about their language use and give students opportunities to use language. This means not only allowing students to speak in scientific language, but asking clarification questions like “What do you mean by…?” in order to ensure that language is being used appropriately. This enables the teacher to gather input in order to prepare and give useful and meaningful feedback to students. However, in order to simulate immersion, the teacher must use scientific language often and explicitly refer to the language that is being used. For example, if a teacher is talking about *heat* or *energy*, which are words that have very different meanings in scientific technical language than they do in colloquial speak, she should take time to talk about what these words mean, give students opportunities to use them in scientific contexts, and continuously give feedback on their use. In order to establish functional cues, operational definitions can help students encode word functionality with meaning. For example, when discussing *heat*, it should be in a context which makes it necessary to use the word. Additional examples should also be provided. By using a combination of frequent, meaningful probing and feedback and operational definitions, teachers can create an environment more suited to help students acquire scientific language proficiency.

Barriers to Understanding Word Meaning

Markman[8] discussed three assumptions made by language learners that inhibited understanding of word meaning: the whole object, taxonomic, and mutual exclusivity assumptions. The whole object assumption, made by language learners, applies a word to the entire object rather than a category it might exist in or as a descriptor of its individual parts. The taxonomic assumption enables language learners to classify objects that a word may refer to based on classifications or categories. For example, if someone uses the word *vehicle*, the language learner first assumes that *vehicle* refers to the entire object. Second, the language leaner assumes that *vehicle* probably describes other large objects that are used for transportation and have similar properties to the observed object. These two assumptions are consistent with previous work on schema theory. Alba and Hasher[9] described information as being stored in categories based on like classifications. The mutual exclusivity assumption allows language learners to assign labels to parts of objects, or to objects that may not belong in general categories[7]. For example, rather than call every object used for transportation a *vehicle*, a learner may learn to distinguish *planes*, *trains*, or *automobiles*. While these things all fulfill the general requirements of a *vehicle*, they are mutually exclusive of each other and have very different engineering design requirements and applications. For engineering or scientific language, teachers must realize that students learning engineering and science language are making these same assumptions. Students are classifying like terms and assigning mutually exclusive labels to others. However, without feedback or proper encoding, these assumptions may hinder learning.

In the classroom, teachers must be clear and discuss the use of limitations and proper associations of terms. Again, the use of operational definitions, or terms defined within specific contexts or uses can help students understand which assumptions may or may not apply. For example, upon introduction of new terms, teachers can discuss the contexts that the terms may or may not be appropriate for. This enables students to become comfortable with the generalizability and exclusivity of new words. This will help compact limitations of the whole-object, taxonomic, and mutual exclusivity assumptions. Additionally, it allows students to understand the use of assumptions and limitations, which are concepts central to the nature of science.

Student Understanding of Atomic Bonding

In 1989, Peterson, Treagust and Garnett[10] developed a test for identifying misconceptions about bonding and molecular structure called the Covalent Bonding and Structure Test. The test provided insight on student conceptions and aided in developing distractors for concept inventories on atomic bonding[9,10]. Misconceptions found included "equal sharing of an electron pair occurs in all covalent bonds", "the shape of molecules is due only to the repulsion between the bonding electron pairs", and " nitrogen atoms can share five electron pairs in bonding"[6].

Peterson and Treagust[11] found that, while student ideas about atomic bonding developed throughout advanced chemistry courses, often misconceptions did as well. For example, they found that 60% of 17-year-old students knew the correct position of the electron pair in a bond between hydrogen and fluorine while 55% of first year university students did. This work implied that students who held misconceptions about bond polarity in high school tended to retain their misconceptions in later coursework. Barker[12] examined conceptual development over bonding topics time and reported the changes in students' basic ideas about covalent bonds and molecular structure over a two-year period. It was found that 88% of 16-year-olds could distinguish between single and double covalent bonds in methane, ethane and water molecules in terms of the numbers of electrons involved. However, only 66% of that sample could so the same approximately fifteen months later. These studies showed that it was more likely for students to retain misconceptions than correct concepts. To further investigate the resilience of student bonding misconceptions, the Covalent Bonding and Structure test was used by Birk and Kurtz to look at the strength of the misconceptions within students' conceptual frameworks[13]. The test was given to six groups of people: high school chemistry students, first semester general chemistry students, second semester general chemistry students, advanced undergraduates, new graduate students, advanced graduate students and faculty. Results suggested that misconceptions were robust and resilient over time, with similar types of misconceptions existing in all groups[12].

In 2006, Ünal, Çalik, Ayas, and Coll[14], conducted an extensive survey of all research on bonding conceptions and understanding. Much work had already been done to probe student conceptions and misconceptions of covalent and ionic bonding. However, little research had been conducted exploring student thinking about metallic bonding or secondary bonding, specifically van der Waals bonding[2]. A summary of student bonding misconceptions as reported by them is shown in Table 1.

Table 1

Summary of Atomic Bonding Misconceptions as Reported by Ünal et al.[13]

Bonding Type	Known Misconceptions
Covalent Bonding	• one atom donates an electron to another atom
	• bond between metals and nonmetals
	• bond polarity depends on quantity of valence electrons
	• all electrons are shared equally
Ionic Bonding	• bonds result in creation of molecules
	• bond strength is determined by quantity of bonding electrons
	• bond cancels charge difference between ions
Metallic Bonding	• not real bonds
	• metallic bonding forms molecules
van der Waals Bonding	• no recorded conceptions

In 1998, two separate literature reviews were done in which student conceptions about the nature of bonding were examined. Boo[15] and Robinson[16] both found, independently, that students considered covalent and ionic bonding to be the "real" bonding types, while metallic was not[14,15].

In 2003, Coll and Treagust examined student conceptual understanding of metallic bonding[17]. Students were first asked to create a visual representation of metallic bonding and then to choose a visual depiction (provided on cards) most similar to their mental model of metallic bonding. It was found that secondary school students were most likely to choose a sea of electrons model while undergraduates and postgraduates preferred a space-filling model. While this did not reveal misconceptions, it did elicit preferred models for understanding metallic bonding. While work on metallic bonding concepts and misconceptions is limited, even less has been done and documented on student concepts and misconceptions on van der Waals bonding. Research in that area of student concepts referenced mainly confusion between intra and intermolecular forces[13].

The Materials Concept Inventory has been used to report conceptual change in introductory materials courses[1]. Typical gains regardless of academic major were found to be 7-15% for traditional, lecture based classes[18],[19]. Kelly isolated a subset of bonding relevant questions from the MCI for this research to emphasize conceptual change of atomic bonding concepts. She found that gains on the five question subset were significant and ranged from .82 to 1.16 depending on pedagogy[20].

Research Purpose and Question

In an introductory materials science an engineering over 400 new engineering terms are introduced to students as determined by examining a selection of chapters from a common introductory materials text[21]. As students transition into becoming engineers, they must be able to speak about engineering and engineering phenomena proficiently. However, in traditional engineering courses, little attention is paid to this challenge for students. By treating development of engineering speak as a second language acquisition, the process can be better examined and understood so that engineering students can overcome the language barrier between colloquial speak, which they enter the classroom with, and engineering speak, which is used by experts which include professors and practicing professionals in the field.

Conceptual understanding is difficult to measure. If a model can be created using predictors such as engineering language proficiency, it will be easier for engineering faculty to assess student conceptual development. In a field that seems to continue to be taught using traditional methods, a model that would simplify the process to assess students, such as this, may make it easier and more likely to engage in student driven pedagogy. In this study we seek to answer the question, "How is academic language acquisition related to conceptual development of engineering concepts?"

Methods

The primary purpose of this study was to understand how academic language acquisition is related to conceptual development in introductory engineering courses. After examining these characteristics, the relationship between engineering language acquisition and conceptual development will be explored.

Participants

Participation in this study was voluntary, though assessment was discussed and primarily collected during the course of a regular class. Participants in this research were from a sample of 38 students enrolled in a 2009 semester of an introductory materials science and engineering course. Of the 38 students who remained enrolled in the course, all students were engineering majors with 13 (34%) chemical engineers, 9 (24%) mechanical and aerospace engineers, 8 (21%) industrial engineers, 7 (18%) materials science engineers, and 1 (3%) bioengineer. There were 9 (24%) females and 29 (76%) males.

Teaching Methods and Interventions

The introductory course in which the sample was drawn was a 15-week semester course required for most engineering majors meeting for seventy-five minutes two times per week. The course was taught by a professor with a Ph.D. in engineering and 28 years teaching experience. Throughout instruction students were asked to frequently express their mental models in multiple modes. Student expressions and explanations of thinking took place in different ways, or representations, including written, verbal, diagrammatical, mathematical, graphical and, kinesthetic. By having students explain their ideas in each of these modes at various times throughout the course of instruction, frequent multimodal expressions of ideas were consistent throughout the entire course.

Measures

Bonding Module Assessments

To obtain specific information about student conceptions, an open ended pre and post Bonding Module Assessments was created. In order to develop the assessments, common misconceptions were reviewed from the literature, past research, the Materials Concept Inventory[1], and experiences from prior sections of the introductory materials science and engineering course. These assessments required students to respond to questions using multiple representations. These multiple representations, or modes of expression, included written descriptions, concept sketches, and diagrammatical representations. The Bonding Module Assessment, shown in Figure 1, incorporated two parts. One was a science based portion in which students were requested to concept sketch the three primary and one secondary bond types bond types and then also provide written descriptions of bond types. The second portion of the assessment requested students to provide the bond type and important properties of common household items that were from the three families of materials. These items were a polymer water pipe, a metal paper clip, and also a glass whiskey bottle. The assessments were graded for both conceptual understanding and proficiency in engineering language.

Figure 1

Bonding Module Assessment

Pre Module Concept Exploration on Bonding Your Letter + 4 digit number ______________ Date ___________ M or F

1. In the space below, briefly describe and sketch a picture of each of the different types of bonding listed:
2.

Type of Bonding	Brief Description	Sketch
Covalent		
Ionic		
Metallic		
van der Waals		

3. For each object listed below, list 2 important property requirements of the application which the material must have and also the type(s) of bonding present for the material given.
4.



Object	2 Properties Required of Material	Type of Bonding
Polymer Water Pipe		
Metal Paper Clip		
Glass Whisky Bottle		

To measure conceptual understanding on each question, each student had the opportunity to score a maximum of two points. Any answer that was correct was awarded two points. An answer that was partially correct, but may have had some incorrect ideas was awarded one point. An answer that was blank, completely incorrect, or non-relevant was not awarded any points. This rubric allowed for achieving a maximum nonzero score that ranged from a maximum score of 14 down to a minimum score of 0. The Bonding Module Assessment was administered before instruction on the topic of bonding began. The same assessment was then again administered after instruction about the two-class bonding topics, including return of graded homework. An example of the various student responses for ionic bonding and the scores each earned is shown in Table 2 below.

Table 2

Examples of Scoring Responses for Ionic Bonding

Score	Student Response		Description
0	~~Generally takes place~~		Blank
1	Bond between a metal and a gas--		Very Wrong
1.5	transfer of electrons.	Like table salt.?	Partially Correct
2	A metal and nonmetal trafer an electron to the other to fill the octet rule		Correct

To measure proficiency in engineering academic language, or engineering speak, student responses to open ended questions on the Bonding Module Assessment were examined. Responses were either assigned a value of 0 (for no response), 1 (for colloquial speak), 2 (for quasi colloquial/engineering speak), or 3 (for technical engineering speak). While grading, there was no emphasis on whether student responses were conceptually correct or not. Instead, only the language used in the answer was taken into consideration. Words considered engineering speak were those were included in the vocabulary for the introductory materials engineering semester curriculum. Words considered colloquial speak were those not included in the introductory materials engineering semester curriculum. Examples of scoring for engineering speak are shown in Table 3.

Table 3

Examples of Scoring for Engineering Speak

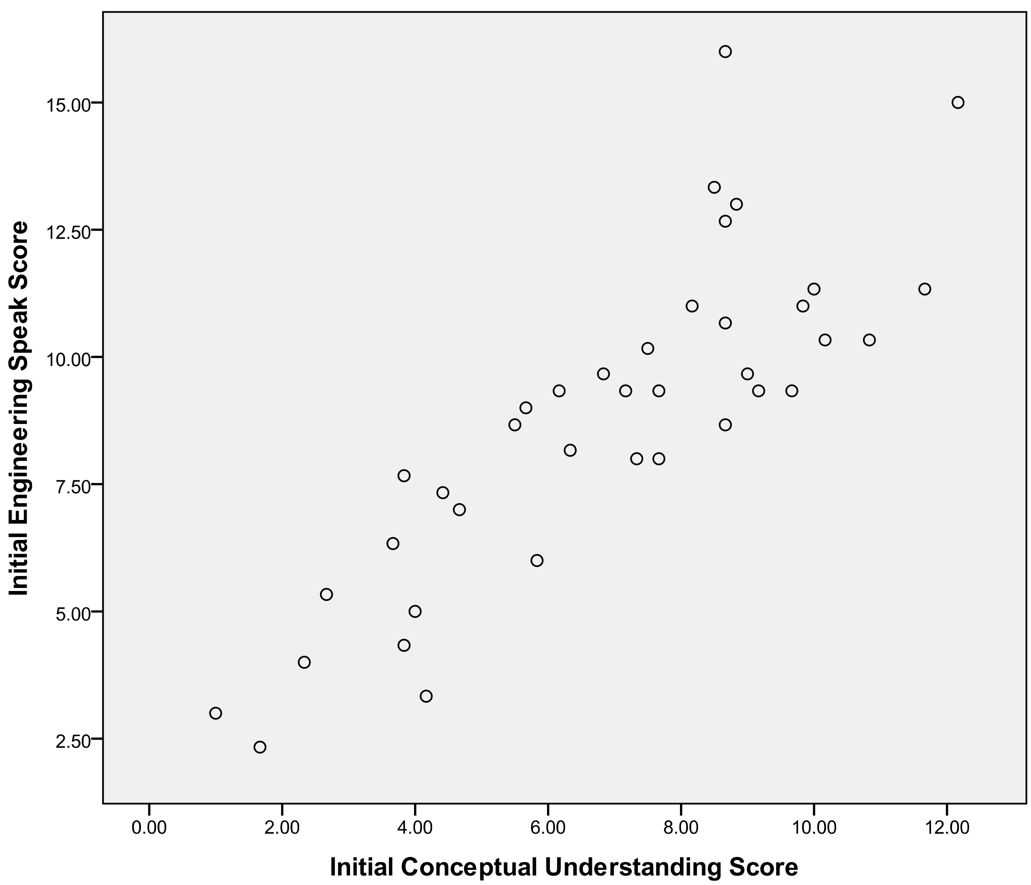
Score	Student Response	Description
0	--	Blank
1	(For Metallic Bonding) "Two metals"	Colloquial
2	(For Covalent Bonding) "sharing of electrons"	Quasi Engineering Speak
3	(For Metallic Bonding) "mutual sharing of delocalized electrons	Engineering Speak (and conceptually correct)
	(For van der Waals bonding) "London dispersion that bonds metalloids"	Engineering Speak (and conceptually incorrect)

In order to compare and examine the relationship between conceptual understanding and proficiency in engineering academic language, a linear regression analysis was conducted, with the understanding that classroom data may yield errors that are not independent among each measurement, thus potentially limiting the strength of analysis. A pre score (before instruction) of frequency of use of engineering speak was used as the independent variable and a pre score conceptual understanding was used as the dependent variable. This configuration allows for use of engineering language to predict conceptual understanding.

Results and Discussion

Initially, a scatter plot of initial conceptual understanding score vs. initial engineering speak score was produced and is shown in Figure 2.

Figure 2



As shown in Figure 2, the data seemed linear and a linear regression was justified. The analysis revealed a significant correlation between the frequency of initial use of engineering speak and initial bonding conceptual understanding of .844, $p < .01$. The unstandardized coefficient, B=.750, suggests that for every one unit increase in engineering speak, students would experience a .750 unit increase in conceptual understanding as measured by the Bonding Module Assessment. It was found that initial level of engineering speak could significantly predict

70.4% of the variance in initial conceptual understanding scores in the area of atomic bonding, adj $R^2 = .704$, $F(1,36) = 89.12$, $p < .01$. These results suggest that the frequency that students use engineering language, whether correct or not, is highly predictive of their conceptual understanding upon beginning a module.

Because of this relationship, it is critical that academic language be considered as an important factor in effective teaching and learning in engineering classrooms. It can be related as being strongly predictive of how well students understand concepts on a particular topic. Students able to use technical language of a topic are more likely to understand concepts of that topic. This makes it imperative that students be given opportunities to learn and practice the use of technical language so that they are best prepared for learning new concepts and increasing conceptual understanding.

Summary, Conclusions and Implications

In order to monitor student conceptual understanding, instructors must heavily rely on language. However, in science and engineering, many times colloquial language varies significantly from science and engineering technical language. As a result, there must be a common academic language. This requires students to acquire an additional dialect of their language to be used for the context of science or engineering. The future of science and engineering has global demands, making it necessary to have common language and understanding among the fields. This, again, emphasizes the importance of teaching students to become proficient in science and engineering academic language. Various approaches have been utilized to build proficiency in second language acquisition. These can be adapted for science and engineering contexts so that students become proficient in science and engineering language.

Instructors and students must be aware of the necessity to acquire additional language as a part of the process for the learning of science and engineering. Without this understanding instructors may make incorrect assumptions about the depth and understanding student knowledge. Students may get frustrated or misinterpret information if language is not well articulated, understood and practiced. Observing and assessing scientific or engineering language is necessary, but accessing it possesses challenges. Both use the medium of English. So, to someone outside the community of a particular area or discipline of science or engineering, they appear the same. And it is this assumption that must be avoided. So, at the least, for students learning science or engineering, it must be made explicit that, if they are going to become practitioners of a discipline using its foundational knowledge, then they too must learn the language associated with the courses and subjects upon which that discipline is built.

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