ENGINEERING STUDENTS' WORD CHOICE ACTING AS A REALIZATION OF CONCEPTUAL UNDERSTANDING

By

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REALIZATION OF CONCEPTUAL UNDERSTANDING

Abstract

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Language has been studied extensively as a means to measure conceptual understanding in the science education field, but is lacking in regards to engineering education. Kittleson and Southerland (2004) and Kelly (2012) published research studies that focused and found ties between language and conceptual understanding specific to engineering education. Yet, the research studies were narrow in focus and demanded further research to be conducted in various contexts, engineering disciplines, and communication mediums to validate their research results.

This study utilized past research methods, including the Systemic Functional Linguistics framework, to measure conceptual understanding by giving attention to language, more specifically word choice, in an interview setting. The words used among the participants when discussing a structural engineering problem provided insight into the similarities and differences among cohorts. Along with the word choice analysis, conceptual understanding was measured by the creation of a standardized rubric to quantify students' completeness, correctness, relatedness, and realisticness throughout the interview. Finally, the results of the two analyses were compared to discuss connections between word choice and conceptual understanding. The research results proved to support that language and conceptual understanding are connected and also created unique findings focused on structural engineering that are valuable to engineering education.

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I. INTRODUCTION

Engineering, like most science and mathematics fields, strives to create complete understanding in subject areas that are typically seen as complex or difficult to master for many students. Research has been conducted extensively in hopes to improve academics and in achieving high levels of conceptual understanding (Halloun & Hestenes, 1985; Hestenes, Wells & Swackhamer, 1992; Hake, 1997). The aforementioned research studies all focused on the physics field and in doing so discovered common misconceptions and suggested ways for improving academics. While research in physics and other fields has found success in measuring and identifying conceptual understanding, the research in engineering is relatively new (Montfort, D., Brown, S., Pollock, D., 2009; Montfort, D., Brown, S., Frye, N., 2012; Frye, N., Montfort, D., Brown, S., 2012) and there are many advancements to be made. Engineering is especially keen on understanding troublesome areas for students due to the high levels of technical content and potential for creating conceptual change.

Language analysis is one theory that has been proposed as a solution for measuring and assessing conceptual understanding problems. Research interviews and surveys have been used extensively to collect data and the role of language in data collection has been noted as being important. Prior research studies have analyzed the role language plays in science and mathematics (Moje, 1995; Fang, 2004), but most did not focus on making connections with conceptual understanding.

The relationship between how students talk, language use, and their conceptual understanding is best connected in the engineering discipline by Kelly's 2012 dissertation, *Understanding the Role of Academic Language on Conceptual Understanding in an Introductory Materials Science and Engineering Course*. Kelly (2012) studied how language proficiency influenced conceptual understanding, specifically in an introductory materials science and engineering course, and concluded that engineering academic language proficiency is strongly linked to conceptual understanding. Kelly's research findings in the engineering education field revealed opportunities for further research to be conducted.

The purpose of this paper is to build upon Kelly's findings and to demonstrate the potential value of rigorously addressing the connections between students' talk and their conceptual understanding. In particular, this paper applied systemic functional linguistics to explore how students' word choice provides important insights into their conceptual understanding of structural engineering concepts.

II. LITERATURE REVIEW

The research study presented in this paper focused on both conceptual understanding and linguistic analyses where ideas and methods were taken from prior research studies. There is a need for review of former research in both analysis areas to show influence and to validate research practices that were carried over into this research study. Finally, there is a need to review prior research that attempted to connect linguistics and conceptual understanding and ultimately created the research question of this study. The following review focuses on these three main points: first, theories of conceptual understanding and change are presented. Next, previous research on linguistic monitoring and analysis in science education is addressed. Finally, as they relate most to this research study practices, prior research studies in engineering education focused on students' conceptual understanding while using linguistics are discussed.

Theoretical Approaches to Conceptual Understanding and Change

Three themes in conceptual understanding by past research have emerged, with all having contribution to this research study and a need for discussion. Firstly, research focusing on what conceptual understanding is and how it can be measured. The second focus upon conceptual understanding is towards how student understanding relates with the delivery and presentation of the information by the source. Finally, the third theme is specific to how language is a tool that affects conceptual understanding.

Chi presents various research studies and perspectives in regards to what conceptual understanding is and how it is best quantified. A major emphasis among Chi's work is upon how conceptual understanding is best observed through conceptual change, which is a cognitive process (Chi & Roscoe, 2002; Chi, 2005; Chi, 2008). Chi and Vosniadou (1992, 1994) argue that most errors in conceptual understanding, misconceptions, are due to pre-existing knowledge of subject matter being incorrect and that students resist replacing pre-existing knowledge, even if it is incorrect. Theories are also presented regarding the impact of various ways information is organized and that conceptual change may require assimilation and/or revision to overcome concept misunderstanding. While conceptual understanding and conceptual change are the direct focus of these research studies, also a major focus of this research study, rarely is language analysis involved or a focus.

A second focus on conceptual understanding and change that has been studied is in regards to information delivery and the potential for high influence on student learning. This focus brought attention to conceptual understanding studies utilizing interview settings and the importance of language. Chi (1997) developed an analysis method for verbal data and diSessa (2007) criticized techniques of collecting verbal data in a clinical interview setting and showed when verbal data could be validated. The two research cases presented brought focus upon language and that there should be caution and procedures for measuring conceptual understanding. Yet, the research studies did not measure conceptual understanding, a major focus of this research study, as it relates to language but merely address language as being important.

Finally, relating greatest to this research study, prior research studies began to focus upon the connection between language and conceptual understanding. Ivarsson, Schoultz, and Säljö (2002) decided to focus on language in their research and highly referenced Wittgenstein as stating "When I think in language, there aren't 'meanings' going through my mind in addition to the verbal expressions: the language is itself the vehicle of thought" (p. 78). Thus, reflecting that Ivarsson, Schoultz, and Säljö saw the importance of tools, in this instance the tool being language, as the key to studying conceptual changes and understanding rather than a focus on mental shifts, a theory previously focused upon by Chi. Säljö (1999) previously argued in the paper, *Concepts, Cognition and Discourse: From Mental Structures to Discursive Tools,* that language is the key to measuring conceptual understanding and there is no need to focus on the process of thought since that is the "middle man" between understanding and the expression of understanding through language use. Säljö goes further in arguing that instead of "concepts," researchers should be concerned with a student's "discursive resources" in effect, Säljö argues that research should not only *measure* conceptual understanding linguistically, but also *define* it as a linguistic process.

Language and Conceptual Understanding in Science Education

Research in science education has highlighted the interrelations of language and conceptual understanding. One of the most influential works in this area is Lemke's (1990) *Talking Science*. Lemke and others approached the complex relationship from the lens of social semiotics, being described as "the study of our social resources for communicating meanings" (p. 183). An emphasis is that science is a different language and the language must be mastered to be able to master the subject and content within. Moje (1995) studied the interaction between a science teacher and students among a classroom for two years and concluded “it is not clear whether students always developed conceptual understanding as a result of their facility with the terminology and phraseology of chemistry” (p. 365). Moje’s insight is important because the use of technical terms is easily measured in engineering and could then possibly be tied to conceptual understanding. Lemke and Moje’s findings show that rigorous attempts to relate language use to conceptual understanding must dig deeper into the uses of language.

There is general agreement that linguistics play an important role in learning and the development of conceptual understanding, but the specifics of that interaction have proven complex and difficult to characterize, as seen by previous researchers (Ivarsson, Säljö, et al.). Lemke argues that “learning science means learning to talk science” (p. 1). There are two broad tracks of research on language and conceptual understanding in science education: the first investigates the ways in which language can be used by students and instructors to develop conceptual understanding, and the second investigates how students’ language use reveals conceptual understanding. As an example of the first type, Varelas, Pappas and Rife (2006) studied how dialog and argumentation helped second graders understand the phenomena of evaporation, boiling and condensation. Varelas et al. showed how deeply and closely linguistic features are tied to conceptual understanding and the role the interaction plays in student learning. The study concluded that “children predominantly used scientific genre and registers to express and develop their understandings” (p. 655). An example of the second broad track of conceptual understanding involving linguistics in science education is Seah, Clarke and Hart (2011). The study sought to show “the ways in which students employ language to realize scientific meanings related to expansion and insights into the challenges involved” (p. 856). Seah et al. discovered important connections between language and conceptual understanding and also concluded with methodological implications for future research seeking to accomplish similar tasks.

The cited works presented covered a range of scientific concepts, often focusing on processes and phenomena (like phases of matter) considered “fundamental” in science curricula. This research study turns attention to engineering education, specifically structural engineering, and therefore a need for review of literature specific to engineering education with a focus upon the connection between language and conceptual understanding.

Engineering Education Research Focused on Language

Due to progress and successes in investigating the connection between conceptual understanding and language in science education, the research has carried over and is being applied to the engineering education field. The two prevalent studies involving engineering are by Kittleson and Southerland (2004) and by Kelly (2012).

Kittleson and Southerland’s article *The Role of Discourse in Group Knowledge Construction: A Case Study of Engineering Students* was identified as an “exemplar” of discourse analysis in a recent article titled “Emerging methodologies in engineering education research” (Case and Light, 2011). Kittelson and Southerland’s work was on concept negotiation and how discourse (verbal elements of language) and Discourse (nonverbal elements of language) played a role in a mechanical engineering senior design project. The authors studied group interactions and concept negotiations rather than individual conceptual understanding, but still utilized language analysis and transcripts to do so. This research discovered many interesting trends and important information about group interactions, concept negotiations, roles in a group, and academic hierarchy; but did not find results specific to students’ conceptual understanding. This research study differs from Kittleson and Southerland by seeking results specific to conceptual understanding and does not focus on knowledge construction. Kittleson and Southerland also analyzed groups of students while this research study focused on individual student performances. The difference in scales causes need for a different analysis method. Kittleson and Southerland utilized Gee's (1999) discourse analysis method which focuses on both verbal and nonverbal elements of language. This method is suited for group interactions because of the high levels of nonverbal communication, whereas this research study is on an individual level and gives less value to nonverbal language.

Kelly's 2012 dissertation, *Understanding the Role of Academic Language on Conceptual Understanding in an Introductory Materials Science and Engineering Course*, is a direct inspiration for this work in that Kelly applied systemic functional linguistics to engineering discourse, and investigated the relationship between conceptual understanding and "language proficiency" in engineering. In a separate conference paper (Kelly, Krause and Baker, 2012), Kelly demonstrated how systemic functional linguistics (SFL) can be used to characterize a student's academic language proficiency. This study likewise utilized the SFL framework to link the construct of academic language with measures of conceptual understanding. Kelly found that "Engineering academic language proficiency was found to be strongly linked to conceptual understanding" (p. 101) and that simple exposure to engineering academic language did not influence engineering language proficiency.

This study expands upon Kelly's findings while addressing areas that were deemed as research limitations and further research recommendations. Specifically, this research study alters the engineering content; Kelly's study utilized bicycle and airplane designs while this study utilized a structural building. Also differing is the communication medium; Kelly's study examined language through writing samples whereas this study used verbal interview data.

Finally, rather than simply agreeing that engineering language and conceptual understanding are connected, this study delves deeper into how the two are connected.

III. PURPOSE AND RESEARCH QUESTIONS

The purpose of this study was to continue the existing efforts to apply linguistics to the study of conceptual understanding in engineering education. Since language analysis has been shown to be meaningful and applicable in the science education fields, this paper hopes to expand that success into engineering education and provide meaningful insights into students' conceptual understanding. A sought future application is to identify misconceptions and levels of conceptual understanding among a student body by analyzing language use.

The guiding research question was, "How is word choice in an interview setting comparable between sophomore and senior level civil engineering students and how does it realize conceptual understanding?" The methodology section describes how this question is related to the theories of conceptual change and linguistics previously presented, and then describes how the question is answered through the use of analyses for both student word choice and conceptual understanding.

IV. METHODOLOGY

Overview

The goal of the research conducted was to analyze data from an ongoing longitudinal study (Montfort, Brown, and Frye, 2012; Frye, Montfort, and Brown, 2012) and see how language analysis and conceptual understanding measurements are connected. The data used in this study consisted of interviews with twelve sophomore and fourteen senior civil engineering students regarding a structural engineering problem. The problem involved a wind load applied to an L-shaped building. The data was analyzed in two methods, the first being a comparison of word choice used on a cohort-level (sophomore versus senior) comparison and then again for each individual. The second analysis conducted graded and measured the student responses for conceptual understanding while using a standardized rubric. Finally, the results were connected and provided an answer to the research question and supporting evidence of how language is an identifier for conceptual understanding. Before the methodology and analysis details are discussed, first some insight into prior research studies that led to the methodologies are summarized as theoretical background. A need for theoretical background in both language analysis and conceptual understanding exists because the methods used specific criteria among both broad categories. Language and conceptual understanding are both vast subjects that need to be defined in order to study specific portions applicable to this research study.

Theoretical Background

As stated, the research conducted was based on two separate analyses. Thus, there is theoretical background for both the language and conceptual understanding analyses to better define the specific methods applicable to each analysis.

Approach to Language

This study is based on Halliday's (1994) systemic functional linguistics (SFL) Framework. The name systemic functional linguistics is meant to capture both that language is systemic and functional, which means that language follows rules and has structure while providing insight and having a purpose. SFL focuses on grammar which provides structure rules (e.g. punctuation, sentences, paragraphs), but there are many other focuses, such as the context in which the communication is occurring. In SFL, the function of language is to realize an intended meaning. In this use "realize" means "to make real," so the statement "language realizes meaning" defines that language is the mechanism by which a desire to express something is transformed into an action (i.e. speech or other forms of expression). Halliday's SFL framework is complex in that there are many applications and that language is a complex system, thus there is a need to explain how SFL plays a role in this paper. The research does not explain the theory behind SFL, but merely adopts the established framework and how the analyses and results are dependent upon the theory.

This study is concerned with a very specific and narrowly defined portion of language as defined by SFL. In basic terms, this research is concerned with the words students used in response to interview questions about the analysis and design of a structure, and how those words reflect their conceptual understanding of structural engineering. In terms of SFL, this research is investigating the *ideational meanings* created in the *field* of structural engineering as *realized* by students' word choice. This more technical phrasing is important because it provides structure and definition to the general purpose of this research study. SFL defines language as consisting of different strata, and each strata as consisting of different types. So, for example, the highest strata of language is called metafunction, which can be understood as the type of meaning being made. In this study, intentions are to investigate *ideational* meaning which involves the communication of ideas and concepts. Table 1 briefly summarizes the strata within SFL and where this research lies within the vast system that is SFL.

Table 1. Study description within the framework of Systemic Functional Linguistics

Strata	**Simplistic Name**	**Types in SFL**	**Emphasis in this Study**
Metafunction	Meaning	Ideational, Interpersonal, Textual	Ideational
Register	Context	Field, Tenor, Mode	Field
Lexicogrammar	Vocabulary and Grammar	Clause, Phrase/Group, Word, Morpheme	Word

While there are many uses for SFL, this study pulls a specific set of strata from the theory. Conceptual understanding is being measured with focus on ideational meanings – the ideas and concepts students are trying to express. This study is using interview settings as the context and conceptual understanding acts as the *field* – topic of focus of the activity. Tenor (role relationships of power and solidarity) and mode (amount of feedback and role of language) are difficult to measure while in an interview setting and vary greatly for each individual participant and thus are not the focus since difficult to quantify. Deeper analysis would be required to measure the impact of tenor and mode.

Words break phenomena into categories and types by distinguishing them and organizing their similarities. This matches the research approach to conceptual understanding more closely than other lexicogrammatical structures and resources and thus word choice rather than clause, phrase/group, or morpheme is the emphasis of this research.

Approach to Conceptual Understanding

As discussed in the literature review, conceptual understanding is a broad subject and is generally studied and defined by conceptual change; therefore theoretical background is needed to define how conceptual understanding is measured. While an observation of conceptual change in previous research studies showed levels of conceptual understanding, such an application is difficult when working with interview data. Previous research studies were conducted over time intervals where conceptual change developed and was observable. With interview data, the time interval being short caused difficulties in observing conceptual change and so instead of measuring conceptual understanding based on conceptual change, a grading rubric was created.

To best capture conceptual understanding, four grading criteria were created: completeness, correctness, relatedness, and realisticness. The criteria selection are best supported by prior work by Chi and Roscoe (1994) with the statement "students may possess a very complete, but flawed mental mode, or possess a basically correct model, but with sparse details" (p. 8). Chi and Roscoe were attempting to quantify student responses and determine if the students' mental model reflected a level of conceptual understanding. The first criterion in doing so was if the responses were coherent, i.e. logical, and then if the students' responses were complete and correct, as per the above statement. This research studies' grading rubric agrees with Chi and Roscoe's and also adds relatedness as a fourth measure of conceptual understanding. Relatedness is added since value is seen in student responses where ideas and responses to different questions are connected. Further discussion of the grading rubric exists in the methods section specific to the grading rubric.

Sample Selection and Participant Demographics

The sample selection was carried out by volunteer sampling, in which twenty-six volunteers from two separate course levels participated in the research. The students were recruited and asked to join the research population based on being enrolled in either the sophomore level Engineering Mechanics-Statics course or by graduating in the Fall or Spring semesters of 2011. Sampling was complicated by the fact that the overall research project is a longitudinal study and in that a 3-year research commitment was sought from all participants, and by the requirement that participants from the graduating cohort acquire engineering-related jobs. A total of twelve sophomores enrolled in the research. The senior level engineering cohort was composed of fourteen total participants, including three Masters students.

The study cohorts varied greatly and within each cohort the students were extremely diverse. Students differed in academic standing and engineering emphases (structural, water resources, environmental, transportation, infrastructure), along with having different levels of prior engineering and work experience. Beyond academics, there was a distinct majority of male participants; only three participants from each of the cohorts were females. Another important diversity factor was that some students appeared to have English as a second language, but this did not appear to hamper with their ability to partake in the research.

While the diversity would appear to hamper the analyses and results of the research study, attention was given to each factor and accounted for accordingly. Differences in academic standing and prior knowledge are expected in a study amongst students. While there are different genders within the cohorts, this study does not distinguish or focus on gender differences. The sample size of female participants and male participants is too small to compare the language similarities and differences between the two genders. Such differences could be a focus of future research. The factor that some participants had English as a second language was the most concerning diversity characteristic of the research population since this was anticipated to impact word choice. Yet, the word selection was compared with students that spoke English as their first language and the two compared similarly.

The research study focused on word choice and conceptual understanding and measured both with the cohorts being the unit of analysis. Cohort diversity and range in conceptual understanding helps in identifying differences in word choice. While the sophomore versus senior cohorts had large variations and anticipated differences in word choice and conceptual understanding, analyses could be done within a single cohort to find more fine-grained differences if desired. While the overall research focus was upon comparing the cohorts against each other, attention was given to within-cohort differences.

Data Collection

The data was collected in the form of interviewing the participants in a semi-structured clinical interview format (Posner & Gertzog, 1982). The research required two interviewers due to the large number of participants, thus there was a need to standardize the content between the two cohorts. While the interviews were standardized by having the same content and preset questions, the interviewers were allowed to ask follow-up questions to clarify student responses and thus creating the semi-structured format.

The given structural problem involved a high-rise building that has an L-shaped footprint and was experiencing an imposed wind load perpendicular to the longer leg of the building. Figure 1 shows the provided images of the problem, in which students were allowed to use the drawings in aiding their explanations.

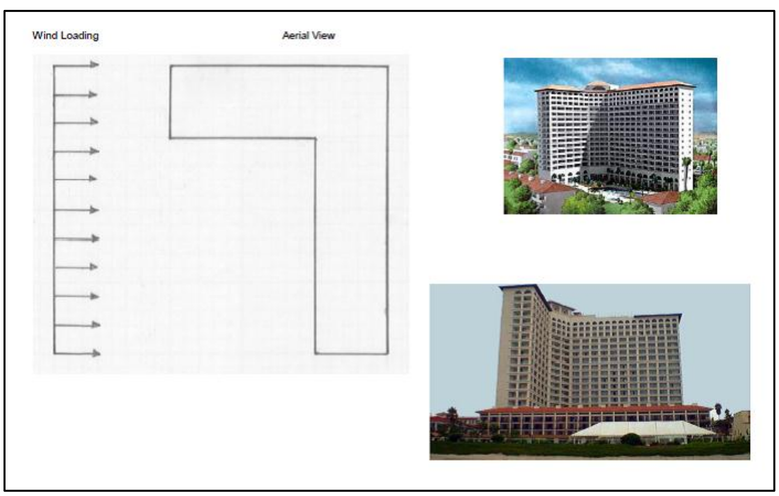

Figure 1. Provided visual references of the L-shaped building with the applied wind load, images from Flickr Creative Commons

The participants were also told they could draw and write on the provided drawings and were generally asked to draw in the case of needing clarification to their answers. The action of the research participants drawing was not part of this research study and was not considered in the methods or results.

Standard questions were asked in regards to the structure and how the building would react to the wind load. The questions asked focused around the aspect of using the SFL framework to capture student meaning in the verbal responses and in leading to measuring conceptual understanding. The standardized questions created equal context across interviews and consistency between the two interviewers. The set of predetermined questions were asked during the interviews after introducing the problem and visual aids. The questions consisted of:

- *How would the building move?*
- *Would different parts move differently?*
- *If so, how would those movements compare to each other?*
- *Do you see any potential problems that could occur in this building with the wind blowing like this?*
- *What could be done to counteract them?*
- *If you were to design this building, how might you go about it?*
- *What parts would need to be the strongest, or what parts would you have to worry about in your design?*
- *Is there a simple way you could model this?*

The interview method has been used before to investigate student conceptual understanding based on their responses (Ioannides & Vosniadou, 2002, Montfort, Brown, & Pollock, 2009). The semi-structured format allowed for follow-up and clarification questions to be asked upon conversation flow, but the intention was for the predetermined questions to be the guide to the conversation. Also, there were a few cases where the predetermined questions required clarification of what was being sought from the student because of key terms (e.g. *design* and *model*) that a student did not understand. All conversations were video and audio recorded to provide documented data during the post-interview stage of the research, along with notes taken by the interviewers. The audio recordings were then converted to transcriptions by a transcription service. In the course of this study, the transcriptions were compared with the audio recordings, word-by-word, to check for consistency in the conversion process, specifically with a major focus on correcting technical language that was found to be transcribed incorrectly.

A. Language Data Analysis

The analysis of the collected data involved four steps due to the immense amount of information collected; the transcripts combined to include more than 35,000 words utilizing more than 1,900 individual terms. The first round of analysis began with general familiarization with the data and then choosing areas to focus upon based on the questions asked of the interviewees and the systemic functional linguistics framework. The next step was to then reduce the amount of data due to the large number of unique terms and unique approaches in answering the interview questions. The reduction in data allowed for comparisons between the two cohorts and among the participant individuals. Various ways of analyzing the condensed data were conducted. Finally, data verification was created by checking to ensure that words were used in the correct context and that appropriate categorizations were assigned.

There were expectations prior to data analysis that the senior cohort would use more technical, engineering-specific terms, since they had greater knowledge of the subject area. The majority of the senior cohort had studied structural design and thus would have a larger vocabulary applicable to the provided problem and questions. The fact that students had varying technical vocabulary does not necessarily show levels of conceptual understanding as proven in prior research by Kelly (2012) and others. Yet, this facet would still have to be considered in analysis. The study still aimed to measure how word choice by participants would vary and/or be similar. Based on the predetermined questions and context of the interviews, different categories were created to observe how the students described the engineering phenomenon and lead to the creation of coding families. One method approach to address the concerns was to include terms that were not necessarily engineering-specific and could be seen as synonyms or replacements for the technical terms.

Familiarization and Focus Families

Using the transcriptions, data analysis was conducted by inputting the data into ATLAS.ti, a qualitative data analysis and research software program. ATLAS.ti consists of many tools for analyzing the transcriptions. One of the tools is the ability to code terms, which is the process of tagging words or phrases that appear important and being able to group the terms into related families. Families for this project were composed of four groupings of terms: Building Components and Characteristics, Loadings, Reactions, and Analytical Constructs. The categories were chosen based on the predetermined questions with an intention on capturing meaning projected by the participant. The Building Components and Characteristics words used by the research participants were grouped and identified as being important to distinguish how the building was considered (e.g. a whole system, individual members, etc.). The provided visual references showed a wind interacting with the L-shaped building and thus how the students thought of the wind was captured within the Loadings family. Wind causes behaviors among and within the structure and in turn those behaviors were identified in the Reactions category. The Analytical Constructs family was added after observing many students referring to design processes, steps, software, and outside resources such as class experiences that influenced their responses and word choice. All families return back to the root of the SFL framework in trying to capture meaning from what the students are projecting and works towards measuring conceptual understanding.

Coding was conducted on all transcripts to help familiarize and condense the vast amount of data. The coding process involved reading the transcripts and identifying word-by-word if the term used belonged to a family and if the term carried meaning or justification in the student response. If so, an identifier was created, typically the word itself, and grouped together with similar terms. By grouping the terms, the analysis process became simplified since similarities and differences could easily be seen. Figure 2 shows a transcription example with words coded that would be of interest and have potential meaning in the students' explanation of concepts and in answering the questions asked.

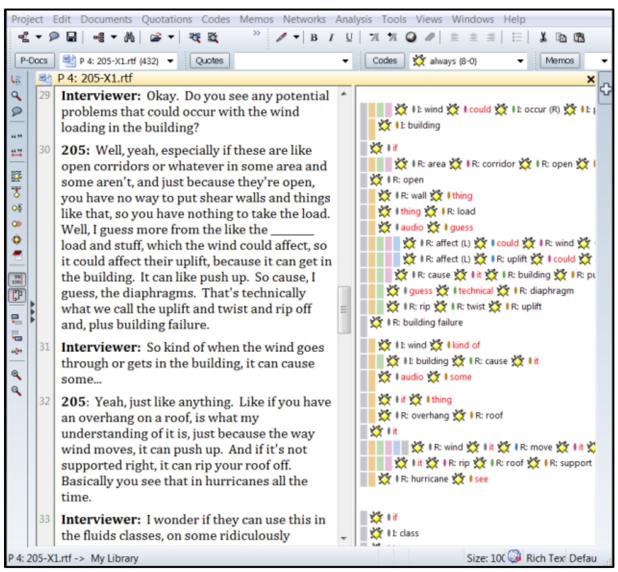

Figure 2. ATLAS.ti transcription coding example (senior participant)

Condensing of Data

The process of coding allowed for terms that did not carry meaning (e.g. *the*, *that*, *is*, etc.) and are typically filler words to be neglected. Many terms common in everyday language were of no interest and were ignored from coding, for example the use of personal pronouns, conjunctions, and other forms of grammar that carry little meaning. The main focus during coding was based on nouns and verbs that fit into any of the aforementioned families, but attention was also given to words that fit when used as adjectives or in other senses. In the process of managing the data, words were also coded to condense the data based on the root word. Pluralization and different tenses were combined unless they were used in a different context from the root word usage. When discussing terms, the designation, term*(s),* denotes the root word plus includes the plural and other tenses. The process allowed for every word to be checked for context and that it carried meaning, which is the goal of the SFL framework. To achieve this ATLAS.ti was used to initially code all terms of interest and then during the sorting process and assignment into families, all terms were criticized to whether they carried meaning or not. If not, they would be neglected from the families and continuation of analysis.

In condensing the data, the transcriptions consisted of both the participant and interviewer word choice and were the entirety of the conversations during the interview. The research sought to analyze and make connections between word choice and conceptual understanding of the participant and typically did not need or focus on the interviewer word choice or input. The term usage was then separated from terms used by the interviewers and terms used by the participants. The interviewer had the potential to influence student word choice, and that aspect is considered and elaborated upon in the results.

Cohort Comparisons

The second tool used after the coding process was complete involved the Word Cruncher function within ATLAS.ti and was where cohort comparisons were made. The tool created a word count frequency table that quantified individual word usage for each participant. Figure 4 shows a modified word count frequency table and how the term usage is broken down.

WORDS	Overall Soph. Use	Soph. Level Group Use	Overall Senior Use	Senior Level Group Use	Total Count	P 2 (Senior)
Total:	48%	100%	52%	100%	18841	1140
building	44%	100%	56%	89%	186	9
buildings	9%	9%	91%	56%	11	2
top	61%	91%	39%	67%	57	3
tops	25%	9%	75%	22%	4	1
parts	100%	45%	0%	0%	13	0
part	76%	64%	24%	56%	54	0

Figure 3. Example of a modified word count frequency table

A comparison between the two cohorts was conducted, in which the percentage of term use per cohort was determined, and the percentage of the participants within each cohort that used the term was found. The research question aims at comparing the two cohorts' word choice and thus a breakdown of term usage per cohort is applicable. The values were then used to compare the two cohorts against each other to find similarities and differences in word choice based on the given problem. Comparisons were made by multiple means between individuals and between cohorts. The first comparison was in term frequency use and terms that were used the most by each cohort. Table 2 shows an example of terms that have high cohort use specific to either the seniors or sophomores and are identified as important and a potential for differences between the cohorts.

Table 2. Term examples with high differences in cohort use

Term	Number of Term Uses (Excluding Interviewer Uses)	Percentage of Overall Term Use by Sophomore Cohort	Percentage of Overall Term Use by Senior Cohort
Shear	98	3%	97%
Deflection(s)	53	0%	100%
Parts	44	75%	25%

The second comparison was by finding the difference in term usage between the cohorts and identifying terms that had similar frequency uses between the cohorts. Such examples of similar use between cohorts are represented in Table 3.

Table 3. Term examples with high similarities in cohort use

Term	Number of Term Uses (Excluding Interviewer Uses)	Percentage of Overall Term Use by Sophomore Cohort	Percentage of Overall Term Use by Senior Cohort
Building(s)	229	38%	62%
Center	13	62%	38%
Base	15	47%	53%
Movement(s)	24	46%	54%

The terms in Tables 2 and 3 are included in the analysis and results sections along with other terms found to play a role in how language and conceptual understanding are related.

Verification of Data

After the term-frequency-use tables were created using the Word Cruncher tool, words that had been coded and belonged to one of the four families were then focused upon. All words were checked for context and that they belonged to the categorization in which they were placed. For example, the term *experience* could be used in the context of a participant speaking about their personal experience with structural design and coursework taken. Or, in another context the participant could use the term such that the building would *experience* deformation due to the imposed wind load. The latter of the context use for *experience* is applicable to the Reaction family while the other context would be removed since it does not carry meaning applicable to this research. The process helped verify words that could be used in multiple contexts as being used as they were being interpreted for usage. The verification process also eliminated all off topic conversations, such as discussion of wind behavior on sports cars or of a current air quality study being performed in Mexico City. Conversations were considered “off-topic” when they did not directly relate to the building or questions about it. It was important to remove these because not every participant talked about the same topics, other than the building, so the word count comparisons would have been less meaningful.

During analysis, one major potential impact on the results was that the senior cohort tended to use a greater amount of words in their interviews than the sophomores. The senior cohort participants used thirty percent more words than the sophomore participants. Yet, there is a wide range of word use (i.e. conversation length) within each cohort versus between the cohorts. The lowest word count was by a sophomore participant with only 711 words used to address the questions, while the greatest word count was by a sophomore participant with 2308 words used. The great range also exists in the senior cohort with one participant only using 750 words while another used 2120 words. The great range was anticipated from the diversity and character of participants and the interview setting being semi-structured. The diversity in word use within cohorts shows that while the seniors used more words on average, it did not indicate a significant difference between the two cohorts.

B. Conceptual Understanding Analysis

The second analysis performed was to measure the conceptual understanding of participants and then to make observations regarding the similarities and differences between the cohorts. To measure the conceptual understanding, a standardized grading rubric consisting of four criteria that captured the student responses was created and applied to each research participant. Once the grades were assigned, data verification was performed to ensure consistency throughout the grading process and to authenticate the criteria. Finally, comparisons between cohorts for conceptual understanding could be made.

Conceptual Understanding Grading Rubric

The method of conducting the conceptual understanding analysis consisted of creating a grading rubric that would capture the student responses and enable comparisons between the cohorts to be made. The grading rubric would be based on a scale to measure the different levels of conceptual understanding ranging from high to low. Rather than a numerical value or letter grade assigned, a simple high, medium, low scale was chosen. The reasoning behind the scale metrics was that this would represent the rough values assigned and not state a linear or equal distinction between levels. A numerical scale for grading states that every change in grade must be equal, whereas the scale chosen allows for broader conceptual understanding levels to be categorized equally. The conceptual understanding between students was anticipated to vary greatly since the large diversity in cohorts, thus grading criteria that would capture high variance was important.

Four categories were chosen to reflect a wide range of responses and overall conceptual understanding throughout all responses. The first criterion was completeness. Completeness aimed to capture responses to the three most standardized and consistent questions asked by both interviewers and quantify that students could provide responses to all of them. The three questions are outlined in Table 4; along with accepted responses that would count towards showing the student had complete conceptual understanding. A student obtained a medium score for completeness if they provided one response to each question that matched the acceptable completeness responses listed in Table 4. The three questions were chosen since they were asked to all participants whereas some participants were never asked about design or a simplification process, which would be inconsistent to include such content in a completeness grade. The acceptable completeness responses were chosen with input from professional engineers with engineering design experience related to L-shaped structures and is discussed in the verification of data section

Table 4. Questions and responses graded for complete conceptual understanding

Questions:	Acceptable Completeness Responses
Building Deformation: How would you expect the building to move, based on the wind load?	▪ Building tends to rotate/twist/torque ▪ Relative displacements horizontally (The long/narrow leg moves differently than the other leg of the building) ▪ Relative displacements vertically (The top of the building moves differently than the bottom)
Potential Problems: Do you see any potential problems that could occur in this building with the wind loading case?	▪ The inside corner could deform/crack/break ▪ The foundation can be jeopardized if not designed properly (building tip over, overturning, sliding, etc.) ▪ Upper Corner farthest away from inside corner is the farthest from the original location ▪ Roof would need to be designed for suction pressures
Potential Problem Solutions: How could the problem be solved or counteracted?	▪ Add more lateral force resisting systems (shear walls, bracing, etc.) and/or increase stiffness ▪ Separate the building into two segments ▪ Increase the ductility of the structure to allow for deformations

The second grading criterion for conceptual understanding was correctness. Students frequently provided responses to questions that were incorrect and act as an identifier of having misconceptions or low conceptual understanding. A student that had zero incorrect statements would receive a score of high for correctness whereas students that made errors in their responses received a medium or low score. The distinction between a medium and low score for correctness relied upon the frequency of errors and the severity of the incorrect statements made. Students with few and minor errors received a medium score whereas students who made major and frequent incorrect responses were assigned a low score. The distinction between minor and major errors was determined by comparing the student errors against each other and as a sign to how much conceptual understanding was lacking. An example of a minor error included a participant discussing the load determination and load factors and used an incorrect load factor.

This was a minor error since these load factors and combinations are readily available and are heavily referenced rather than recalled from memory. A major error included a student who stated the bottom of the building would move equally as the top. This was considered a major error since the bottom would not move since it is considered a fixed connection. This concept is easily observed by many, including non-engineering professionals, and would be considered critical to an engineering students' basic knowledge. This grading criterion was also validated in the verification of data process.

The third grading criterion was relatedness. Relatedness captured conceptual understanding by analyzing a student's ability to connect ideas and responses together and to provide justification to answers and discussed content. Students that identified a problem in the building due to the applied wind load and then connected a solution to the same problem are seen as showing higher conceptual understanding. Many students identified how the building would deform but did not relate an identified problem with the deformation caused, which showed a lower level of conceptual understanding. Beyond relating to prior responses, relatedness captures student justification. Students who simply answered questions with yes and/or no responses do not show high levels of conceptual understanding. Students that relate their responses often receive a high score for relatedness. Students that provided at least one reference between responses received a medium score. And those participants that failed to relate any of the responses to the standard questions are identified as having low conceptual understanding.

The final grading criterion was realisticness, which corresponds with students that can provide responses that would be in line with actual engineering practice. This grading category is typically seen as most applicable and valuable in the student responses to how the problems can be solved. Some students attempted to make building changes and remove the L-shaped geometry. Such a solution is typically not accepted as an engineering solution since that decision lies with the architect and owner of the project. Thus, students that provided unrealistic responses or solutions are seen as having low conceptual understanding and thus a low score. Students that incorporate actual engineering design practices and solutions to identified problems show high conceptual understanding and thus earned a high score for this category. Some students did not exhibit realistic or unrealistic responses and so a medium score was assigned.

Verification of Data

As seen in the grading rubric and process of assigning scores for conceptual understanding, there were many judgments made on what scores to assign. The high, medium, low grading system has potential for errors throughout and thus a need to verify the data and assigned scores for conceptual understanding. One way that this was achieved was by employing the constant comparative analysis method (Glaser, 1965). Once the scores for all participants were assigned for the four conceptual understanding categories, comparison between the scores was conducted and checks for consistent grading were made. Slight differences were recognized and thus scores were altered to convey a standardized grading system.

Another method of verifying the data involved interviewing and requesting professional engineering input from experts with practical design experience. The input brought insight into what responses could contribute to a complete participant interview and to answer questions about responses being correct and realistic. One engineer provided a figure, Figure 5, which shows the actual deformed shape of the L-shaped building and thus verified the grading for correctness and completeness specifically regarding the building deformation. The building deformation is seen as complex and Figure 5 provides a comparison that could be made between how the students drew the deformation and the actual building behavior. Again, this research study focused on word choice and the comparison between drawings was not conducted. The figure shows a ground motion applied, which mimics a seismic loading. The problem for this research project involved a wind load, but is comparable to the seismic load effects since both are applied lateral loads to the system.

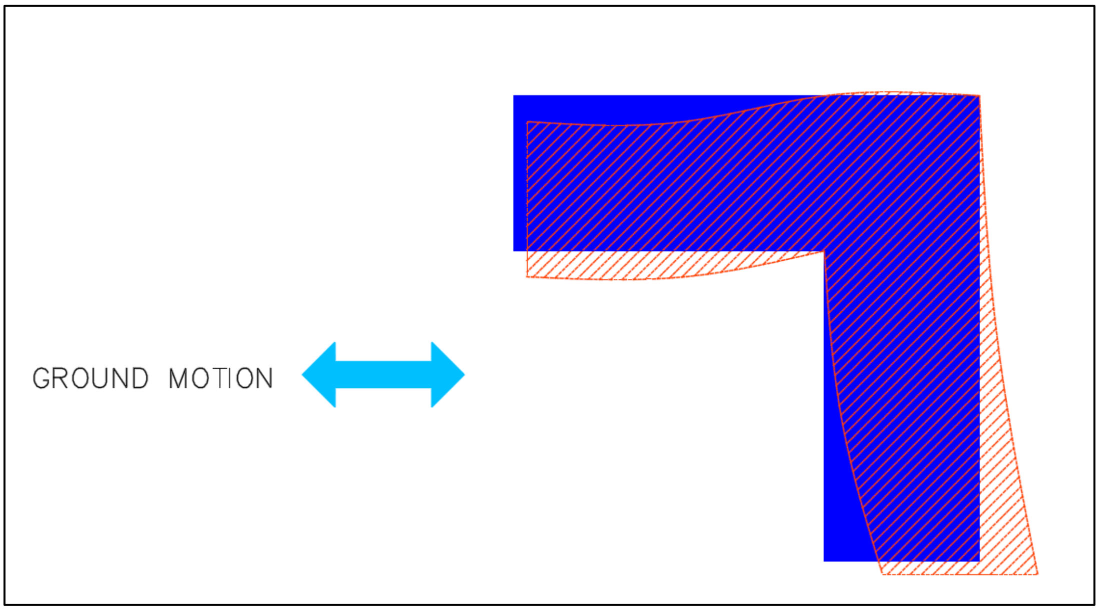

Figure 4. Actual deformed shape of the L-shaped building with a lateral load applied, image provided per Dr. J. Daniel Dolan interview

V. RESULTS AND DISCUSSION

As with the two methods and analyses conducted for the students' word choice and conceptual understanding, there were also separate results for each. The overall research question was whether the two analyses can be connected and thus how language, specifically word choice, identifies levels of conceptual understanding.

A. Language Analysis Results

Interesting similarities and differences were discovered between the two cohorts in their responses to the structural engineering questions among the major word choice families. The Results and Discussion will be organized around the coded families created in the methodology section. Again, note that these categories are essential to the task of relating participants' word choices to their conceptual understanding: for example the terms they use to describe the building reveals the categories and concepts they use to give meaning to the building. Within structural engineering, there is a relationship between applied loads, for our problem the wind load, and how the building reacts. Thus, the loadings and reactions families for word choice are combined and linked together to make comparisons between the cohorts. The final family created for word choice, Analytical Constructs, is also analyzed and results found.

A. Building Components and Characteristics

As expected and seen in the results, there exists a wide range of terms in both frequency and participant and/or cohort usage. Attention was directed towards terms that one cohort used proportionately more than the other and terms that appeared to be shared equally between the cohorts. Any term was identified as having cohort dominance if a cohort used the term greater than sixty-five percent of the overall usage, which shows differences between the cohorts. Terms not identified as having cohort dominance were then identified as shared "equally" between the two cohorts and show similarities. The term equally does not mean exact same term usage between the cohorts since there would be very few terms that have exact equality in usage between cohorts. Terms that are applicable to building components and characteristics are summarized in Table 5 and best show the differences and similarities between the cohorts.

Table 5. Dominant and shared cohort terms for building components and characteristics

Sophomore Cohort Dominant Terms	Shared Terms	Senior Cohort Dominant Terms
Back, Bottom(s), Center, Material(s), Concrete, Middle, Part(s), Support(s), Window(s)	Base, Portion(s), Roof(s), Side(s), Top(s)	Beam(s), Bracing(s), Building(s), Column(s), Connection(s), Corner(s), Diaphragm(s), Edge(s), End(s), Face, Floor(s), Foundation(s), Frame(s), Framing, Ground, Joint(s), Leg, Steel, Timber, Wood, Member(s), Outside(s), Piece(s), Section(s), Story, Structure(s), Surface, Wall(s)

When comparing the terms used by the sophomores and seniors, two major distinctions appear in the word choice used to discuss the building and its components and thus differences in cohorts. The first distinction is that the sophomores chose words that reflected external components of the building, can be seen in the provided visual references, whereas the seniors used words that showed interior components, not included in the provided visual references, and exterior components. The second difference in cohort word choice was that the seniors used words that represented components of the building at an individual member scale while the sophomores tended to identify components on a larger scale and less focused on structural function. Details into the findings and the significance of each are provided, along with word count frequencies and cohort usage to better support the differences.

To summarize and better describe that the sophomore cohort tended to identify components of the building that could be seen on the provided visual references and that the senior cohort identified visual and non-visual components, term grouping as visual versus non-visual components was completed. Table 6 shows terms identified as being visual or non-visual and provides the usage per cohort. Within the usage per cohort, there is designation on percentage of overall term usage and percentage of cohort that used the term.

Table 6. Visual and non-visual building component terms

Terms	**Usage by Sophomore Cohort**		**Usage by Senior Cohort**	
	% of total term usage	% of cohort using the terms	% of total term usage	% of cohort using the terms
<u>Visual Building Component Terms:</u> Base, Bottom(s), Center, Corner(s), End(s), Leg, Roof(s), Side(s), Top(s), Window(s)	43%	100%	57%	93%
<u>Non-Visual Building Component Terms:</u> Beam(s), Bracing(s), Column(s), Connection(s), Diaphragm(s), Foundation(s), Frame(s), Member(s), Wall(s)	16%	75%	84%	100%

As seen in Table 6, there is nearly even usage of visual building component terms, with the seniors having slightly more overall usage with fifty-seven percent. The slight difference is usage is non-significant since there was such range in participant word counts and content, thus the overall usage can be seen as shared equally for visual terms. The non-visual building component terms are heavily used by the senior cohort and the severity shows with the statistic that every participant in the senior cohort used at least one of the terms identified as being a non-visual component, while only three quarters of the sophomore cohort did such. The sophomore students that did identify a non-visual building component typically only made a quick mention and did not elaborate or incorporate the term into extensive discussions. The terms *bottom(s)*, *center*, and *window(s)* are examples of terms representing features of the building that are visible and even prominent in the given drawings and that both cohorts typically identify in their dialogue. Terms such as *beam(s), column(s)* and *connection(s)* are prime examples of non-visual building components, and all three terms were used nearly one hundred percent of the time by senior participants.

Structural engineering requires students and professionals to identify and design various building systems and sub-components. The findings suggest that students who did not identify sub-components, typically non-visual components, possess a simple conceptual barrier. Those students tend to define the building based upon the exterior, typically visual components, and neglect important systems and components within a structure. Senior engineering students have greater exposure to non-visual building component design, but the sophomores also have exposure to non-visual building components such as *wall(s),* but did not tend to address the component importance. Further support is that the sophomore students tended to identify the building as being made of concrete, which is true of the exterior given structure, while the seniors tended to identify all of the building materials (including steel and timber) that would cover both the exterior and interior components.

The second major distinction of word choice when discussing the building and its' components involved identifying the components as having a structural function. The seniors identified *diaphragm(s), floor(s), frame(s),* and *wall(s),* which all carry an engineering function to resist loads. The sophomores on the other hand identify components such as *center*, *middle,* and *portion(s)* which do not necessarily specify an engineering function. Care had to be taken when identifying a term as having function or not, such an example as "the portion that resists the wind" shows the term *portion* as having a function, function is to resist the wind. The terms were checked for context as described in the Methods section and in this analysis the sophomores' word choices did *not* reflect functional groupings, but rather spatial ones. Table 7 supports the finding and provides the term usage distribution between components that show engineering function and those without. One interesting note about Table 7 is that the sophomore cohort overall had a high percentage of participants that used a function term at least once, but the overall term usage was far less than that of the seniors. This finding shows the sophomores were capable of using the same terms as the seniors, but the sophomores did not find reasoning to continue to use the terms (i.e. the functional terms were much more important to the seniors). There appears to be a conceptualization error on behalf of the sophomore cohort towards how a building is composed and what components have functions.

Table 7. Distribution between components having engineering function and those without

Terms	**Usage by Sophomore Cohort**		**Usage by Senior Cohort**	
	% of total term usage	% of cohort using the terms	% of total term usage	% of cohort using the terms
Building Components with Function Beam(s), Bracing(s), Column(s), Connection(s), Diaphragm(s), Floor(s), Foundation(s), Frame(s), Framing, Joint(s), Roof(s), Wall(s),	23%	70%	77%	100%
Non-Functional Building Components Base, Back, Bottom(s), Building(s), Center, Corner(s), Edge(s), End(s), Face, Leg, Member(s), Middle, Outside(s), Part(s), Piece(s), Portion(s), Section(s), Side(s), Structure(s), Surface, Top(s),	48%	82%	52%	91%

A final finding in regards to the building components is the level of break down each cohort performs on the problem. As seen with the senior cohort word choice, the seniors broke the building into individual elements, *beam(s)* and *column(s)*, whereas the sophomores defined the overall building as much larger components. Material taught in Statics includes equilibrium of a rigid body and introductory structural analysis problems involving trusses, frames, and machines, all of which require the similar scales of break-down as seen in the provided problem. Such an example is that a given problem in Statics may be composed of three elements and then information asked about one particular element, requiring decomposition of the problem. The sophomores generally tended to disregard this process when applied to the given L-shaped building. Those that did separate the building into components merely broke the building into two large elements and disregarded any further decomposition. Upper level engineering design courses mainly focus on the design of individual components, such as beams, columns, and shear walls and are reflected in the level of building decomposition by the senior participants. The finding shows the transition through academics and a possible insight into conceptual understanding levels.

The findings are based on analysis of data that neglected the interviewer's word choice and word count. There became concern that the interviewer might have potential influence on word choice by the research participants. Checks for percentage of conversations with the interviewer using a term first and then the participant following by using the term were made. The only building component terms that appeared to have interviewer influence were *part(s)* for the sophomore cohort and *end(s)* for the senior cohort. *Part(s)* was used in asking the question to the sophomores, "Would different parts move differently?" and the sophomores generally followed by using the term. Yet, the term was used extensively after the question was asked where the sophomores had the opportunity to use different terms to describe the building components and the interviewer had stopped using the term. There appears to be little to no interviewer impact throughout due to this factor and that *part(s)* and *end(s)* were the only two terms out of hundreds for the building components to initially be concerning.

B. Loadings and Reactions

During data analysis, attention was given to terms related to loadings and reactions due to the importance each plays in structural engineering and especially in the research problem. Also, the two families are being discussed together here because the ways in which students' word choices emphasized or deemphasized the interaction between loadings and reactions proved to be particularly important in the analysis. A relationship exists between the two and can be considered a cause and effect relationship. Table 8 presents the terms from the two families that have cohort dominance and terms showing similarities with shared usage.

Table 8. Dominant and shared cohort terms for loadings and reactions

Sophomore Cohort Dominant Terms	**Shared Terms**	**Senior Cohort Dominant Terms**
Bend, Bending, Break, Support	Blow(s), Force(s)-Load, Move(s), Rotate(s), Wind(s),	Cause(s), Compression, Deflect(s), Deflection(s), Experience(s), Force(s)-Reaction, Hit(s), Load(s)/Loading(s), Moment(s), Moving, Push(es), Resist/Resistance, Shear, Stress(es), Tension, Torsion

Two distinctions or differences were made in the families involving the loadings and reactions. The first difference between the cohorts is similar to that of the building components and characteristics family in that the sophomore students did not tend to discuss internal phenomenon. The senior cohort related external loadings and the effects on the internal reactions and this was reflected in their word choice. The second major difference in cohorts is the understanding and expression that the wind is an applied “load”. Recognizing that the wind is a load leads to a cause and effect relationship similar to that seen in the first major difference.

The dominant terms expressed by the sophomore cohort and the senior cohort show differences in being able to identify the loadings and reactions as internal versus external. The sophomore cohort used *bend*, *bending*, and *break*, which are all visual and external reactions. The senior cohort used both external, *deflect(s)* and *moving*, and internal terms, *tension*, *compression*, *shear*, and *moment(s)*, to discuss the loadings and reactions. The finding supports the visual and non-visual finding from the building components results. The significance of the loadings and reactions results is that in structural engineering there is demand to find both internal and external reactions. In regards to the research problem and questions, there was a need to find multiple reactions, including on a local and global scale and both internal (element) and external. The results again relate to the findings from the building components and characteristics in the cohorts tendencies to break the building down on different scales. The senior cohort broke the building down as individual elements whereas the sophomore participants did not identified small building components. This action can be seen as the cause of the sophomore cohort not identifying small building component reactions.

The second finding relates to the interaction of loadings and reactions. The wind in this problem acts as a load that then causes a reaction from the building. The sophomore cohort word choices do not show signs of an interaction, whereas the seniors' word choices of *push(es), resist/resistance,* and *cause(s)*, all express a relationship. The sophomore cohort word choice also expresses that the sophomores do not consider the wind as a *load(s)* unless the interviewer introduces the wind as such. A term seen used by the sophomores in the place of *load(s)* was *force(s),* the sophomores actually had slightly greater usage than the seniors for this term. The term *force(s)* is found to be a unique term since there was use as a load and context as a reaction. The use of *force(s)* as a load was used by both cohorts and considered a shared term, while the use as a reaction was primarily by the senior cohort, providing further support that the seniors used words that describe the interaction.

Once again, the check for interviewer influence was conducted. The only terms used by the sophomore interviewer with concern for interviewer influence were *load(s)* and *rotate(s)*. Yet, the term *rotate(s)* was only used in four of the twelve conversations and only two conversations had the interviewer using the term first. The term *load(s)* had interviewer influence as discussed above and shows an even more extreme case of the finding. The only senior cohort dominant term that had major interviewer influence was *loading(s)*, in which the senior interviewer described the problem by stating "the dominant wind loading is perpendicular to the longer leg". Yet, the occurrence only happened in half of the overall senior cohort conversations. The seniors also introduced new terms that replaced *load(s)* and *wind(s)* used by the interviewer, which counters any consideration that there was interviewer influence.

C. Analytical Constructs

The final category to be considered for the word choice analysis involved the family of analytical constructs. The prior families of building components and characteristics and loadings and reactions are easily defined, while the analytical constructs family requires further definition. Any terms that represented the engineering design process, steps or engineering specific aids (e.g. software, codes, and other resources) were considered in the analytical constructs family. Recall that the coding family "analytical constructs" was created to capture an important feature of how the students talked about the problem. In addition to discussing the building and the loadings and reactions experienced by it, the interview structure also encouraged students to explain their approaches for problem-solving and design processes related to the building. Thus, the analytical constructs family of terms arose. The process terms emerged mainly due to the direct question asked by both the sophomore and senior interviewers, "If you were designing this building, how might you go about it?" and created a demand to address the overall engineering problem solving process. A collection of terms that were used throughout the research study by the participants were coded and are summarized in Table 9 for cohort dominance use and shared terms

Table 9. Dominant and shared cohort terms for analytical constructs

Sophomore Cohort Dominant Terms	**Shared Terms**	**Senior Cohort Dominant Terms**
Build, Draw, Make Sure	Model	Analyze, Assume/Assumption, Check, Consider, Design, Simplify

Two distinct findings emerged from the word choice analysis, the first being that the sophomore cohort substituted non-engineering specific steps in for the engineering design process steps. The second finding involves the fact that there were few analytical construct terms used by both cohorts.

The words used by the sophomore cohort show a lack of understanding of the engineering design process and alarming responses to the direct questions asked in regards to the analytical construct family. The use of *build*, *draw,* and *make sure* by the sophomores are terms that can be said during conversations outside of engineering. While the senior cohort used the terms *analyze*, and *assume/assumption* that are more specific and highly used within the engineering field. No terms are exclusive to the engineering field alone, but the senior terms used are not as widely used in the various fields like construction and manufacturing. The seniors do use non-engineering terminology such as *construct* rather than *build* as a substitute, but the sophomores remain in the non-engineering realm exclusively. The terms *model* and *design* were both used while asking the cohorts questions within the study. Thus, there is a high level of interviewer influence for these two terms. The surprising aspect to the terms *model* and *design* were that the sophomore students did not use the terms once they were introduced by the interviewer. In fact, most sophomores appeared confused and needed clarification by what was being asked in regards to a *design* process or what *modeling* was. Sophomores not knowing the design process is concerning since academic problem solving teaches students to use steps and processes that are related to the actual design process.

Along with identifying the engineering processes, the cohorts introduced analytical constructs that are within and beyond the processes. Such terms within the process that are important and are exclusive to a specific cohort are *cost* considerations by the sophomores and *engineering code references*, *engineering programs,* and *engineering theory* as stated by the senior cohort. These components within the processes reinforce the fact that the sophomores continue to focus upon non-engineering specific steps to solving the problem. The surprising fact associated with these terms used is that they were only used by very few participants in the study. Overall, the term usage in the analytical construct sense was found to be lacking, even with direct questions relating to the family. Senior level engineering students interact on a daily basis with design codes and for there to be little discussion regarding such an important aspect seems alarming and came at a surprise. One possible reason to explain the lack of analytical constructs is that some students discussed former classes that were applicable to the material rather that expanding on practical engineering constructs. The low analytical construct discussions in the interviews are best reflected when comparing tables between families and the term usage for analytical constructs is noticeably shorter.

B. Conceptual Understanding Analysis Results

A second analysis was performed to measure and compare conceptual understanding levels between cohort participants. Each individual participant was graded for completeness, correctness, relatedness, and realisticness based on the standardized grading scale discussed in the Methodology section. Scores of high, medium or low were assigned. The assigned grades for each participant in each grading category are summarized in Table 10. The justification towards each score is provided in the Appendix as a summary of the interview and important aspects that affected the score. Along with the summary are citations, (¶), for reference to what paragraph in the transcription the information is referring to. Once the individual scores were assigned, the overall cohort scores were averaged to then compare cohorts. To better compare the cohort average scores, the qualitative data was approximated as quantitative data by assigning each level with a numerical value, from zero (low) to three (high). The cohort average scores for each grading category are presented in Table 10 also.

Table 10. Participant conceptual understanding scores and cohort averages

	Completeness	Correctness	Relatedness	Realisticness
P1 (Senior)	Medium	Low	High	High
P2 (Senior)	Medium	Medium	Low	Low
P3 (Senior)	Low	Low	Low	Low
P4 (Senior)	High	Low	Medium	High
P5 (Senior)	Medium	Low	Low	Medium
P6 (Senior)	High	High	High	Medium
P7 (Senior)	High	High	High	High
P8 (Senior)	Medium	Medium	Low	Medium
P9 (Senior)	High	High	Medium	Medium
P10 (Senior)	High	Low	Low	Medium
P11 (Senior)	High	High	High	High
P12 (Senior)	Low	Low	Low	Medium
P13 (Senior)	Medium	Low	Low	Medium
P14 (Senior)	Medium	Low	Low	Medium
P15 (Sophomore)	High	Medium	Medium	High
P16 (Sophomore)	Medium	Medium	Medium	Low
P17 (Sophomore)	High	Medium	Medium	High
P18 (Sophomore)	High	Medium	Low	Medium
P19 (Sophomore)	Medium	Low	Low	Medium
P20 (Sophomore)	Low	Medium	Medium	Medium
P21 (Sophomore)	Medium	Medium	High	Low
P22 (Sophomore)	Low	Low	Medium	Low
P23 (Sophomore)	High	Low	Medium	Low
P24 (Sophomore)	Medium	Medium	Low	Medium
P25 (Sophomore)	Low	Medium	Low	Low
P26 (Sophomore)	Medium	Low	Low	Medium
Sophomore Cohort Averages	Medium (2.08)	Low-Medium (1.67)	Low-Medium (1.75)	Low-Medium (1.67)
Senior Cohort Averages	Medium (2.29)	Low-Medium (1.71)	Low-Medium (1.71)	Medium (2.14)

There were students in both cohorts that received nearly perfect scores in all grading categories and there were also students that received minimal scores. Thus, the averaging effect merely shows an overall cohort score with the understanding there is a large standard deviation. Individual participant conceptual understanding averages between grading categories was not a focus of this research study. Yet, the conceptual understanding scores of each individual participant within the cohorts is still worthy of noting and could be a focus of another research study. Based on the conceptual understanding results and grading of each individual participant, there were noticeable similarities between the cohorts and a discussion of each category is provided.

The first grading category for conceptual understanding was completeness, where the most noticeable comparison between cohorts for conceptual understanding was in regards to the ability to provide multiple responses to each required field. The seniors tended to provide multiple building deformation behaviors, problems, and solution responses. This led towards having greater conceptual understanding scores because the grading rubric solely captured responses to these universal questions. Students who did not identify multiple responses to each question were penalized as having lower conceptual understanding. The average scores presented for completeness were close because of the averaging effect of the results. There was an extreme flux in scores for both the senior cohort and the sophomore cohort.

Correctness was a conceptual understanding measure that appeared to have exposed problems within the senior cohort. The aspect of making errors was anticipated for all students, but as a whole the senior cohort having more knowledge of the subject area could be expected to perform with fewer errors and show higher conceptual understanding. The major error that many senior level students made involved analyzing the building as being two separate structures and then attaching the two together to return to the original problem. The analysis method does not anticipate for how the independent structures interact once connected together to form one large irregular shaped building and is a significant error. The majority of the students that made this error had discussed that they had experience with this type of problem and were confident in their answers. The professional engineer data validation by Dr. Daniel Dolan exposed this incorrect response trend. If the majority of the senior cohort participants had not made that error, the margin between the senior cohort and sophomore cohort for correctness would have been much larger. While there were major errors among the seniors, there were also a few major errors among the sophomore cohort. A typical error was a participant believing that the base of the structure would deform equally as the roof, which revealed a lack in conceptual understanding. With the knowledge of the particular problem extremely diverse for each participant, there were diverse errors made among both cohorts and are reflected in the various scores in Table 10.

The third grading category, relatedness, showed that sophomores tended to provide a linear thought process that dealt with identifying a problem and trying to create a solution for that specific problem. The seniors tended to have multiple responses, relating with the high scores for completeness, to questions and did not connect thoughts as well. Seniors with high completeness scores tended to jump between responses and not fully connect thoughts and typically failed to elaborate on one response. Sophomores with low completeness scores tended to do well for relatedness because they had one response-thought process that they had to carry throughout the entire interview.

The realisticness grading category showed the senior cohort as having a higher ability to apply practical engineering solutions to the provided questions. Rather than the senior cohort having a distinct ability to show realistic engineering applications, as seen with a low number of analytical construct terms, the sophomore students tended to increase the margin between the cohorts due to the inability to understand the design process and modeling procedures. The majority of sophomores wished to change aspects (building locations, orientation, and layout) of the problem that would not be in an engineer’s control and created a low score for realisticness.

C. Language and Conceptual Understanding Results Comparisons

As stated, the overall question of the research project was how language analysis, particularly word choice, can be connected to conceptual understanding. Thus, there is need to compare the results from both analyses and answer the research question. To do so, each conceptual understanding grading category will be compared with how word choice affected the score and what was observed among research participants.

Completeness and word choice are highly connected when comparing the results. Students that scored high for completeness were those participants that identified both visual and non-visual building components which led to the participant identifying multiple deformation behaviors, building problems, and potential solutions. Participants who scored high for completeness also tended to discuss the building at a smaller scale and discuss internal reactions well. To best discuss how word choice resulted in a high completeness (high conceptual understanding) score, it is best to look at the sophomore participant word choices. Of the sophomores who scored high for completeness, nearly all of them identified a non-visual building component (three identified the foundation and one discussed bracing). Another sophomore student discussed compression, an internal reaction, to reach a high conceptual rating. To better understand how word choice and completeness are connected, analysis of the senior cohort participants who scored low was completed. The two senior cohort students that scored the lowest for completeness both failed to discuss internal reactions and one participant even claimed to not care what the internal portion of the building was for this problem.

The second conceptual understanding grading category, correctness, is found to not be linked to word choice. Many cases existed where participants used the same words and yet would use them differently and cause different levels of conceptual understanding. During establishing the methods for the research project, it was determined that the context of every word would have to be checked to be sure that all words were being used as they were being intended and in the appropriate context. That analysis anticipated reducing the number of misused words, but students still found ways to make incorrect statements while mimicking students that used the same words correctly. An example is that one participant discussed internal components and reactions involving shear walls, but still received a low score for correctness because he/she claimed that walls are unimportant in structural design compared to the roof. The discussion of shear walls would make a reviewer think there is conceptual understanding just by word choice, but the word is being used incorrectly. The student claims to have worked on a similar project but appears to be just regurgitating information and does not understanding the material (low conceptual understanding). Thus, this represents an example of why correctness does not connect word choice and conceptual understanding.

The third grading category for conceptual understanding involved measuring relatedness and the comparison to word choice yielded no connection to conceptual understanding. Many students struggled with relating thoughts and ideas but still registered an overall high score for conceptual understanding. The other areas of the grading rubric covered the fact that the students were weak with connecting ideas. One method used to analyze the relationship between word choice and the conceptual understanding score was to look specifically at the load and reaction interaction terms. The terms *caus(es)* and *resist/resistance* show an interaction and how loads and reactions are connected (i.e. related). When comparing students that used these words, there was not a correlation with the conceptual understanding scores. One participant used *resist* nearly the most out of all participants, but received a low score for relatedness since they never connected their responses from one interview question to the next. The nature of the interviews with asking questions and the various connections of thoughts and answers does not show a realization of conceptual understanding through word choice.

The analytical constructs family had few terms to compare with the conceptual understanding scores, but there was still a valid correlation between the two. Students that detailed the design process, discussed engineering design aids (codebooks), and correct potential problem solutions scored high for realisticness and showed the application of linguistic analysis towards measuring conceptual understanding. The seniors were the cohort that used the analytical constructs the most and were also the cohort that scored extremely well within realisticness. Thus, a connection can be made between the two analyses. There are multiple cases where sophomore students that used the term *assume* scored high for conceptual understanding, but also a few cases where some had scored low. There is need for looking beyond the case of one word proving a student having conceptual understanding and the benefit of having multiple grading criteria and many sets of technical words.

VI. CONCLUSION

As seen with both the word choice and conceptual understanding analyses and the results comparisons, word choice can be used to realize (make meaning of) conceptual understanding. This research study specifically focused upon how word choice and conceptual understanding are tied together. While only a portion of the results and analyses proved specific connections between the two measures, two successful connections proved the research question can be answered. The conceptual understanding grading for completeness and realisticness tied well with the word choice results to prove that language can become an identifier for conceptual understanding. Caution must still be taken when trying to connect word choice to conceptual understanding because the grading criteria of correctness and relatedness did not cause realization and thus an argument could be made against there being a connection between word choice and conceptual understanding.

Changes to future research projects and established methodologies prior to data collection would allow for clearer and more definitive results. The results and conclusion per the findings were based off of a research project that had analyzed existing data and thus large variability existed. Having an established research question and grading rubric prior to conducting the student interviews would allow for a more standardized approach and thus more reasonable results. A comparison between sophomores and seniors produced results that almost appeared obvious whereas a junior versus senior comparison would have closer results and more valid findings, but would also be more difficult since the language can be anticipated to have greater similarities. Having standard questions allowed for consistent interviews, but the student responses still varied greatly. Possibly studying a more defined topic that has a well-defined singular solution would also simplify the results and create a stronger conclusion by reducing uncertainty and variability.

Beyond the findings of and past this specific research in language and the connection that can be made to conceptual understanding, the research has raised the need for further research to be conducted. One focus that has been neglected by the research with an interview setting and a comparison made to applicable texts is that of the instructor influence. A major part of academics at the college engineering education level is the instructors' roles in students' learning of the material presented. The language that instructors use varies and can be anticipated to affect conceptual understanding and have an impact on word choice by students. Studies could be conducted by gathering language used in lectures and comparing it with language used by students outside of the lectures. Also, a comparison between students in separate sections with different instructors, of the same course, could show interesting differences and/or similarities between students. Along with instructors, possibly different textbooks by different authors would have a similar effect.

Another study that would be of interest would involve the use of drawings or models in explanations of similar problems to the one given in this research study. Seah, Clarke, and Hart (2011) noticed that the use of diagrams and drawings altered the use of language among study participants. Seah et al. make the statement "*It* resembles a direct translation of speech to writing" (p. 872) and shows the role drawings play in such a research study. *It* was heavily used throughout the interviews and was neglected in this research study and is known to have major impacts. Anticipation of the ability to use drawings or physical models would predict differences in conceptual understanding levels. A possible study with two cohorts, one with the use of drawings or models and the other without, could potentially yield interesting similarities and differences between cohorts as pertaining to language use.

Finally, research focused on other aspects of SFL would be valuable to identifying conceptual understanding. The conducted research exposed a trend that many participants expressed uncertainty in their answers. Terms such as *maybe* and *possibly,* along with others, hinted towards the participant not being confident and causing the research to question if that affects conceptual understanding from a language and SFL framework.

VII. REFERENCES

ATLAS.ti 2014, Qualitative Data Analysis Software.

Case, J., Light, G. “Emerging methodologies in engineering education research”, *Journal of Engineering Education*, 2011, 100 No. 1, p. 186-210.

Chi, M.T.H. “Commonsense conceptions of emergent processes: Why some misconceptions are robust”, *The Journal of the Learning Sciences*, 2005 14 No. 2, p. 161-199.

Chi, M.T.H. “Quantifying Qualitative Analyses of Verbal Data: A Practical Guide”, *The Journal of the Learning Sciences*, 1997 6 No. 3, p. 271-315.

Chi, M. T. H. “Three types of conceptual change: Belief revision, mental model transformation and categorical shift”, *International Handbook of Research on Conceptual Change.* 2008, p. 61-82.

Chi, M.T.H., Roscoe, R. *The processes and challenges of conceptual change*, in *Reconsidering Conceptual Change: Issues in Theory and Practices,* M. Limón and L. Mason, Editors. 2002, Kluwer Academic Publishers: Boston.

DiSessa, A. A. "An interactional analysis of clinical interviewing", *Cognition and Instruction*, 2007, 25 No. 4, p. 523-565.

Dolan, J. Daniel. Personal interview. 19 Feb. 2014.

Eggins, S. *An Introduction to Systemic Functional Linguistics*. 1994, Pinter Publishers: London.

Fang, Z. “Scientific Literacy: A Systemic Functional Linguistics Perspective”, *Science Education,* 2004, 1 Dec., p. 335-347.

Frye, N., Montfort, D., Brown, S. “I’m absolutely certain that’s probably true: Exploring epistemologies of sophomore engineering students.” Paper presented at the ASEE/IEEE Frontiers in Education Conference, Seattle, WA. 2012.

Glaser, B. *The Constant Comparative Method of Qualitative Analysis*. 1965, University of California Press on behalf of the Society for the Study of Social Problems.

Hake, R. “Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses”, *American Association of Physics Teachers,* 1997, 4 May, p. 64-74.

Halliday, M.A.K. *An Introduction to Functional Grammar*. 1994, Edward Arnold: London.

Halloun, I., Hestenes, D. “The initial knowledge state of college physics students”, *American Journal of Physics,* 1985, 53 No. 11, p. 1043-1048.

Hermosillo y Asociados. “Rosarito Beach Hotel.” 2 Aug. 2008. Online Image. Flickr Creative Collections. 9 Sept. 2013. < https://www.flickr.com/search/?q=rosarito%20beach%20hotel>

Hestenes, D., Wells, M., Swackhamer, G. "Force Concept Inventory", *The Physics Teacher,* 1992, Vol. 30, p. 141-158.

Ioannides, C., Vosniadou, S. "The changing meanings of force", *Cognitive Science Quarterly,* 2002, Vol. 2, p. 5–61.

Ivarsson, J., Schoultz, J., Säljö, R. *Map Reading Versus Mind Reading: Revisiting Children's Understanding of the Shape of the Earth,* in *Reconsidering Conceptual Change: Issues in Theory and Practices,* M. Limón and L. Mason, Editors. 2002, Kluwer Academic Publishers: Boston.

Kelly, J. "Understanding the Role of Academic Language on Conceptual Understanding in an Introductory Materials Science and Engineering Course." Diss. Arizona State University, 2012.

Kelly, J., Krause, S., Baker, D. "Using Systemic Functional Linguistics to Analyze Engineering Speak in an Introductory Materials Science and Engineering Course", *American Society for Engineering Education*, 2012.

Kittleson and Southerland. "The Role of Discourse in Group Knowledge Construction: A Case Study of Engineering Students", *Journal of Research in Science Teaching*, 2004 p. 267-293.

Lemke, Jay L. *Talking Science*. 1990, Ablex Publishing Corporation: New Jersey.

Moje, E. "Talking about Science: An Interpretation of the Effects of Teacher Talk in a High School Science Classroom", *Journal of Research in Science Teaching*, 1995, Vol. 32, No.4, p. 349-371.

Montfort, D., Brown, S, Frye, N. Work in Progress: "Theoretical approach to characterizing changes in students' and engineers' conceptual understanding and personal epistemologies." Paper presented at the ASEE/IEEE Frontiers in Education Conference, Seattle, WA, 2012.

Montfort, D., Brown, S., Pollock, D. "An Investigation of Students' Conceptual Understanding in Related Sophomore to Graduate-Level Engineering and Mechanics Courses", *Journal of Engineering Education*, 2009, Vol. 98 No. 2, p. 111–129.

Pollock, David. Personal interview. 22 Feb. 2014.

Säljö, R. "Concepts, cognition and discourse: From mental structures to discursive tools", *New perspectives on conceptual change, 1999,* W. Schnotz, S. Vosniadou and M. Carretero. Netherlands, Pergamon, p. 81-90.

Seah, L., Clarke, J., Hart, C. "Understanding Students' Language use About Expansion Through Analyzing Their Lexicogrammatical Resources", *Science Education*, 2011, 4 March, p. 852-876.

Varelas, M., Pappas, C., Rife, A. “Exploring the Role of Intertextuality in Conceptual Construction: Urban Second Graders Make Sense of Evaporation, Boiling, and Condensation”, *Journal of Research in Science Teaching*, 2006, 24 May, p. 637-666.

Vosniadou, S., Brewer, W. “Mental Models of the Earth: A Study of Conceptual Change in Childhood”, *Cognitive Psychology*, 1992, p. 535-585.

Vosniadou, S. "Capturing and modeling the process of conceptual change", *Learning and Instruction*, 1994, Vol. 4, p. 45-69.

VIII. APPENDIX

Appendix A: Conceptual Understanding Scores and Justification

<u>Participant 1: Senior</u>
<u>Completeness: MEDIUM</u> The interview participant discussed the idea of differential horizontal displacements due to the different stiffnesses of the two legs (¶7). The response to the deformation question only covered the horizontal relative displacements and never addressed the issue with different deflections in the vertical dimension. The student did then move towards addressing the problems caused by different horizontal deformation and that the inside corner of the L-shape would tend to tear apart (¶7). The solution to the problem was to build two separate buildings that would then be connected somehow to address the differential displacements (¶21). The interview responses covered all topics of building movement, potential problems, and a solution. Yet, the responses were limited to one answer per topic which neglected the vertical relative displacements, the roof and foundations as potential critical components, and any discussion of components that would resist the lateral wind load (lateral force resisting system). They receive a medium score since they covered all major topics but not a high score since they didn't address other important features.
<u>Correctness: LOW</u> The interview participant provided mainly incorrect answers in their discussion. The first case is when talking about stiffness; the student mentioned that units are important to stiffness and said that E, the modulus of elasticity, has the units of pounds per inch (¶33). This is incorrect since the modulus of elasticity is a relation between stress (force per area) and strain (dimensionless), thus the units of E are force per area (i.e. pounds per square inch). This is only a minor incorrect statement since the participant had the principle of stiffness correct. Another minor error is that the participant states that stiffness will be assumed and then member selection can be conducted, whereas member sizing can be determined from gravity system analysis and then a more accurate stiffness determined rather than solely assumed (¶23). A major case of being incorrect is that the participant states a solution to the problem is to separate the building into two components. This then allows for deflections of each component to be calculated (now regular shaped structures). The final step would be to design the connections between the two components to withstand the different deflections (¶23, ¶47). This is an incorrect approach to the irregular shaped structures problem because the two are connected and thus you can't analyze them as if they were separate. The participant receives a low score for correctness since the incorrect statements about units for modulus of elasticity and determining stiffnesses were only minor but the design idea of splitting the building is a major flaw that outweighs any correct statements.

<u>Relatedness: HIGH</u> The participant discussed the relationship between the different stiffnesses causing relative displacements horizontally and the problem caused at the inside corner by such action (¶7). Thus, the participant was able to link the movements to a problem without being asked directly to identify a problem caused by the movements, which shows a high level of being able to relate important topics (cause and effect). Also, the participant mentions idealizing the building as a cantilever (¶3) and later refers back to this idea when talking about simplifying the building by stating "what I discussed earlier is doing the same thing, because then I said you have a cantilever and you found the deflection" (¶53) which shows high levels of being able to relate different topics and questions. Finally, the student was asked about the design process and provided a variety of steps and factors that are important (¶23), including: determining loads, identifying the building use, use the International Building Code, member selection, analysis, and iteration. All these steps show a connection of the overall process that is important for such a problem. Also, the student discusses how the material is learned and applied for their timber class (¶19). The participant receives a high score for relatedness since they connect thoughts and concepts throughout the interview as seen with a few examples provided.
<u>Realisticness: HIGH</u> The participant provides multiple cases that relate heavily to actual engineering design practice and analysis. The student states the wind can come from any direction and thus the building must be analyzed with multiple wind loading scenarios in mind (¶11). Other participant responses state the building could be designed with the wind being applied from another direction to alleviate problems due to geometry. This solution is unrealistic and thus shows high levels of conceptual understanding for this participant by recognizing this factor. Another case of being realistic is that the student talks about simple beam theory with the interviewer and mentions the idea about it being a rough estimate of deformation since the beam would be considered homogeneous-isotropic (¶51). The student also clarifies the idea that the simple beam theory would be cantilever action. Thus, a high score for realisticness is given since there is little to no unrealistic statements made.

Participant 2: Senior
Completeness: MEDIUM The research participant is able to identify all the major movements of the building including: differential horizontal displacements (¶7) and that there is a rotation issue (¶29), along with vertical relative displacements (¶11, 13). When discussing the problems though, the participant only talks about the issue of the inside corner (¶21) and that the solution would be to make the corner angled rather than ninety degrees (¶25). With identifying only one problem and providing only one solution, there are major issues with conceptual understanding with identifying other problems and solutions, especially with the lateral force resisting system. Yet, being able to identify all the movements of the building shows a high level of completeness. With the interviewer proving both high and low levels, the balance provides an overall medium score.
Correctness: MEDIUM A few minor errors are made throughout the interview, but the majority of the statements made are correct. The first error is when discussing the inside corner as being a concern the participant states that the outside corner will never be troublesome (¶29). The inside corner is being "opened" and causing tension issues and thus the outside corner is being "closed" and compression is of concern. There would need to be compression capability in the outside corner components and would need to be considered. Another minor error is that the interviewee discusses component forces (x and y directions) would add together to equal the original. Both a true and false statement since they wouldn't be simply added but geometry is involved (¶39). The final error that is seen as minor rather than actual conceptual issues comes when discussing the determination of load and the participant discusses load combination factors and says "1.2 dead plus 0.6 live" which the load combination is 1.6 live load (¶53) and that the design methodology is ASE (¶55) while the actual method is ASD. Minor errors and simple values and definitions that engineers would look up. The participant receives a medium overall score since the majority of statements like, "open structures reduce stability (¶47)" are correct.
Relatedness: LOW The most noticeable problem with the participant's interview is when discussing concepts and material the interviewee never refers back to what they had discussed before unless follow-up questions are asked. The conversation is very structured with a question asked and a simple answer provided that doesn't have major justification as to the student's thinking or process of determining an answer. The only major times the student appears to have actual knowledge of the material is when discussing load path (¶49) but that isn't unique to this problem. There is some relatedness when talking about the design process, but the material is merely a list (¶51). Thus, the student receives a low score for relatedness.

Realisticness: LOW

The student appears to have little experience with structures and engineering design in this field mainly because the opening statement shows doubt (¶3) when said “It’s like a structures question. I have no idea about deflections at all.” The answers provided to multiple questions show that the student doesn’t have knowledge to solve the practical problems with this irregular structure. Two solutions include taking the corner out (¶31) and by not having the bottom floors as “open” (¶47). Both engineering and architecture practices of open floors and having corners in buildings are highly seen and solutions are found. The only realistic statement made was about the design process and using the code and software (¶51) which again is not unique to this problem but common throughout all engineering practices.

Participant 3: Senior
Completeness: LOW 204 is able to identify both issues of horizontal relative deflections between the legs (¶7) and vertical deflection varying from the ground up (¶13). The participant states this is the way the building moves, but doesn't identify how this is troublesome besides saying they would be worried and would have to design to reduce these deflections (¶43). The participant does state extra bracing could be added (¶25) but doesn't expand on the idea of why. Thus, the participant is able to identify how the building moves but not really the problems caused or a solution, giving a low score for completeness.
Correctness: LOW Beyond not expanding or explaining the thoughts and ideas presented in the interview, the participant makes a few large mistakes in their reasoning. The first being that the participant believes making the ninety degree corner more of a forty-five degree corner would cause significant (enough to solve any problems) air flow around the building (¶29). For how little the corner alteration is, the air would still hit the face of the building. The participant also discusses treating the building as a single member and that this would allow accurate deflections to be calculated (¶39), which is incorrect. The participant even makes the statement that mass is the reason for the difference in deflections between the legs of the building and highly doubts their answer (¶15). There aren't noticeable areas where the participant makes correct statements since little justification and clarity are provided, thus a low score for correctness because the major errors can't be outweighed by correct information provided.
Relatedness: LOW Again, as seen in completeness and correctness, the participant appears to have an incomplete interview by the way that justification and thought processes are lacking or nonexistent. Most responses are simple responses with little content and provides a broken interview. Thus, the score for relatedness is low.
Realisticness: LOW Along with low scores for all other categories, the score for realisticness is low. The participant believes if the building were designed with the wind coming from another direction that would help the situation (¶19). The problem is that wind can come from any direction and thus buildings must be designed for all scenarios. Also, the participant believes removing the ninety degree corner would solve any problem with the wind being trapped (¶29). Actual engineering practice wouldn't use this solution but solve the problem while keeping the building architectural features.

Participant 4: Senior
Completeness: HIGH When discussing how the building would move, the participant covers two of the major three responses, first that the building would twist/rotate (¶7) and second that the legs deform differently horizontally (¶17). Problems discussed involved the possibility of roof failure (¶39), and that the open floors would be troublesome since there wouldn't be shear wall capacity (¶31). Finally, solutions covered were to divide the building into two sections (¶5, 29, 45) and/or add bracing (¶11). The participant covered multiple components of the three completeness tasks and thus gets a high score.
Correctness: LOW There is concern with the participant simply regurgitating information since they state they had worked on a project like this before and that the group informed the student of all the knowledge (¶9). This is shown in the many major errors committed by the student in the thought and reasoning provided. The first is that the student states bracing could be added, which would improve the lateral force resisting system and resist the wind load, but the student then says this would help so the building doesn't rip itself out of its' foundation (¶11). The foundation wouldn't be highly affected by bracing since the bracing would simply transfer the load into the foundation and could cause more issues. The student should focus more on hold downs to address the foundation issues. Next, when talking about adding a seismic joint, the participant says it would eliminate collapse of the building (¶17). Not necessary true either, collapse could come from other forms of failure and the seismic joint would simply allow differential displacements in the separate legs. The participant states wind and seismic have the same effect (¶29) which is sort of true that they are both lateral forces, but incorrect in that the behaviors are different. Finally, when talking about the roof failure, the student claims walls aren't important and that they merely "keep us warm" as their purpose (¶43) which is contradictory to the problem of shear walls that was presented. There are major flaws in the conceptual understanding and thus a low score for correctness. Also, designing the legs as separate to address the torsion issue is not a correct method because the legs are going to be attached (¶53), as discovered when discussing the solution method with a practicing engineer.
Relatedness: MEDIUM The student does appear to simply repeat what information has been provided to them by group members and seen in the low correctness score. This is also shown in the relatedness since the student doesn't provide full justification to reasoning. An example is when the interviewer asks where torsion is acting and the participant replies with "the building twists this way, so I'm guessing it would be acting right here" (¶13). This statement shows little to no justification towards answering the question besides "guessing." While the justification is lacking, the student does provide connected thoughts throughout as with the idea of dividing the building into two sections said at the beginning, middle, and end of the interview when explaining ideas and thoughts. Thus, with a balance of poor justification and connected ideas, the participant gets a medium for relatedness.

Realisticness: HIGH

The participant makes a reference to the ASCE-7 code and that this would be the reference to follow for design. This is a true and accurate statement that shows the realistic design procedures (¶59). There is slight talk of a design process (¶53) that all seems practical with designing the sheathing and supports to withstand the load. The participant doesn't consistently make realistic statements, but doesn't appear to make unrealistic statements and thus a high score for this grading category since enough was provided to show realistic design considerations and concepts.

Participant 5: Senior

Completeness: MEDIUM

The participant talks about differential movement in the horizontal dimension (¶57) after talking about splitting the building in two (¶29). The interviewer early on tried to ask about vertical differential deflections and the student responded with talking about overturning (¶13) and then once the interviewer asked specifically if there was a difference between the deflections at the ground versus the top, the student agreed (¶21). I don't give credit to the student for identifying vertical differences since the interviewer pushed greatly for the topic to be covered. As far as problems, the only main issue that gets carried throughout is the deflection difference between the legs. The idea of overturning and foundation design is discussed (¶13), but not identified as a problem since the student talks about a reduction in forces rather than focusing on the added compression as a major issue. The only solution which is to reduce the deflection issue and identify shear path is to divide the building into two sections (¶29). Since no major problems were identified, but the other two topics were covered by more than one movement and only one solution, the student gets a medium score for completeness.

Correctness: LOW

The student makes major errors in important concepts. The first is that the student believes the greatest deflection would be "in the center of the feature" (¶5). This problem would see the greatest deflection at the top corner of the narrow leg. The deflection greatest at the center is associated with a simply supported beam and this would act more as a cantilever. The next is when discussing a diaphragm the student says it is the exterior of the structure (¶7), whereas a diaphragm is actually a horizontal system such as a floor system. The next statement is that gravity loads affect shear (¶37). Gravity loads and shear typically don't impact each other and not for a structure like this. Finally, the student states the structure can be modeled as a beam (¶47) which would not be true since the two interact and there is a connection at the ground. This would be more like a frame structure. The many and major errors cause a low score.

Relatedness: LOW

There are a few points throughout the interview where the student does a good job at connecting ideas. Such an example is that of relating shear resistance to wall length and then to the amount of deflection (¶27, 33). Another example is that the student mentions their timber class and that the lateral force experience comes from that material (¶25). Yet, the student doesn't go beyond that statement and actually pulling knowledge from that fact. While there are some connections in thoughts, the justification provided for most questions is lacking and or incorrect. Many follow-up questions from the interviewer create clarity and further justification. A low score is assigned.

Realisticness: MEDIUM

The student has one major realistic statement that discusses the option to create a joint between the segments that would either allow differential displacements between the legs or that you could create a connection that resists this and mimics a fixed connection (¶57). This is extremely realistic and would be a designer decision and based on other variables not known or given in this problem. Yet, with only one major realistic and statement and no major unrealistic proposals, the student only receives a medium score for realisticness since compared to a high score of providing multiple examples or at least throughout the interview.

Participant 6: Senior
Completeness: HIGH The student covers all major movement characteristics, which are: horizontal displacement differences between the two sections (¶3, 21), vertical differences (¶23) and the fact the building has a twist/torsion effect (¶27). The problems are identified as the displacement differences and specific action at the inside corner (¶29). The student even provides multiple fixes to the problems, build two sections and/or add more shear walls (¶45). Thus, a high rating for covering all questions and with multiple answers.
Correctness: HIGH All the information the student provides appears to be correct. No major flaws in conceptual understanding exhibited due to providing false statements. Even justifications to answers are correct and support understanding, thus a high grade.
Relatedness: HIGH This student provides one of the greatest arrays of relatedness. The first idea is that the different legs are related to the action of loading a 2x4 on face versus edge (¶5). The second is when discussing wind behavior and lateral load characteristics; the student refers back to a structures course (¶37). Finally, the student even considers lateral load behavior of a light frame house to the problem (¶49). Besides relating to other material, the student responses are related heavily with proper justification. A high score.
Realisticness: MEDIUM The student doesn't provide unrealistic responses, but only a few that are practical to engineering design. The student talks about the building material as wood and then says it would most likely be steel (¶15). This building couldn't be wood since the height restriction on wood structures, thus practical, but the building would most likely be concrete. Another realistic topic covered was the use of a codebook (¶31), especially ASCE, to analyze the L-shaped building as irregular. Since only one practical reference was true, the student receives a medium score for being realistic and not providing unrealistic response, but not enough to achieve a high rating.

Participant 7: Senior
Completeness: HIGH The student actually starts the interview backwards by identifying the solution to the problem as being either splitting the building (¶9) or adding a seismic joint (¶13). The student then adds the issues and why to do these solutions since the building would tend to rotate (¶23) and the two sections would want to collide (¶13). Other solutions are about the lateral force resisting system and shear walls and moment frames (¶13, 23). The other topic covered is the differential deflection in the vertical sense (¶59). The student actually covers all the questions and the questions are typically not even asked and multiple aspects are covered for each question, thus a high grade for completeness.
Correctness: HIGH The student provides some of the most correct responses to the questions, such as the reason for rotation is the shear center location and any eccentricity (¶25). Also, the student talks about how the shear wall between the two sections is shared and load is applied from both sections and thus it would need to be the strongest (¶41). There are no identifiable incorrect statements given, thus a high grade assigned.
Relatedness: HIGH The student does mention at the beginning of the interview that they had this as their capstone course project and highly refers back to prior application and knowledge from that fact (¶5, 37). Also, justification is provided throughout that connects thoughts, such as the concept of flexible versus rigid (¶57). A high score for relatedness is assigned.
Realisticness: HIGH Since 208 has the most experience and application of the concepts, the realisticness can be assumed as high. The fact that the student refers to design procedures followed from ASCE (¶11) shows the high realisticness. Also, the student states there wouldn't be allowed light frame construction for such a problem (¶13) and that the structure would most likely be concrete or even steel. In presenting the solution to the problem as inserting an expansion/seismic joint or increase the lateral force resisting system, an actually designer would make that choice (¶37) based on other design criteria. The only minor unrealistic statement is that the student said the back wall would be full and not have windows. Since the building appears to be a hotel, there would be windows throughout and nearly all walls. Yet, that fact can't be proven since the identity of the building is unknown and there is no proof the student is wrong. Thus, a high score.

Participant 8: Senior
Completeness: MEDIUM The participant has a fairly complete interview with covering many topics. The movements of horizontal (¶17, 59) and vertical (¶33) relative displacements are covered. The problem with the inside corner stress concentrations (¶59) is covered. And 209 talks about increasing the shear walls to fix the problems (¶49, 68). The student really only covers one of the displacement topics on their own since the interviewer adds details. Thus, only one topic is covered for each question and a medium score for completeness is assigned.
Correctness: MEDIUM The interviewee has a mix of major correct and major incorrect statements that show conceptual understanding of the problem. First, the major incorrect thoughts are that the student states they don't know how shear walls work (¶27, 31) but then make many important claims and carry the topic throughout the discussion. The second incorrect idea was that the student says the roof gets pushed one way while the foundation gets pushed the other (¶33). I think there is confusion between external and internal reactions here. Yet, the student redeems them self by stating the building can't be idealized as a solid block since the shear flow in a solid block occurs everywhere whereas the building shear flow would be restricted to only components capable of carrying shear (¶39, 53). Thus, with such a balance between important correct and incorrect statements, a medium is assigned.
Relatedness: LOW The student never refers to outside material or knowledge when discussing the topics and answering questions. Also, a majority of the answers provided are simple responses with nearly zero justification to support the thoughts. When justification is provided, the student typically is uncertain about their response (¶27, 29, 57, 68, 76). Thus, there is no reason to give a score other than low.
Realisticness: MEDIUM Beyond not providing references to outside material and little justification, the student doesn't show any use of realistic engineering practice. Zero references to design codes, methods, or material. Yet, the student doesn't tend to make unrealistic statements either. Thus, there is a balance and a score of medium can be assigned.

Participant 9: Senior
Completeness: HIGH The participant covers a wide range of topics when discussing how the building would move. The first thought is that there would be torsion in the building (¶13). The conversation then moves towards differential deflections in both the horizontal and vertical aspects and the participant distinguishes the difference between the two legs related to deflection (¶19). Thus, the interviewee covers all the important response topics for how the building would move. Yet, when identifying problems in the building, the participant says torsion but doesn't say how torsion would cause specific problems in the building (¶21). The solution to torsion was by increasing the stiffnesses of structural components that resist the wind load (lateral force resisting system) (¶23). Thus, 212 covers the most important solution to the problem. Overall, during the discussion about differential deformations between the two legs, there is an undertone focused on the inside corner and how the separate legs would interact, thus a focus on an actual problem caused from torsion (¶39). Another solution that was suggested involved separating the buildings and removing the irregular structure aspect that is causing torsion (¶31). Thus, the participant covered multiple ways the building would move and multiple solutions to the problem which meets the criteria for getting a high score for completeness.
Correctness: HIGH The participant overall makes many statements about the building and the reaction to the wind load, but doesn't tend to make errors when discussing concepts. There is great detail in the discussion of stiffnesses versus deflections and the participant does an excellent job of stating that stiffnesses is the relation between how much a component will deflect based on a load (¶27). The definition of stiffness is just that. The only minor error would be in discussing removing the torsion load. The participant says that if the deflections of the legs were made equal that it would cause the torsion load to be eliminated (¶29). This action doesn't eliminate the torsion loads but merely adapts or accounts for them by trying to increase stiffness in the narrow leg to get equal deformation. Yet, this being a minor error and all other statements appear correct, the score for correctness will be assigned as high.
Relatedness: MEDIUM The participant covers many different concepts with a large range, and occasionally ties concepts together. An example of when the concepts are tied together and justification is sufficient is such as the discussion of differing deflection in each leg. The participant identifies the problem and then states why and how the moment arm between the tension and compression cords in each leg is very different and thus causing more deflection in the narrow leg (¶19). Justification is provided and 212 relates to an added concept. Yet, this action isn't presented in many other places throughout the interview. An example of non-relatedness is when the participant is asked about potential problems in the building and simply says torsion (¶21), there is no added justification to support this claim. With a mix between having and missing relatedness, the grade is a medium.

Realisticness: MEDIUM

The participant doesn't make any statements about what would actually be done in engineering practice, but throughout the statements that are made are practical. Such as the solution being to increase the shear wall stiffnesses to reduce deflections and account for the lateral load. Also, early in the interview the participant makes the point that the deflections would have to be exaggerated (¶17) and that we wouldn't see very much deflection. The participant isn't clear about realistic action, but doesn't make statements that are unrealistic, thus earning a score of medium for realisticness since not enough evidence was provided that would be done in practice but no reason to score low.

Participant 10: Senior
Completeness: HIGH The participant covers the horizontal and vertical differential deflections as the building movement, but questions the horizontal highly and doesn’t have a reason (¶31). Problems identified are that overturning (¶25) will cause issues with the foundation (¶33). And that suctions will cause problems with the roof (¶35). The ultimate solution is to increase stiffness to reduce deflections (¶39). The problem at the inside corner is introduced by the interviewer, thus not counted as 213 discussing the topic independently (¶40). Since multiple movements, problems, and solutions are proposed, the grade is a high.
Correctness: LOW A couple of major conceptual errors are made by the student. The first being that the distributed loads are idealized as point loads (¶21). There is a large difference in behavior when this is done. The participant also carries the idea that the building would not tend to turn or rotate (¶25) which is a mistake since the shear center would most likely not align with the geometric center. The participant also states that moment frames should be used to counter the overturning tendency (¶39). Moment frames would resist the lateral load and not necessarily help the overturning. Also, the student states they don’t know the difference between overturning and bending moment (¶53). These major errors in correctness show a lack of conceptual understanding and thus a low score.
Relatedness: LOW When the discussion of the idealized or simple case of a building as a single member is talked about, the student talks about skyscrapers acting as columns, and other simplified models that relate (¶44). Yet, with one minor case of relatedness, there is unrelated content throughout the interview, such as the fact the student identifies problems with the building and a solution but that neither connect. This behavior occurs throughout the transcription and gives a low for relatedness.
Realisticness: MEDIUM The student has two prime examples of realisticness. The first being that the student discusses “breaking beams” (¶33) which would not occur in a design. Possibly yielding or excess deflection, but unrealistic to break. The second is that the student discusses cracking drywall before structural damage is expected (¶39) which is highly likely and realistic since architectural features are more sensitive to deformation that structural components, typically. Thus a balance and a medium score.

Participant 11: Senior

Completeness: HIGH

Covers multiple movements of the building: rotate (¶7), horizontal differential deflections (¶11), vertical differential deflections (¶7). The student doesn't say specifically vertical differences, but makes the statement "a non-prismatic cantilever beam from the foundation" which implies this action. Justification and details are added to all topics, such as non-prismatic cantilever whereas most students just say cantilever. Problems are discussed: inside corner (¶19) and story drift (¶15). And solutions are provided: rigid diaphragm (¶19), shear walls and bracing (¶23). Thus, a high score.

Correctness: HIGH

The student shows their intelligence when discussing and being correct about the idea/purpose of a rigid diaphragm (¶21). Very well explained and supported statements that all appear correct. Also, the discussion that the building can't be a single member due to a single member has continuous resistance is spot on also (¶39). No incorrect statements identified, so with the very well explained correct statements a high score is given.

Relatedness: HIGH

The student relates heavily to what was practiced in their capstone project that was the same concept (¶4). The student uses some analogies and ideas outside of engineering such as the action of a sail in the wind and secured at the bottom to resemble the building (¶7) and the idea of a noodle to distinguish rigid versus flexible characteristics (¶27). The student even references a double-helix to give the idea of the cantilever action vertically and horizontally (¶13). All very valid relations to other ideas. And, the student relates heavily from one topic or concept to the next along with that material is comparable to another class they had taken (¶27). A high score is given.

Realisticness: HIGH

The only weakness in the student's interview and answers is their ability to give examples and connect actual engineering practice. They do reference the ASCE-7 code and the fact the building is irregular (¶19), but not many other references are given. Yet, the student's thought and process do align with actual engineering phenomenon. The score is between a medium and high, but since no unrealistic statements were given, the score becomes a high.

Participant 12:Senior
Completeness: LOW As far as building movements, the only topic covered was that the building would rotate due to less area and more shear wall for the deep leg (¶3). A problem identified was that the inside corner would be concerning (¶11, 23). Solutions to the problems weren't discussed. To get a medium score, the student must address all three question topics and provide one answer per each. This student didn't discuss solutions, thus a low score for completeness.
Correctness: LOW Many incorrect statements were made. The first being that the uniform wind load would cause the long and narrow leg that it load perpendicular to remain straight (¶14, 15) which is false since the building would be connected and the lateral resistance wouldn't be uniform. Yet, the student then says the walls loaded perpendicular would bend in (¶47) and shows contradiction and a lack of conceptual understanding. The largest incorrect concept is when the student says the inside of the building information would not be needed to determine behavior (¶57), which is highly false since a solid concrete building would perform very different from a hollow balloon building. There is one correct and incorrect response and that is the student says simple beam theory can't be applied since the exterior doesn't cause tributary area applied to each beam. There wouldn't be one way slab load transfer, which makes the statement correct, but there could be simple beam theory applied depending on details and construction (¶51). Since a majority of the major concepts discussed are false, the student gets a low score for correctness.
Relatedness: LOW The only relation the student makes is comparing shear wall action to a box and that the walls are loaded in their longitudinal plane giving them shear resistance, versus loaded perpendicular to the surface (¶39). Besides this relation, the student has very distinct answers and nothing related from one paragraph to the next. The score is between a low and medium, but since they provided only a brief relation to the box rather than adding details, the relation is weak and thus a low score.
Realisticness: MEDIUM Two statements/responses gave insight into the realisticness category. The first being that the student referenced cost (¶21) which is a major factor in all engineering decisions and not commonly considered by students. The second is that the student tends to talk about wood framing in their discussions, which this building could not be (¶39). The balance provides a medium score.

Participant 13: Senior
Completeness: MEDIUM The participant does discuss the movements as torsion (¶3) due to a larger force and surface and there being a vertical deflection difference (¶7). Yet, the vertical deflection difference is very unclear since the student doesn't go into detail but just says "leans back". As far as problems, the connection between the buildings is identified (¶17) and the solution is to separate the buildings (¶17). The student does cover a topic from each question, thus a medium score since only one per topic with the vertical differential displacements being questioned.
Correctness: LOW The student is very vague with the responses and proves to provide very little justification towards the responses, thus making it difficult to measure conceptual understanding and correctness. Yet, one major flaw is seen when discussing whether details of the inside of the building would need to be known or not. The student agrees and thus is incorrect (¶33). Because of the limited response, there is little proof and evidence of correct statements and thus can't counteract the sole incorrect statement. A low score is provided. Same if you didn't know interior and then says framing makes up resistance (33)
Relatedness: LOW As discussed, the student is very vague and doesn't provide justification or connect ideas throughout the interview. An example is when the interviewer asks "is there a way to frame it?" (¶34), the student responds with "I guess" (¶35). Since there are no connections made, the student receives a low grade for relatedness.
Realisticness: MEDIUM The only proof of having realistic answers and responses comparable to actual design is in the statement of "deflections depend on framing type" (¶11) which is practical. The framing type could be braced frames, moment frames, shear walls, etc. and all have different deflection characteristics. The student shows they are thinking about what system would be used for construction and design. A score of medium is assigned since there is little evidence of realisticness but little counteracting the example.

Participant 14: Senior
Completeness: MEDIUM Movements discussed include: rotate/pivot because of the larger surface area (¶3). Horizontal displacements were discussed do the geometry of the building (¶9, 11). The vertical component of the differential displacements was highly influenced by the interviewer since the direct question was asked. No specific problems were identified in the discussion, but the idea that a solution had to be provided was given. The student said more cross bracing (¶19, 23) and framing (¶39) would need to be added to the system. Also, the discussion of breaking the building apart was mentioned (¶45) but solely due to the senior capstone team. Since the problems identified weren't clear, the student receives a medium score since the other questions compensated with multiple responses.
Correctness: LOW The interviewer asked specifically about relative displacements in the vertical dimension and the student said the vertical deformation was constant throughout the building. This is highly incorrect since the foundation would create the greatest resistance and thus the smallest deflections (¶5). This is one of the largest conceptual errors made in the entire cohort. The student does state the interior structure matters for analysis (¶45), which is correct, but that one minor positive correct response can't outweigh the severity of the incorrect thought. A low score is given. Also, the correct responses are typically followed with uncertainty.
Relatedness: LOW The only level of relatedness provided was that of the student being part of the senior capstone group that had this project. Yet, the student spoke as if they were in third person when involving the group (¶45). The student also mentioned their lack of structural knowledge. To support a low score for relatedness, the interview flow and answers provided appear very independent from the rest of the content throughout the interview.
Realisticness: MEDIUM The student points out their weakness in structural design and thus there isn't anticipation towards having a high or even medium score for realisticness. Yet, one statement supports why this is a grading category. The student when discussing movement of the building says it would all depend on the size of the wind load (¶17). The student is correct and that in engineering a large enough wind load would have to occur for consideration because other lateral forces such as seismic might control. This provides the student with a medium grade for realisticness since they were able to reference practical design.

Participant 15: Sophomore
Completeness: HIGH The student mentions the building would tend to rotate since on leg is well supported and the other has a larger area (¶13). The student does go back and forth between the building rotating or not, but does finally settle that it would. Also identified how the building would move is that the two legs move differently horizontally (¶31) due to the moment of inertia being different (¶35). Identified problems are at the roof (¶41), the inside corner (¶43), and at the foundation (¶45). Possible solutions include adding bracing throughout the structure (¶45). Since the student answers all questions and provides multiple answers for all, the score is a high for completeness.
Correctness: MEDIUM The student generally is correct in the explanations throughout the interview. There are a few examples of giving incorrect statements. The first being that the student says beams don't matter for the lateral load (¶45) while they actually would distribute the lateral load to the lateral force resisting system. The other major error comes in stating the building could be treated as one whole beam (¶75). Again, this isn't accurate because the homogeneous and isotropic properties do not exist. Besides these minor errors, the student is generally correct and thus a balance so a medium score.
Relatedness: MEDIUM Two key points are tied together with the student throughout the interview. There are multiple references to the Statics class and determining and using the moment of inertia of the building throughout (¶45). This relates old and relevant concepts while the student doesn't have technical knowledge. Another concept is that the student mentions simplifying the problem by treating the two legs as sections (¶55). The student does go into detail about the design process (¶57) and this shows the weakness in relatedness. The student solely focuses on adding bracing throughout the structure in different locations but doesn't talk about load determination or other important aspects that shows a lack of technical knowledge. Thus, a medium score since there are both positive and negative relatedness occurrences.
Realisticness: HIGH Where this student lacks the knowledge to relate and be completely correct, they do well with only discussing realistic aspects the problem. Such examples are: the building wouldn't move very much for a design (¶19), behavior depends on the material (¶31), wouldn't be worried about failure and structural issues if designed and well supported for such (¶41), and that the wind would need to be considered as coming from the other direction (¶45). With high levels of realistic engineering design in the explanations, there is a high score for this category.

Participant 16: Sophomore
Completeness: MEDIUM The participant discusses the aspect of the building moving by identifying the tendency for the building to turn (¶6) since there is a greater force on the long/narrow leg. Also, it is stated that the top would move more than the bottom (¶20). Concerns were with the top part blowing off (¶30) and the solution was to add support in that region (¶38). The student answers all questions and only provides multiple responses to the movement question. Thus, the student is graded between a medium and high. Yet, the vertical added deflection difference was brought upon by the interviewer and thus could be considered to not count. Thus, the grading is a medium.
Correctness: MEDIUM The student has a mix of correct and incorrect statements. Such correctness lies in their responses about how the building would move, potential problems, and the added solution. Yet, there are still a large number of incorrect topics covered. The first being that the student says the top layers would fall off when failure occurs (¶24). The top layers wouldn't just fall off, most likely they would yield or cause excessive damage, but not fall off. The second is that the student says they would design the building starting at the center and working outwards (¶36), whereas you would design from the top down to help include self-weight throughout in the dead load calculations. Finally, the student does mention simplifying the problem by looking at a single beam (¶42) which wouldn't be accurate due to various variables. Thus, a medium score is assigned based on the balance.
Relatedness: MEDIUM The student relates back to actual and observable phenomenon throughout the interview. The first example being that the student states "hotels don't move, they might sway" (¶24) and is an observation and relating to outside information. The second being that the top may blow off such as what is observed in a hurricane (¶30). And finally, the student discusses how the building could be compared to blueprints (¶40). While there are relationships developed to outside sources, the student doesn't relate their thoughts from one answer to the next for the interview content. Provided justification is in a non-linear thought process. Thus, a medium score.
Realisticness: LOW The only measurable statement that relates to realistic engineering and practice is in solution to the problem The student identifies problems in the narrow leg and thus the solution would be to widen the leg (¶32). This isn't practical since the lateral force resisting system would be improved before changing geometry and building characteristics. Since there aren't any positive realistic examples presented, the student gets a low score because of the only unrealistic case.

Participant 17: Sophomore
Completeness: HIGH The building is discussed as having differential deflection horizontally since one leg is well supported and the other is not (¶7). The top corner is also discussed as having the highest deflection and thus shows the vertical aspect (¶25). Potential problems include: the top corner and/or the entire section falling over (¶21) and the foundation supporting the entire load and being sound (¶31). Solutions to the problems are to add supports (¶27) and to make sure the material around and below the foundation is solid (¶31). The student addresses all three of the questions and is able to provide explanations towards multiple reasoning, thus a high score.
Correctness: MEDIUM The student makes mainly correct statements, such as that you don't want to design structures to be extremely rigid because an earthquake would come and crack your building (¶25). This statement alone is advanced and surprising that it was made by a student with little educational experience. Another correct statement involves the idea of designing to be conservative and designing for a slightly larger wind load than anticipated (¶27). Finally, the student discusses simplifying the problem by looking at 2D cases and then combines the work to consider the overall 3D case (¶35). The only minor error made is in the design process and is stated as designing from the corner up and outward (¶29) which is incorrect. There are other minor errors in the interview that create balance and a medium grading.
Relatedness: MEDIUM The student discusses experience with the foundation and by putting in a retaining wall knowing the foundation is very important (¶31). Thus, relating previous knowledge to the problem. While, the student does succeed with this one incidence, there is very little evidence throughout the interview that thoughts are related. Thus, there is a balance in related and unrelated justification that gives a medium score.
Realisticness: HIGH The student does a good job at understanding and trying to apply actual design practice. Such an example is when discussing the building movement, the student states they don't know wind load values and if they are significant to cause movement (¶19). Another example is that the student states that we can't engineer for everything and that we couldn't consider the worse imaginable wind storm because that would be unrealistic (¶27). Also, the material presented as being correct is very realistic. The cases of realistic considerations and zero to very little unrealistic statements, there is a high score.

Participant 18: Sophomore
Completeness: HIGH The movements include the typical rotation of the building (¶15). The student identifies many potential problems throughout the interview and includes: building tear apart at the inside corner (¶39), foundations and the roof (¶59), and that the entire building could tip over (¶71). Solutions include: making sure the building is reinforced appropriately (¶59) and to use strong materials (¶69). Multiple responses for each question shows great completeness and a score of high.
Correctness: MEDIUM Whereas the student covered a lot of material, there were a few major mistakes. The first being that the reason for rotation is that the wind hits one leg in the line of action and apparently the other not so (¶15) while they occur in the same line of action. I believe the student was trying to explain the idea that one section is well supported and strong axis properties. The second is that the student believes the building would split apart perpendicular to the wind load at the inside corner (¶41) which is the least likely location of the split. While there are errors, the student also explains the idea that if the building splits then there would no longer be rotation issues (¶45) which is correct. And, that the building is hollow and thus a need for a deeper analysis (¶77) which is also true rather than a solid single member. The balance is a medium score.
Relatedness: LOW Only one occurrence of relatedness is seen in the interview and it happens to do with building and comparing the structure to a scale model (¶79). This relates actual observations to phenomenon, but is the only relation rather than connecting all the ideas and justification presented throughout the interview. Thus, a low score is given.
Realisticness: MEDIUM Two cases of realisticness are covered. The first being unrealistic since the student says that a potential problem is that the windows would be blown in (¶55). The windows would be designed for the wind load as components and cladding and as a critical system would most likely not occur. The other phenomenon is when designing, the student says that you could get record wind data and then design to that level or value to help determine values (¶61) and that you would have to consider earthquakes also. The two cancel and provide a balance for a medium score.

Participant 19: Sophomore

Completeness: MEDIUM

The participant discusses the building movement by first stating there is a tendency to rotate (¶7). Then there is great conversation on how the bottom is more fixed then the top (¶7) which implies there are different deflections at the ground then the top. Finally, there is discussion about different deflections horizontally (¶13). As far as problems go, there isn't very many given. The only problem is talked about the long section being of concern and that the top of that long section would need to be monitored (¶32). The solution if there is a problem in the top section of the long leg is to make is stronger and lighter (¶32). The student lacks the ability to identify specific and important problems and valid solutions to those problems. This inhibits them from getting a high grade for completeness, but the discussion about movement allows a medium score.

Correctness: LOW

There are quite a few errors in thinking when discussing the L-shaped building that are mixed in with a broad range or correct statements. The first major error can be seen when stating the building will all move together as one (¶15), which would not be true. The building does have flexibility, thus there isn't rigid body motion. Next, the student believes designing for a certain wind direction is important (¶25), which is both true and false. The prominent wind direction may be taken into consideration when designing, but most likely isn't a major deciding factor since structural design could account for how the architect wants the layout. Next, the student says the middle section is least concerning (¶31) which is far from true since the irregular shape requires attention to design at the corner. Finally, the student says the wind could be considered a point load (¶37), which would change behavior and calculations whereas it should be considered a distributed load. There are major flaws in the conceptual understanding of the problem and not enough correct statements to counteract the negative. Thus, a low score.

Relatedness: LOW

Relatedness is difficult to measure for this student since there aren't references to codes or actual design practices. There isn't reference throughout the entire conversation about some main ideas that affect the movement, create problems, and require solutions, but more of separate ideas. And the justification that is provided is lacking any evidence that the problem is all tied together. Thus, with no evidence showing relatedness, the student receives a low score.

<u>Realisticness: MEDIUM</u>

There are some great statements and topics covered that shows the student is thinking on a practical level. The first being that the wind has to be assumed strong enough to cause movement (¶5) which is true and a consideration in design. There is talk of tornados causing greater wind forces and thus consideration of higher damage (¶23). Yet, there are two major statements that counteract the intuition of the student. The student discusses the wind being trapped in the corner and thus a solution would be to build a system to direct the wind over the top of the building (¶27) which is impractical since the lateral force resisting system should account for these added forces. And finally, a solution is to build the building thicker and less tall (¶29) which isn’t an engineering option. A medium score since the negative counteracts the positive.

<u>Participant 20: Sophomore</u>

<u>Completeness: LOW</u>

The movement of the building is discussed as rotating (¶7), but there is an inner debate whether or not that would actually happen (¶27). There is the fact that the student discusses the top moving more than the bottom (¶15). Throughout the interview, the student identifies some major components that are important but doesn't relate them to having actual problems (¶39). And, the only solution is to build the building symmetrical (¶29) which doesn't specifically address a problem but just to reduce rotation. The lack of identifying a problem and need for an engineering solution because of the movement gives a low score for completeness.

<u>Correctness: MEDIUM</u>

There are some concerning statements made that show a lack of conceptual understanding. When directly asked about differential displacements or relative displacements, the student says there are none (¶9) but had discussed such action prior. A minor error involves the idea to design from the bottom up which is an incorrect approach (¶37), but the student does discuss finding the support reactions which is true. There are other minor true statements in the interview that give a medium score for correctness but the major flaw keeps the student from obtaining a high grade.

<u>Relatedness: MEDIUM</u>

There is a great deal of trying to relate the unknown problem and material to what the student does know. When discussing movements, the student relates to a tree in the wind (¶19) which then leads to discussing the top of the building swaying. There is also a section when talking about the design process where the student talks about set steps as if from a prior class, Statics (¶37) where there is methodology to solve problems. Finally, when talking about the foundation (¶39) the student relates to a house needing a critical foundation to stand and resist wind loads. These are all great examples of relating to phenomenon outside of this problem, but the student's answers don't tie together when talking about any actions. There isn't a connection from building movements to creating a problem, and then needing a solution to address that problem. Thus, the two cancel each other and gives a medium score.

<u>Realisticness: MEDIUM</u>

The student makes a balance between realistic and unrealistic practices. The major unrealistic statement is the solution to make the building symmetric, which shows a lack of conceptual understanding to practical design (¶29). The practical statements are that there would be some wind load that requires the building to move and anything below that wouldn't and doesn't need to be considered (¶37) and that a simplified model would be the same structure without windows (¶41). The window elimination is great for overall wind design since they are a separate design for ASCE components and cladding. Again, a balance and mediocre responses creates a medium score.

Participant 21: Sophomore
Completeness: MEDIUM Movement discussions are covered well since the student talks about both horizontal displacement varying (¶13) and vertical deflection being greatest at the top versus the bottom (¶17). When asked about potential problems, the student just says the movement but can't identify specific locations until late in the interview when the middle section is a concern because it flexes (¶29). Finally, the solution to the problem is to stiffen the building to reduce deflections (¶25). The student covers all questions with touching on a major response topic for all. The lack of discussion about problems is made up with the extra talk on deformation differences and thus a medium score.
Correctness: MEDIUM With the correct movements, problems, and a valid solution, the student appears to be on the track for a high level of correctness. Yet, there are conceptual understanding issues with responses such as when talking about increasing stiffness the idea to add more beams is presented (¶25). Beams wouldn't increase lateral stiffness and solve the lateral problem. Also, the student says they would design from the bottom up for the building (¶27), but that lacks self-weight considerations and other important features. The design methodology isn't expected to be known by students that haven't done design, so that is a minor error. Thus a medium score.
Relatedness: HIGH When the students aren't expected to know the exact solutions, it appears the relatedness category becomes highly important. Such as how 107 states a model of a piece of paper with a fan blowing on it would tell us a lot about this problem (¶33) which is highly true and helpful. A great reference to something beyond this design. Also, the student appears to have connected thoughts and proper justification in the remainder of the interview. There isn't a reason not to give a high score.
Realisticness: LOW Another observation is that students that don't have design experience or prior knowledge of such a problem tends to vary in realisticness. This student shows just that. They identify the building as being concrete which is true and a consideration is design (¶27) but then the unrealistic solution to the problem is to shorten and widen the building (¶25) which isn't allowed. The concrete realisticness is merely an observation and thus nothing to support the realistic positive scoring, so a low is assigned.

Participant 22: Sophomore

Completeness: LOW

The student does discuss the idea that there would be different deflection horizontally (¶15), but can't provide a reason why. Also, the student states they don't know consistently throughout the interview (¶17, etc.) which shows they are uncertain of their response. As far as discussing problems, the student says the top would sway (¶19), but again isn't sure that is correct (¶21). The final topic of a solution to the problem is to add support (¶25) and bracing (¶27) but again follows the conversation with uncertainty. With failure to provide proper justification and touching on major topics or reasoning, the student gets a low score.

Correctness: LOW

With little content throughout the interview and a great amount of uncertainty, there are few and far correct statements. A major incorrect statement is that the student believes the problem can be considered as a single beam (¶33), which neglects many details that would affect the problem. Another low score provided.

Relatedness: MEDIUM

This student has one of the most incomplete and sporadic interviews and responses. There is zero connection of ideas and little justification provided for each response. Thus, a low score for relatedness. Yet, the student does pull ideas and information from outside the unknown by introducing concepts such as axis of bending from Statics (¶9). Also, the student references a piece of angle iron and behavior since they are both L-shaped (¶13). Great relatedness to other material, but again the student repeats much of the content (¶31) from prior and so a medium score.

Realisticness: LOW

The only positive aspect of the interview that could be applied in engineering practice is that the wind would need to be strong enough to cause deformation (¶19), but that is all the student says and no justification or expansion. Very unrealistic content is that a solution would be to change the geometry (¶25). Also, when the student is asked about design, the student focuses on the location of the pool rather than engineering which is highly impractical and goes to show the student doesn't know what they are doing. A low score is appropriately given.

Participant 23: Sophomore
Completeness: HIGH Movements are highly covered in the conversation, including rotation (¶19) and differential horizontal deformation (¶23) since one leg is more supported. Also, the discussion of supported at the center and thus less deformation (¶33). Problems concerned would be the back side of the building since there are high levels of compression (¶43). Also, the corner has high stresses (¶45). The foundation and frame are later discussed (¶53). As far as a solution, the student mentions that support should be added in the back (¶47). Since multiple of each topics is covered, the student gains a high score for completeness.
Correctness: LOW While the student covers all the major topics, the justification is typically incorrect and doesn't support the claims. Such examples are that the student draws a normal force diagram and then derives a bending moment diagram (¶19). The minor error here is that the student would be talking about a shear diagram not a normal diagram. Yet, the major mistake is that the student doesn't know the supports are intermediate and thus the shear and moment diagrams are far different from those drawn. Another large mistake is that the student claims the moment is high at the end (¶43) which actually there would be zero moment at a free end. The final major error is that the student assumes an L-shape would be better than a box shape since the one leg is supported by the other (¶45), but the student doesn't understand the support isn't carried throughout the entire narrow leg. The score for correctness is low since the major errors.
Relatedness: MEDIUM The student makes a few claims that show conceptual understanding and misunderstanding. The student relates to various materials but then goes on to talk about them and states they don't know about them (¶43). Applying concepts that a student doesn't know about are some of the largest errors. While there are minor issues, there are some great relations made about how the wind forces are similar to the distribution of hydrostatic forces on a dam (¶53). Also, the idea of modeling as a fan or blow dryer on actual problems is discussed (¶55). A balance shows a medium grade.
Realisticness: LOW The only realistic conversation is that when solving the problem and how to design. The solution proposed is to build wind barriers such as growing tall trees (¶47). Also, the student says they would design and build with no major corners and make the building more aerodynamic (¶49). Both of these ideas are highly unrealistic and thus a low score.

Participant 24: Sophomore
Completeness: MEDIUM The participant does cover two of the topics regarding how the building would move, both the vertical difference in deflections (¶17) and the horizontal difference between the legs (¶17, 19). When discussing the most problematic portion of the building, the student simply talks about the center part (¶29) having the greatest issues which is vague and difficult to score that as identifying stress concentrations at the inside corner. Yet, later in the interview the student identifies the top corner of the building as being the farthest from the original position and thus concerning (¶43). As far as a solution to the problem, the student states they would add more support behind the section that moves most (¶37) and/or widen the base of the building (¶45). The student provides a response that is identified as being important and showing of conceptual understanding for all three categories, but lacks the detail to identify that they provide more than one per section, thus getting a medium score for completeness.
Correctness: MEDIUM Most of what the student discusses could be identified as being correct, such as the need to focus on the top corner (¶43). Yet, it is difficult to identify if all statements are correct such as the issue of stress concentrations at the center (¶29) which would be correct if they were talking about the center as in the corner but would be incorrect if they are talking about the face of the structure. There aren't any major errors identifiable and thus a medium score is given since not enough correct conceptual understanding statements are made to give a high score.
Relatedness: LOW The student remains very vague with responses and fails to connect thoughts and ideas. Such an example of being vague is that the student says "this on the outside" (¶41) in response to what part would be most worrisome. The student says the most concerning part is the middle part, but doesn't give any reasoning or how the solution of widening the building would help. Due to the sporadic responses and added details, the student receives a low score for relatedness.
Realisticness: MEDIUM The student has a balance in realisticness. The student says that windows would most likely break in the center part (¶29) which wouldn't be the primary location where they would break. Also, the best solution to the overall problem is to change the geometry of the building and the layout (¶37), which isn't practical. Yet, the student does discuss the option of building a small model of the building and apply a wind load to understand the behavior and simplify the problem (¶49) which is something that engineers may do, such as a wind tunnel test. Thus, there is a balance in being realistic and not.

Participant 25: Sophomore
Completeness: LOW The student did a good job with identifying that the legs would move differently from each other (¶9) and thus shows conceptual understanding towards the difference horizontally. They also recognize and identify that the top moves more than the bottom (¶17). Yet, the student is only able to identify the base as the part that needs to be strongest (¶41) and has zero input on a potential solution besides the building could be more aerodynamic (¶37). The aerodynamic solution isn't identified in Table 1 as one of the major response topics and thus they fail to address all questions and receive a low score.
Correctness: MEDIUM The student tends to make correct statements and with the vague details it is difficult to say they are wrong in their reasoning because there is little reasoning provided. There is one major incorrect statement in simplifying the problem by turning the distributed loads into point loads (¶5) since that changes the behavior. Thus, without further incorrect statements the student receives a medium score for correctness.
Relatedness: LOW In the initial discussion of how the building would move, the student does give reasoning into why there is a difference in leg deflections. The statement and reasoning is that one leg has more support (¶9). Yet, the student doesn't relate back to this concept when addressing potential problems or solutions. There really isn't any relation from one response to the next. Thus, a score of low is given.
Realisticness: LOW The student doesn't provide very many details or content that relates to actual engineering practice. The solution is typically where there is a connection, but the student suggests that the building be oriented so the wind doesn't hit perpendicular to the weakest part (¶35). For this building that isn't the best solution and wouldn't be mostly considered. Since there weren't any other realistic statements made, the student gets a low score.

Participant 26: Sophomore
Completeness: MEDIUM As far as how the building would move, the student identifies the bottom of the building would move less than the top (¶6). As far as trouble areas or areas of highest concern, the student mentions the inside corner (¶22). And as far as solutions, which the interviewer never directly asks for in this interview, the student identifies more support (¶24) and/or bracing would be needed (¶32) at the inside corner. Thus covering all three questions and the responses match those identified as being most important, so a score of medium. The student only identified one in each category.
Correctness: LOW The student makes many errors when discussing the problem. The first being that the interviewer asks if there would be different deflections or behavior in the different legs after the student identifies one is more supported. The student responds by saying no since the wind load is uniform (¶20). This is a major error since they identify the more support but don't understand how that affects the problem. Such a major error that the student would be expected to identify beams with the same depth as having the same capacity. Other major errors is that the student believes more weight causes the issues at the corner (¶28), but the weight should be about the same throughout the building horizontally. And finally, the student claims corners are the weakest part of any building (¶30) even a box building, which isn't necessarily true. The score is a low since there are multiple major errors and no major correct responses that support the student having conceptual understanding.
Relatedness: LOW There isn't any recognition of connecting responses to one another throughout the interview. The student simply answers the questions and moves onto the next topic. The only hint at relatedness is the discussion about the corner and trying to give a reason to how it is the weakest part. Yet that is poorly done and ultimately incorrect. A low score is given.
Realisticness: MEDIUM There is a balance between realistic and unrealistic statements the student makes. The realistic portions are that the student says the wind hitting the windows can be idealized as the same as hitting the walls even though they are different materials (¶8). This is true and we do a uniform distributed load across the entire face without considering how the windows affect the distribution. Also, the student wishes to build a scale model which is doable (¶40). A better response would be a scale model in a computer program rather than out of Legos (¶36). Finally, the unrealistic response is the student says they don't like L-shaped buildings and wouldn't design them (¶26) which is impractical. Thus the balance gives a medium score.