From DNA to Deep Space: Investigating scale communication in multidisciplinary engineering projects

by
Tarah Erickson

A THESIS

submitted to

Oregon State University

Honors College

in partial fulfillment of
the requirements for the
degree of

Honors Baccalaureate of Science in Environmental Engineering
(Honors Scholar)

Presented June 2, 2017
Commencement June 2017

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Tarah Erickson for the degree of Honors Baccalaureate of Science in Environmental Engineering presented on June 2, 2017. Title: From DNA to Deep Space: Investigating scale communication in multidisciplinary engineering projects.

Abstract approved:____

Devlin Montfort

An important goal of engineering educators is to prepare students to interact and communicate with other professionals, especially other engineers. Object and process scale is a crucial concept that engineers are required to communicate frequently and effectively. The goal of this study is to characterize how engineers communicate scale within a multidisciplinary design project. This was accomplished by studying a group of NASA engineers presenting a 90% design review of the BioSentinel project, a cube satellite designed to measure radiation in deep space using yeast. The engineers' presentations were observed and data was gathered in the form of field notes, which were analyzed using Systemic Functional Linguistics. The engineers did not frequently use precise values or describe value desirability. Scales were explained very rarely, using personification or comparisons to other scales. Overall, these findings indicate that practicing engineers assume a high level of scale understanding from their peers, which means that engineering educators must provide students with a thorough understanding of scale and the various methods of communicating it.

Key Words: Scale, Engineering education, Systemic Functional Linguistics, Observational Study

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Honors Baccalaureate of Science in Environmental Engineering project of Tarah Erickson presented on June 2, 2017.

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I understand that my project will become part of the permanent collection of Oregon State University, Honors College. My signature below authorizes release of my project to any reader upon request.

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INTRODUCTION:

Engineering knowledge begins with education, and engineering educators strive to provide students with the technical and theoretical understanding of physical systems that they will need in order to succeed in their field. Another important goal is to prepare students to interact and communicate with other professionals (engineers and non-engineers alike). While significant research has been conducted on how to get students to understand physical processes and theoretical concepts more efficiently, less emphasis has traditionally been placed on the communication aspect of engineering education. In recent years, more efforts have been directed toward the ability of engineering graduates to communicate their ideas, and many universities are requiring extensive writing and verbal communication classes for their engineering students (Boiarsky, 2004) (Missingham, 2006).

Teaching engineering students to communicate skillfully across engineering disciplines is critical to prepare them for the environments they will be working in as professionals (Lemke, 1993). In fact, two of the main professional skills required by the Accreditation Board for Engineering and Technology (ABET) are “An ability to function on multidisciplinary teams,” and “An ability to communicate effectively.” (ABET, 2016). If students are inadequately prepared to communicate with their future co-workers, they will be at a disadvantage throughout the beginning of their professional careers. Even worse, if student engineers are taught to communicate in ways that clash with the communication habits of practicing engineers, they will have to completely re-learn those skills on the job, requiring considerable time and effort.

One concept which is communicated extensively across all engineering disciplines is object and process scale. Scale is important to practicing engineers because it is a baseline for every design and is a concept that frequently needs to be coordinated across multiple disciplines in complex projects. If the scales used to describe each component of a design are not adequately communicated between the design group members, the project could face considerable setbacks, even failure.

This study is the first to use ethnographic-style observations to characterize how practicing engineers communicate scale in multi-disciplinary settings via informational presentations. In this study, ‘scale’ is defined as the conceptual system used to arrange, measure, or quantify events, objects, or phenomena. For example, volume (a parameter) can be expressed using several different scales from a cup of milk in a bowl of cereal to a gallon of gas in a car. Ideally, engineering educators will be able to use the information gleaned from this study to teach scale communication skills to engineering students in ways that will help them transition into an engineering career.

BACKGROUND:

Outline of Study:

The best way to classify how professional engineers communicate scale is to observe a group of them communicating in as close to their natural work environment as possible, while causing as little disruption as possible during the observation. In order to produce usable results, the group of subjects being studied must be large and diverse enough that the findings are applicable to an appropriately broad section of engineers, yet also fit within the time constraints of the study. All subjects must also be observed communicating in the same or very similar contexts, so that the data gathered shows trends that are clear and can be tied directly to the context of discussion. The subjects must also be willing to be studied as they interact, which often happens in a proprietary setting given the nature of engineering design projects. These requirements support the use of an observational study format with data collected in the form of field notes. This study design has been used in other observational studies in the field of education research (Emerson, 2011).

Theoretical Framework:

The analysis of the data produced in this study is based on Systemic Functional Linguistic (SFL) theory, an approach developed on the foundation of work by social semiotic linguist Michael Halliday (Eggins, 1994). This approach involves analysis of the grammatical and thematic makeup of language and its relation to the context in which the language is used. The object of this analysis is to better understand how people's specific utterances result from social structures and shared conceptualizations. The main premise of this approach is that each speaker choses specific language to communicate within a given context. This language then contains patterns, which are understood by all speakers and audiences within the same or similar contexts. By observing language patterns in a given context, it is possible to extrapolate an understanding of how language works inside all contexts of the same type. This in turn can be used to comprehend the underlying social structures and shared assumptions of people communicating within the context. In this study, scale communication by a group of professional engineers was observed and examined using Systemic Functional Linguistic (SFL) analysis to define language patterns, social structures, and assumptions that can be considered common for describing scale in similar contexts.

Outline of SFL Principles and Analysis Techniques:

SFL analysis operates under four basic assumptions; first, it is assumed that language is functional, and second, its function is to make meanings. Another assumption is that the meanings of a language are influenced by the context in which they are exchanged (e.g. the social or cultural surroundings in which it is used). Finally, SFL assumes that choosing a language is a semiotic process wherein the meaning of the language is chosen by the people speaking it (Eggins, 1994). The patterns people follow when structuring language to create specific texts in specific settings are referred to as the 'genres' of those texts. In the case of this study, the genre being examined is that of practicing engineers communicating object scale in design presentations. SFL suggests a genre is defined in three ways: the register configuration of its context, its schematic structure, and the realizational patterns in the text (Eggins, 1994). The register configuration of a context refers to the environment or background in which it is used and how that setting affects the way people choose to create texts. The schematic structure refers to the various steps people take to construct a text that are repeated for all texts in the genre. Finally, the realizational patterns of a genre are how the schematic structure relates to the language itself (i.e. how it is "realized"), including grammatical and phonological trends.

In this study, the schematic structure and realizational patterns used by a sample of engineers were observed and analyzed, then used to make generalizations about the structure and realization used in the overall genre. This is only possible if the context (register) of the specific language observed and analyzed is identical (or nearly identical) to the register of the overall genre to be studied. A context can be broken down into several dimensions, all of which affect the way language is used. The first of three main dimensions is the mode of the text, which refers to the role of the language and how much feedback is received by the author (e.g. writing vs. speaking, a presentation vs a discussion, etc.). In the context of both the language studied as well as the larger genre, the mode of the context is a (spoken) presentation. The second contextual dimension is field, which refers to what the speaker is talking about. In this study, the field is satellite design, which is a specific form of design review and explanation. The final dimension is tenor, which refers to the relationship between the author and anyone else who is part of the text (e.g. reader, interviewer, colleague, or friend), which in this case is between design engineers and other engineers/scientists, administrators and managers. The advantage of an observational study is that there are no interruptions to the context of the language being used, as there might be when subjects are interviewed. The downside of this method is that specific questions cannot be asked of the participants when queries arise as to why participants use a certain type of language.

PURPOSE:

The purpose of this study is to characterize how engineers in a multidisciplinary design project communicate scale to other engineers in a design presentation format.

METHODS:

Research Subjects and Data Collection Methods:

The subjects chosen for this study were a group of 43 NASA engineers working on the BioSentinel project. The group designed a satellite that will launch in 2018 as a secondary payload on the NASA Space Launch System's first Exploration Mission. The goal of the satellite is to measure the effects of deep space radiation on yeast cells grown in culture in a series of microfluidics cards, measuring their growth using metabolic indicator dye and an LED-based spectrophotometric detection system. The yeast cells were genetically engineered to reproduce only when a double-strand break occurs in their DNA (which occurs when exposed to radiation), allowing scientists to track radiation-induced damage (NASA, 2017). This project includes engineers from various fields (mechanics, microfluidics, electrical, projectile dynamics, telecommunications, space trajectory, propulsion, radiation), which provides the necessary diversity of engineering professions and maintains the set context tenor required by this study. The design project also takes place across a multitude of scales (nanometers to astronomic units), making it ideal for a study on the context field of scale communication. The observations of these engineers were conducted by taking field notes during a two-day 90% design review for the BioSentinel project, which included presentations by the lead engineers of each section of the project (19 presenters) to a review board of scientists, engineers, administrators and managers. These presentations were accompanied by question and answer sessions (sometimes in the middle of the presentation) by the review board regarding any aspects of the design that they felt needed to be clarified or examined.

Field notes from the study were recorded using a jotting template (see Field Notes Template Example in Appendix) which included sections for direct quotes observed from speakers, immediate comments, and ongoing interpretations. The field notes were intended to record examples of common phrases used by the engineers studied, general themes of communication that linked back to the context of the study, and any of the observer's thoughts during the observations. The field notation methodology was intended to allow sizeable flexibility in the data collected and has been used in other studies which include SFL analysis, typically alongside recorded transcripts and other observational data (Barrowy, 2008) (Harman, McClure, 2017). The use of field notes allowed the observer to decide the level of detail which they could reasonably record while not using biased selection or failing to record all of the desired information. Field notes were taken during 'scale events' wherein the field observer attempted to note every time a reference to scale was made by the presenters, and record as much detail as time allowed. These scale events include all spoken references to size or general scale, descriptions of scale, switches from one scale to another, hand gestures, and graphical representations involving scale. In this study, field notes were recorded and cross-referenced (when needed) with presentation slides created by the group of engineers.

Data Analysis Methods:

After data collection, the field notes were scanned and organized using ATLAS-ti software, which allows the data to be tagged with descriptive 'codes' which can then be organized and searched to facilitate in-depth analysis of the data. Four main code families were used to organize the study data, each of which contained between 30 and 200 individual codes that were further divided using 18 code prefixes (3 to 6 prefixes per family). The four main code families (shown in Coding Structure Diagram, pg. 10) are, ‘Scale Delineation,’ ‘Value Portrayal,’ ‘Scale Explanation,’ and ‘Supporting Project Details.’ The ‘Scale Delineation’ family contains codes which refer to parts of texts which describe the scale or scales that were used during a topic of discussion and contains the code-prefixes “UNITS,” “PARAMETERS,” and “MEASURE OF.” The second family, ‘Value Portrayal,’ contains codes that pertain to how numerical values within each scale are communicated and discussed. This family contains the code-prefixes “SIGFIG,” “ESTIMATE,” “APPROXIMATION,” “IMPLICATION,” “ACCEPTABLE,” and “UNACCEPTABLE.” The third family, ‘Scale Explanation’ is concerned with misunderstandings involving scale or attempts to clarify scale using metaphors, visuals, or explanations. The code prefixes in this category are “VISUAL,” “COMPARISON,” and “PERSONIFICATION.” The final family, ‘Supporting Project Details,’ is meant to be used as a supplement to the first three, and contains details about the project phases, important discussion topics, and questions posed by the review board. This section should be used to connect trends in the first three families to specific topics or sections of the presentation. This family contains the prefixes “REQUIREMENT,” and “IMPORTANT,” as well as “QUESTION” and “EXPLANATION”. Finally, the prefix “SLIDE” indicates relevant supporting information on a power point slide. The coding families and prefix sub-groups (shown in more detail in Coding Structure diagram, next page) were used to find patterns of communication within the context of the design review presentations. These patterns can then be used to make generalizations about how practicing engineers portray and discuss scale.

Coding Structure: **CODE FAMILIES**, **CODE PREFIXES**, Code Description

SCALE DELINEATION
How the presenter describes what scale they are using

- **UNITS**: Denotes if units are mentioned, and which units
- **PARAMETERS**: Denotes parameters mentioned and which parameters
- **MEASURE OF**: Clarifier of PARAMETER, denotes what is being measured if it is unclear from other codes

VALUE PORTRAYAL
How the presenter describes values within a scale

- **SIGFIG**: Denotes if a numerical value is mentioned, and its significant figures
- **ESTIMATE**: Denotes values which are portrayed using estimates
- **APPROXIMATION**: Denotes when numerical values are approximated
- **IMPLICATION**: Denotes when a value was implied without use of an estimate or numerical value
- ***Desirability Descriptors***
  - **ACCEPTABLE**: Denotes when a value was communicated as desirable
  - **UNACCEPTABLE**: Denotes when a value was communicated as undesirable or unacceptable

SCALE EXPLANATION
How the presenter explains a scale or value to the audience

- **VISUAL**: Marks hand gestures in conjunction with scale
- **COMPARSION**: Denotes comparisons of a value to a non-conventional scale
- **PERSONIFICATION**: Descriptions of items in non-human scales as having traits of human scales

SUPPORTING PROJECT DETAILS
Additional project details that supplement other families

- **REQUIREMENT**: Denotes a requirement for project success
- **IMPORTANT**: Denotes when something discussed was considered by group to be important
- **QUESTION**: Denotes when a question was asked
- **EXPLANATION**: Denotes when an explanation was given

SLIDE: Denotes when a slide was mentioned in scale discussion

Since the data from the design presentations was recorded in the form of field notes rather than audio recordings/transcriptions, it is possible that certain information could have been missed due to a notation error or an oversight by the observer. This means that the exact numbers of each code type may not represent the exact frequency of each type of phrase, as some potential data could have been overlooked. Because of this, it would be unwise to evaluate the data based purely on a numerical approach (e.g. number of times a certain phrase was used, number of mentions of a specific unit, etc.), so a more pattern-based approach was applied. In this approach, general trends were noted (with the help of, but not reliant on, numerical code counts) and reoccurring themes were documented. One main way this was accomplished was by comparing the co-occurrence of different code families and specific code types using percentages and ratios of codes from each family. This approach is reminiscent of plotting Venn Diagrams and the grouping of multiple codes during analysis serves to reduce error caused by possible incomplete field notes.

The coding structure was re-evaluated before analysis and two code prefixes were removed from consideration ("ACTION," "EQUIPMENT") as they were deemed irrelevant. In order to be considered for analysis, code prefixes needed to have a distinct definition that was separate from other code prefixes and needed to be used consistently with this definition throughout the analysis. Differences of less than 10% between percent values were not considered significant enough to merit solid conclusions. This type of analysis fits within the overarching format of SFL, merely at a high level (lower specificity) of observation that would already be more relevant for analysis of spoken text (Phillips, 2002). The transient nature of spoken text lends itself to a more conceptual and overarching theme-based analysis since its structure is less rigid and closely monitored than written text, making specific lexico-grammatical observations both more difficult and less relevant.

Slides:

The presenters/engineers made very few references to slides (only 28 “SLIDE” code references, 13% of total) while discussing scale. Of the slides that were mentioned, nearly all of them consisted of either a diagram showing a process or design component, or a graphical representation of values. There was only one instance of a value literally read off the slide exactly as shown. Due to the proprietary nature of the information on the slides, and the infrequency of any direct references to them, further analysis of the power point slides was not conducted as a part of this study.

Methods Check:

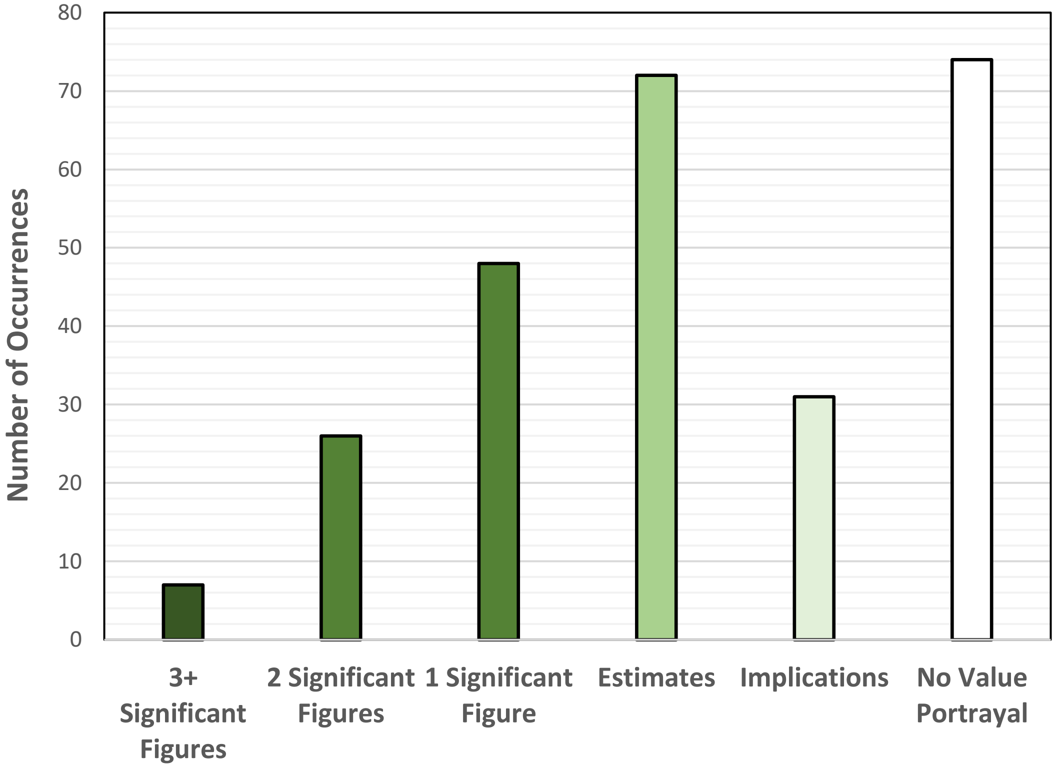
In order to test-run the analysis methods for the coded field notes, a sample comparison was made between the number of significant figures given and the occurrence of “ESTIMATE” and “IMPLICATION” codes. This comparison is between three code types within the same family (Value Portrayal), and has common-sense predictable outcomes. If the analysis method were effective, one would expect to find a higher number of “ESTIMATE” and “IMPLICATION” codes associated with values that have less significant figures. The opposite should also be true for values with high significant figures (they should contain fewer “ESTIMATE” and “IMPLICATION” codes). This result is expected because the codes themselves are designed to represent the different levels of specificity with which a value can be portrayed. When compared, it was found that nearly 50% of values with two or less significant figures had estimated or implied values, while only about 15% of values with three or more significant figures were estimated or implied. This confirms that the analysis method used can provide enough distinct contrast between code occurrences to be useful in comparing the code families.

RESULTS:

Overall, 412 individual codes were used to classify the field notes, with 168 codes from the ‘Scale Delineation’ category, 116 from ‘Value Portrayal,’ 27 from ‘Scale Explanation,’ and 50 from ‘Supporting Project Details.’ This distribution of values implies that scale explanation was rarely used throughout presentations, indicating that even in a diverse and multi-scaled context engineers do not spend much time specifically explaining scale. Overall trends in the way the engineers used scale explanation were examined, along with how values with different levels of precision and desirability were expressed. All quotations in the discussion below are taken directly from the study field notes and may not be verbatim (according to the speech of the engineers) due to the nature of the field notes.

Precision – How and when are precise values portrayed?

The engineers observed in this study used various methods to communicate unit values within scales with varying degrees of precision. These different levels of precision were used to denote importance of the values, as well as to add detail to project requirements. In most cases (60% of all scale references), values were portrayed using numbers or estimates. This 60% included a roughly even number of numerical values (e.g. “3.5 cm”) and estimated values (e.g. “a few hours”), with a slight overlap between the two caused by estimated numerical values (e.g. “approximately 5 days”). The frequency of use for each method of value portrayal is shown in the figure below, with darker colored bars denoting more specific forms of value portrayal.



Frequency of Value Portrayal Methods: Shows frequency of occurrence for various value portrayal methods used by NASA engineers from most specific (3+ Significant Figures) to least specific (No Value Portrayal).

The most specific values were delineated using numbers, with more significant figures having higher specificity. Values with the highest specificity were described using three or four significant figures, which occurred very rarely. More commonly, one or two significant figures were used as the least specific value notation which was still numerical. One and two significant figures were also found to be used interchangeably, as shown by the fact that both one and two significant figures had the same chance of being marked as an estimated/implied value (46%), which dropped sharply after another significant figure was added. This also implies that numerical values containing one or two significant figures were used as estimates about half the time.

The least specific forms of value portrayal were estimates and implications. These were identified in the analysis using codes from the ‘Scale Delineation’ family. There also appeared to be another level of even less specific value portrayal present in the discussion, evidenced by the fact that there were more references to scale delineation (units, parameters and measurement) than to any specific numbers or even generic values within those scales (scale delineation codes). In fact, 23% of scale delineation references did not have any sort of value portrayal language attached to them.

The engineers studied used these different levels of precision in their value portrayal to emphasize values that were important, as well as to move emphasis away from specific values when they were not important to the discussion. Overall, the engineers were found to use more precise values when talking about requirements and important items than they did when generally discussing their design. For example, when values with three or more significant figures were used, 67% were attached to requirements or items of importance. This is more than double the percentage of requirements/important items that occurred when only one or two significant figures were used to portray values, which was about 30% for each. In addition, hardly any estimates were used during discussions of requirements or items of importance. Analysis of value portrayal codes showed that 33% of significant figures (any, in general) were associated with requirements versus 13% of Estimates/Implications.

An opposite pattern was observed for value precision when the engineers asked questions or provided explanations. In these cases high numbers of significant figures (>2) were slightly *less* likely to occur than lower significant figures (1 or 2), with the highest percentage occurring for two significant figures. The number of questions or explanations having numerical values with 1-4 significant figures was very close to (albeit slightly higher than) the number of questions or explanations having estimated or implied numerical values.

Scale Explanation – How and when do engineers explain scales?

Scale explanation ("COMPARISON," "PERSONIFICATION," and "VISUAL" codes), while making up only a small portion of scale references, (13% of total) is one of the most important categories to analyze because these explanations represent situations in which the audience is not assumed to understand the point a speaker is making just by mentioning a scale or value. Scale units which were not explained at all include degrees (rotation angle), rpm (rotation speed), ratios (radiation damage and susceptibility), percent (various), watts (power), volts (electrical potential), hertz (frequency), bytes (data size), and nearly all length and time scales.

The most frequently occurring type of scale explanations were personifications (with 15 code occurrences), which were defined as the use of terms common to human scales to describe the actions of things in non-human scales. These comparisons use familiar processes within human scale as metaphors for less familiar (and often more complex) processes occurring at a different scale. Personifications were found to be used almost exclusively to describe things in very small scales, for example "[molecules and dye] want to go out [through membrane] as much as they want to go in.” describes mass transfer potential through a membrane in terms of what particles ‘want.’ Also, applications are referred to as ‘somebody’ when discussing different programs and are described as ‘hogging’ CPU when they use too much processing power and ‘talking’ to each other when they transfer data (e.g. “App 1 talks to Apps 2-7 to see who’s hogging data.”).

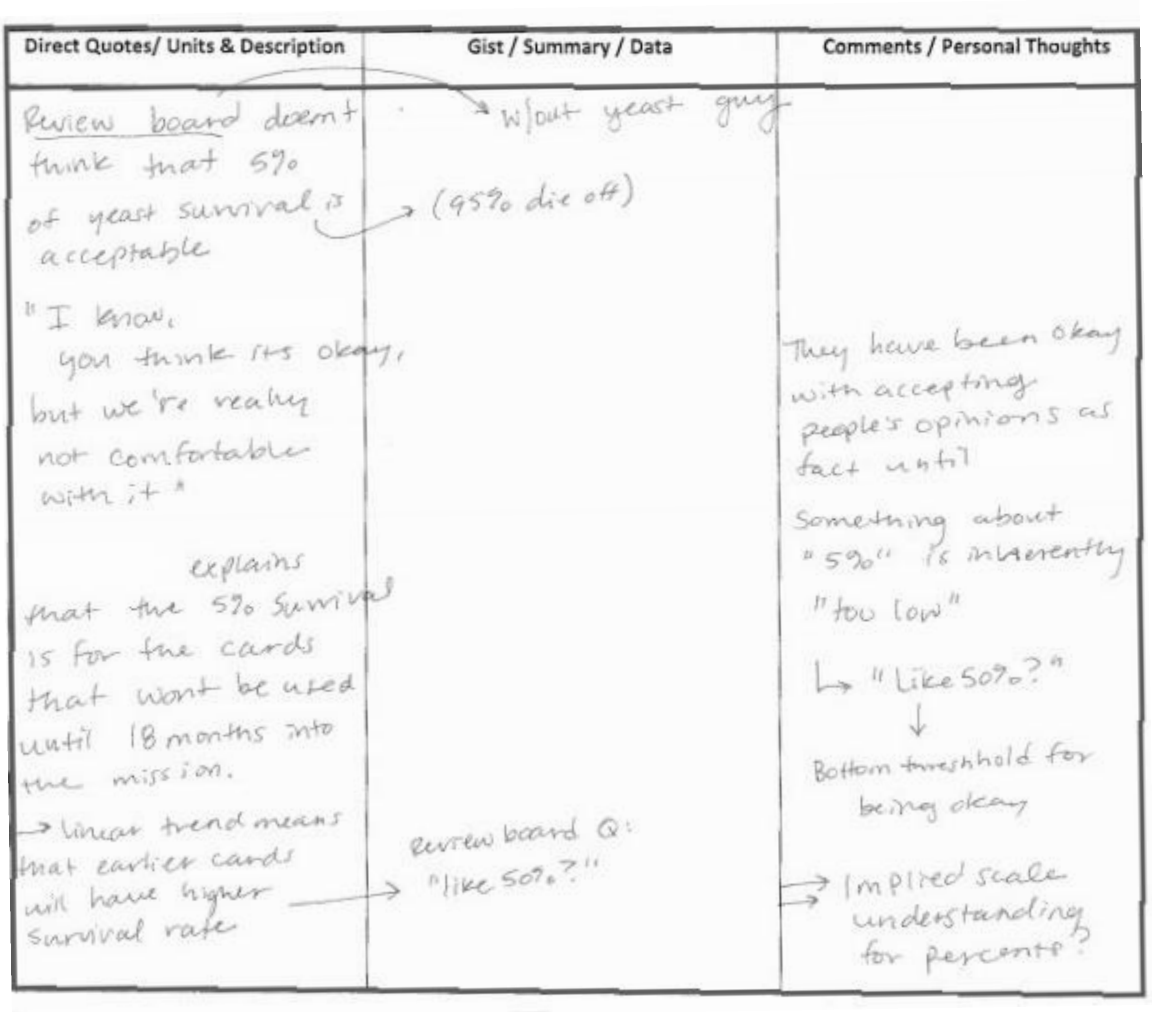
Another method the engineers used to explain scale was to compare objects in one scale to objects of another recognizable scale. These comparisons did not mention any specific units or scales and were very rare (only three “COMPARISON” code occurrences). All three comparisons dealt with size as a parameter and two of them compared the object described to a human or human appendage (e.g. a microfluidics card is shown to be the size of a human hand). One comparison related one piece of equipment to a previously discussed unit, saying, “For scale, this [piece of equipment] is approximately the same size as the Prox-1 Flight Unit.” These results (as well as the above discussion of personification) note that the most recognizable size scale for the audience was that of a human, both via direct comparison or by using it as a metaphor. Parameters associated with personification and comparisons were typically unusual or complex such as solar torque, yeast growth rate, radiation, solar particle count, payload heat transfer rate, and value variance.

During scale explanation events (comparisons and personifications), use of common scale delineation methods (e.g. mentions of specific units or parameters) was significantly reduced. The largest difference was in mentions of units, which occurred in only 18% of scale explanations, as opposed to in 52% of all scale references. In contrast, the code “NO UNITS” was used in 83% of scale explanation occurrences (as opposed to in 34% of all codes). This means that when a visual, personification, or comparison was used to portray scale it was usually used without (or in place of) units. Other forms of scale delineation were also less common, with only 51% of scale explanations containing a parameter code (as compared to 80% of all scale references).

In a similar pattern, scale explanation tended to be accompanied by less specific forms of value portrayal. In every instance of scale explanation where a numerical value was mentioned, less than two significant figures were used. There was also a slight increase in estimates and implications during scale explanation (26% of scale explanations had estimates/implications, as opposed to 20% of overall). Finally, only 37% of scale explanations had any value portrayal tags (“SIGFIG,” “ESTIMATE,” or “IMPLICATION” codes) as opposed to 65% of all items coded.

Percent as a Comparison Scale:

Examining personification and comparison as scale explanation techniques showed that units of ‘percent’ were often used in a similar way. Percent scale was used commonly (had second-highest frequency of use after degrees Celsius) and often coincided with explanations and numerical values portrayed with few significant figures. Percent was also used in place of many other units, e.g., “Previous crates have leaked 1-1.5% [of total pressure] per year,” where percent loss is used instead of pressure loss. Percent scale was involved in the only breakdown of scale understanding that occurred in the entire study (shown in field notes excerpt on next page) in which the number of yeast surviving after 18 months was conveyed as a percent. Some things to note are that 5% is considered too small to be acceptable (Review board: “We’re not really comfortable with it”), and that 50% is considered “acceptable” (Review board suggests “Like, 50%?” when told that the survival rate will be higher for earlier sample cards).



Direct Quotes/ Units & Description	Gist / Summary / Data	Comments / Personal Thoughts
Review board doesnt think that 5% of yeast survival is acceptable	→ W/out yeast guy → (95% die off)	
"I know, you think its okay, but we're really not comfortable with it"		They have been okay with accepting people's opinions as fact until Something about "5%" is inherently "too low" ↳ "Like 50%?" ↓ Bottom threshhold for being okay
explains that the 5% survival is for the cards that wont be used until 18 months into the mission.		
→ linear trend means that earlier cards will have higher survival rate →	review board Q: "like 50%?"	→ Implied scale understanding for percent?

Field Notes Excerpt: Shows breakdown in scale understanding of review panel during discussion of percent yeast survival.

Desirability Descriptors (Acceptable vs Unacceptable Values):

Out of 169 references to scale parameters (“PARAMETER” code occurrences) roughly one fifth were accompanied by a desirability descriptor (35 “ACCEPTABLE” and “UNACCEPTABLE” codes). When using descriptors, acceptable values were more likely to have their desirability more subtly implied whereas for undesirable or unacceptable values it was usually directly stated. Of the 16 instances of "ACCEPTABLE" code occurrences, slightly less than half (7/16) were directly stated. For example "In the beginning [of the mission], we have a pretty nice data rate" or "As the bus (satellite) gets farther away, the angle [to transmit data] gets better." The other nine occurrences of desirability being communicated were all implications using tone of voice, context, etc. such as "[Measurement] error is *very* low." Approximately the same number of "UNACCEPATBLE" code occurrences (marking an undesirable/unacceptable value) were found as "ACCEPTABLE" code occurrences (19 "UNACCEPTABLE" occurrences) but less than a third of these (5/19) were implied. The majority of unacceptable value occurrences (10/19), however, were directly stated as such (e.g. "If the [temperature of biology compartment] exceeds 50 °C it would be a bad day for our science colleagues"). Two "UNACCEPTABLE" descriptor occurrences involved implication via a direct comparison to an acceptable value to show the undesirable value's difference from it, e.g., "[Signal disruption] noise is three times greater than the signal." This difference between implied and directly stated desirability of acceptable and unacceptable values implies that if a value is unacceptable it will be directly labeled as such, whereas if it is acceptable it is more likely that this will merely be implied. A comparison of desirability descriptors to supporting project details found the former were more likely when an important subject was being discussed as 34% of 'IMPORTANT' coded items also included a desirability descriptor compared to 20% of all parameters. In addition, indications about desirability were found to be slightly more likely to be found in questions and explanations and slightly less likely to be found when discussing requirements, but by too small a margin to be considered significant (23% of “QUESTION” and “EXPLANATION” codes, and 17% of “REQUIREMENT” codes).

DISCUSSION:

The results presented in the previous section outline several patterns in the communication of scale by engineers in a multidisciplinary setting. These trends have various implications for the field of engineering education and the manner in which engineering students are taught to communicate scale in a professional setting. Overall, this study has shown that engineers tend to assume a high level of scale understanding and familiarity from other engineers, even in large multidisciplinary project settings.

The engineers studied used value portrayal that was surprisingly imprecise throughout the presentation. Only half of the engineers’ value portrayal contained numerical values of any kind, with the rest composed of estimates or implied values. In fact, about one fifth of the scale delineation references did not have any value portrayal attached to them whatsoever. This gap shows that scales themselves are sometimes used as a demarcation of values; for example, “volume in cubic centimeters” was assumed to be of medium size when discussing a piece of hardware for the satellite. The exact, estimated, or implied value of the volume was never mentioned, but it was assumed not to be too large or too small. Along the same lines, it is a general convention not to use scales for measurement of values that would have over four digits if there is another equally easy way to use scale (e.g. listing an item as 7,400 mm rather than 7.4 m). This means people tend to assume that if a scale is being discussed, there won’t be any values greater than 10^3 or smaller than 10^{-3} of that scale, which gives even a scale alone an (admittedly wide) range of inferred values without even mentioning them. If this range is sufficient, then perhaps it is not always necessary to describe the value further.

When engineers did use high-precision value portrayal, it was usually to outline a project requirement or a topic of importance (e.g. extra discussion time, emphasis on clarification). This is most likely because when discussing project requirements, an exact value is an absolute benchmark and therefore deserves special emphasis. For example, “3.35 volts are required [for a specific section] due to the addition of an amp regulator,” denotes that less than 3.35 volts is insufficient, which is important. In contrast, value portrayal was much less specific when the engineers were asking questions or providing explanations. This is most likely because when questions and explanations occur in discussion their topic is usually related to the engineering design methods, assumptions, or equipment associated with a given value rather than being pointed specifically at the value itself. For example, “Can the bus [satellite] keep that unit cold enough?” is directed toward the heat transfer ability of a section of the satellite, the number is not important; merely that it is not too hot. These findings are of importance to engineering educators because teaching students to use value portrayal that is too specific or too vague for their desired situation could result in students failing to adequately communicate values. For example, they might not include enough precision when important to do so or could overcomplicate questions and explanations with unnecessary significant figures.

Another area where the engineers tended to assume a high level of audience familiarity with scale was when describing the desirability of various values. For most of the parameters in the presentation, the audience was expected to infer whether a value was acceptable or not purely based on value portrayal methods and their background knowledge of the project requirements/scale being used. This finding is of significance to engineering educators because if students are to succeed in these types of settings they must have not only a strong knowledge of typical scale values and precision, but also whether or not a value should be considered acceptable or not given the context of its discussion. Analysis of the situations in which value desirability was communicated by the engineers showed that if a value was described as acceptable its desirability was usually implied rather than directly stated. If a value was unacceptable, this was usually stated outright. Considering the context of a 90% design review presentation there should have been very few unacceptable parameter values mentioned at all. Most problematic values would have been remedied or redesigned and any that remained deserved direct verbal emphasis. It stands to reason that most of the values that received no desirability descriptor were acceptable but, given the late stage nature of the presentation, were not addressed. In a presentation with more unacceptable values discussed, more desirability descriptors may have been found.

Finally, the engineers studied used scale explanation techniques in less than 15% of all scale references. This unexpectedly small number of scale explanations has huge implications for engineering education because it indicates that for most situations and scales there is an assumed basic understanding by all members of the audience/presentation group which forgoes the need for scale explanation. If this is the case, engineering educators must be sure that students are equipped with a solid understanding of a multitude of scales because they will be expected to know (for the most part) how to use them with very little explanation.

In addition to understanding scales that are not explained, engineering students will need to know how to explain the few scales that are unclear to their audience using techniques such as personification and comparison. Analysis of scale explanation events shows that personification tends to occur when the units for a particular process are complicated (e.g. mass transfer) or the process is happening at an unfamiliar scale (e.g. very small). Both personification and comparison use traits from human scales to help comprehend objects and processes in uncommon or hard to understand scales. This is a rudimentary strategy and its simplicity is compounded by the fact that both value delineation and scale descriptions are much less precise, if used at all, when personifying or comparing objects in a scale.

All the traits and usage patterns of a comparison scale (loss of value and scale description, use in explanations, use in place of complex or rare units) were found to describe the usage patterns of percent (%) units. This led to the classification of percent as a comparison scale, which ranges from 0 to 100 and can be used to compare any two values from another scale. Percent was one of the most frequently occurring units and was shown to have an existing range of relative high and low values which most people were familiar with. For example, not everyone would have known how many kilopascals of pressure constituted a large leak, but when expressed in percent it was no longer necessary to explain the units as well as the values, since 1% is generally considered to be low. In this sense percent is a very useful comparison scale since it is common, easily recognizable, and can transform troublesome units into easily recognizable ratios. Analysis of the breakdown in understanding of the percent scale described in the results section provided information on which values are considered high, low, acceptable, and unacceptable. For the engineers studied, 5% was considered low, and 50% was considered an acceptable value in the scale. This gives an idea of the predisposed value hierarchy that is established for the percent scale, as well as what engineers will assume given a random value on the scale. In turn, this means that while using the percent scale gives the advantage of not needing to explain a complex unit value, it may require additional explanation if the desired meaning of the percent value falls outside the conventions of the scale.

Overall, the de-specifying of value and scale descriptions, as well as the use of personifications and comparisons to human and percent scales seems to imply that for engineers, specific values and units are not useful to explaining actions and objects in uncertain scales. Engineering students should be taught to explain complex scales as well as how to differentiate between scales with assumed audience understanding versus scales that require explanation.

CONCLUSION:

Based on the analysis of field note data taken from a design presentation by a multidisciplinary group of NASA engineers, various patterns regarding the communication of scale were discovered. These patterns can be used to make generalizations about how engineers communicate scale across disciplines in a presentation format. One aspect of scale communication studied was how engineers present values with different levels of precision. The study also shed light on how these levels of precision were used to delineate importance, project requirements, or to ask questions and provide explanations. Another set of findings were centered on how engineers explain various scales that are complex, unfamiliar, or otherwise difficult to understand. This finding focuses on various scale explanation techniques, when they are used, and how frequently. Special emphasis was placed upon comparison scales, which can be used to explain other scales and typically have widely understood values. Finally, the study examined how scale values are portrayed as being desirable or not, with emphasis on when desirability is explicitly communicated to the audience rather than implied.

The knowledge gained in this study can be used to supplement a myriad of other research projects in the field of engineering education. One possible follow up study would compare how engineering students present scales in classroom design presentations to the communication habits of professionals. Another potential educational application of this information would be to help refine the way that professors present scales in educational lectures. This would be valuable because a classroom setting is where most students will be likely to learn scale-communication skills. The results of this study may also tie in with several other studies which have observed teacher-student interactions at many grade levels, including analysis of teacher-student communication (Dobransky, 2008) (Smart, 2012). Overall, the results of this study will provide a baseline upon which other research can expound and can also be used in their current form to help engineering educators develop and assess the communication skills of engineering students.

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APPENDIX:

Definitions of Frequently Used Terms:

Term	**Definition**
Context	The surroundings, situations and persons which contribute to the meaning and structure of language
Cube Satellite	Small autonomous satellite with a specific mission or purpose, not designed to return to earth after the mission's completion
Field	Dimension of context describing the topic of language created
Field Note	Ethnographic data collection technique in which an observer records data relevant quotes, inferences, and descriptions of subject behavior during observation
Mode	Dimension of context describing the setting and vehicle for language (e.g. spoken vs. written, formal vs. informal)
Scale	conceptual system used to arrange, measure, or quantify events, objects, or phenomena
Scale Event	Mention of scale reference that triggered notation in field notes
Tenor	Dimension of context describing the relationship between the language speaker and the audience/recipient of the language
Value	A quantity measured using a scale (e.g. 5 meters)

Field Note Jotting Template:

See next page.

Topic/Slide #	Unit	Description	Interpretation	Comments