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Undergraduate Engineering Students' Use of Metaphor in Presenting Prototypes to a Technical and Non-technical Public Audience

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Abstract

In undergraduate technical courses, instructors commonly infuse their teaching with metaphors, analogies, and similes to connect new concepts with students’ existing knowledge base. This pedagogical approach has been shown to be effective in a variety of fields, including engineering. Similarly, professional engineers translate complex technical concepts and data in accessible ways when communicating with a variety of non-technical audiences, and a useful strategy involves the use of metaphorical language. However, undergraduate engineering students are rarely taught how to craft lay-friendly metaphorical explanations, despite universities’ ongoing efforts to prepare students for the communication demands of the workplace. Previous studies have examined students’ use of figurative language in heavily guided metaphor production experiments, as well as during student interviews with researchers. However, there is a gap in the literature concerning undergraduates’ metaphor use in their original texts. To better understand engineering students’ use of metaphor, this study identified and analyzed the metaphors spoken during fifteen mechanical engineering product launch presentations, which were delivered at the Massachusetts Institute of Technology (MIT) from 2013-2017 to a diverse technical and non-technical public audience. The presentations contained the following metaphor types in order of frequency: personification, perceptual metaphor, metonymy, analogy, nonperceptual metaphor, and simile. The majority of metaphors were spoken while students demonstrated their product and explained technical concepts and components to the audience. The students’ metaphors also attempted to enhance the audience’s perception of specific product attributes, such as comfort, reliability, efficiency, and safety. However, across all of the presentations there were instances of technical concepts that were not translated, and six of the fifteen presentations contained no metaphorical explanations of technical content. This suggests an opportunity for pedagogical guidance on ways to generate accessible metaphors while preserving technical accuracy. Educating undergraduate engineers to become effective and creative translators for diverse audiences could help improve students’ readiness for the workplace, as well as strengthen future scientific literacy among the public.

1. Introduction

In the article, "The Desire to Tell a Story," author and educator Roger Rosenblatt begins with the following claim: "Horses run, beavers build dams, people tell stories" [1]. Rosenblatt's triplet employs the rhetorical device of implicit comparison to link three seemingly different animals and behaviors. As with any comparative statement, the trio of images requires the reader to work out the linkages in order to determine the underlying meaning of the claim. This work might include thinking about why horses run and beavers build dams, perhaps defining these behaviors as instinctual and related to safety, sustenance, and survival, and concluding that humans tell stories in a similarly instinctive manner for similar purposes. In a world where at least one metaphor is uttered in every twenty-five words of speech [2], [3], we perform this type of interpretative work constantly, rapidly, and unconsciously, often unaware that we are doing any "work" at all. For instance, when a dear friend who has been diagnosed with cancer tells us that he doesn't have "much time left," many of us will interpret the metaphor without hesitation as a story of impending death. Rather than consciously searching for possible connections between our friend's identity and a quantifiable concept of time (i.e. time as a possession that can diminish), we intuitively grasp the severity of our friend's statement. Moreover, we might not even recognize the phrase "much time left" as a metaphor at all, and instead interpret the words as though they were any literal statement whose meaning is utterly obvious within its given context.

Generating and interpreting figurative statements, which often involves connecting related or disparate people, objects, phenomena, ideas, and attributes, remains central to storytelling in a variety of contexts, including education. As educators, much of our work involves telling stories about ideas, facts, theories, and experiences to help our students acquire knowledge. Particularly in undergraduate technical courses, instructors commonly infuse their teaching with metaphors, analogies, and similes to connect new concepts to students' existing knowledge, and this pedagogical approach has been shown to be effective in a variety of fields, including engineering [4]–[10]. However, while students may acquire technical knowledge through their teachers' use of creative explanations, and may be influenced by the frequent use of metaphor in popular science and technology articles [11], students are rarely taught how to formulate their own creative explanations to educate their present and future audiences in academia and industry. Anecdotally, this type of explicit instruction occurs most often in designated writing courses (e.g. [12]) rather than in technical subjects, yet the latter may expect students to produce original texts involving complex science and technology for audiences with varying levels of expertise. Similarly, professional engineers are expected to communicate orally with non-technical audiences in a variety of rhetorical situations, which requires the translation of engineering concepts, data, and developments [13].

Beyond professional expectations, the societal implications of how experts communicate with non-technical audiences are too significant to ignore. In this time of ongoing discord between scientists, policymakers, and the public, the ways in which scientists communicate with those outside of their profession is critical to improving scientific literacy [14], [15]. As Chan [16] argues, "In order for the lay public to shape an informed opinion of scientific discoveries and controversial developments, it is critical that scientists can communicate about research and the implications of that research to promote awareness, clarity, as well as to respond to public concerns. These are the abilities that are lacking amongst many new science graduates."

Currently, there is a dearth of research regarding undergraduate students' creative explanations in their original communications to diverse audiences. Although some studies have examined student-generated metaphors in heavily-guided "fill-in-the-blank" metaphor production experiments (e.g. [17]), as well as in student interviews with researchers (e.g. [7]), I have been unable to locate a study that has identified and analyzed undergraduate engineering students' metaphorical explanations in their original oral texts. To better understand the extent to which undergraduate engineering students use creative explanations in their attempts to educate, persuade, and engage audiences, this study examines the presence of metaphors in undergraduate mechanical engineering students' oral presentations. Specifically, this study explores the oral communication in fifteen prototype launch presentations delivered from 2013 through 2017 as part of a product design capstone class at the Massachusetts Institute of Technology (MIT). The aims of this study include: 1) to identify specific metaphors communicated by engineering students in hopes of beginning a corpus of student-generated metaphors; 2) to analyze the rhetorical goals of these metaphors; and 3) to inspire discussion about pedagogical opportunities and challenges to educate engineering students about the use of effective translation techniques, such as metaphor, within engineering courses that require students to communicate technical information to specialized and non-specialized audiences.

2. Understanding Metaphor

2.1 Defining metaphor

Broadly defined, a metaphor is a "non-literal similarity comparison" [18] that relies on figurative language to interpret "a thing or action through an implied comparison with something else" [7]. For example, the metaphor "the mind is a computer" establishes a figurative connection between the human mind—a relatively abstract entity—and an electronic computer, which, although complex, is far less abstract than the brain. In this example, linguists would refer to "the mind" as the *target* of the metaphor, and the "computer" as the *base* [3]. Knowledge can be transferred from the base to better understand the target, a process sometimes referred to as *mapping* knowledge from one domain to another [7]. For instance, we might transfer certain attributes of a computer—storing memory, recognizing patterns, responding to inputs, and requiring an energy source—as a means of understanding the human brain.

The implied transference of specific characteristics from one knowledge domain or object to another is the core ingredient of metaphors, differentiating them from literal similarity comparisons. As defined by Gentner [18], a literal similarity comparison is when "there is considerable overlap both in the component objects… and in the relations between those objects." One example Gentner supplies is: "The helium atom is like the neon atom." In this case both objects—the target (helium atom) and the base (neon atom) exist within the same literal domain of atomic structures, and so the comparison is not a metaphor. However, if one were to state that "the helium atom is a bouncing rubber ball," or even "the helium atom is *like* a bouncing rubber ball," the respective metaphor and simile reach across different knowledge domains—atoms and rubber balls—to create a nonliteral similarity that shapes our understanding of the target (helium atom). Ultimately, metaphors imply that certain qualities of the base are associated with the target [3], which propels the audience to perform the cognitive work needed to transfer specific qualities from one object to another [19].

In making sense of a nonliteral comparison, "people implicitly focus on certain kinds of commonalities and ignore others" [18], which produces a generative process within the audience. For example, when we hear about the various "skins" we can purchase to protect and stylize our mobile phones, we likely think of a product that fits seamlessly around our phone rather than a product that will get goose bumps when it is cold. Similarly, in the aforementioned "the mind is a computer" metaphor, most readers will not transfer all of the known characteristics of a computer, such as the screen, keyboard, and plastic parts in relating to the human brain. Instead, we perform selective work by transferring specific characteristics that can contribute to our understanding of brain, and in turn, enable us to determine the meaning of the metaphor.

2.2 Metaphor and the brain

This selective work performed by an audience when encountering figurative language, such as a metaphor, is an ongoing area of interest in the field of brain and cognitive science. Neurological studies seek to understand how the brain processes figurative language, including metaphors. Leveraging advancements in neuroimaging techniques, such as fMRI (functional magnetic resonance imaging), researchers are able to visualize in real-time the most active parts of the brain when a person is presented with a figurative statement in comparison to a literal statement. In a meta-analysis of 354 subjects across 22 fMRI studies, Bohrn et al. [20] found that processing metaphors requires greater brain activity than literal statements. The researchers found that understanding and determining the meaning of metaphors activates "a broad associative network," specifically in the left hemisphere of the brain [20]. This evidence of the cognitive investment required by an audience to process a metaphor lends credence to the understanding of metaphor as a "force to generate bridges" [21], due to its ability to inspire audiences to willingly contribute cognitive effort to the formation of meaning.

This cognitive investment suggests a possible rationale for the memorability of metaphorical explanations in communication. Paradoxically, although metaphors are nonliteral and require greater cognitive effort, they can provide a remarkably accessible path for many people to learn and remember technical information and concepts [11] (though research has shown that individuals on the autism spectrum, including those with Asperger's Syndrome, tend to find metaphors more difficult to understand than literal statements [22]). Conversely, while successful metaphors are convenient to ingest for many audiences, the circuitousness path of nonliteral expressions makes them challenging to produce effectively. Thus, while students may readily absorb an instructor's metaphorical explanations when learning a subject, students may find it difficult (or not even grasp the value of attempting) to generate metaphors in their own original oral and written texts.

2.3 Social implications of metaphor

While the language of a metaphor is figurative, the resulting impact of metaphors on our understanding, perceptions, and behavior is very real. Rather than viewing metaphors as mere poetic fluff, the notion that the metaphors we speak reflect the "metaphors we live by" (i.e. how we formulate thoughts and perform actions) has become the dominant thinking among cognitive scientists, linguists, psychologists, philosophers, literary critics, and composition and rhetoric scholars [3], [23]–[26]. Indeed the understanding of metaphor as more than an aesthetic tool can be traced back to Aristotle, who remarked in *Rhetoric*, "Midway between the unintelligible and the commonplace, it is metaphor which most produces knowledge" [27] ctd. in [26].

In the seminal book, *Metaphors We Live By*, cognitive linguist George Lakoff and philosopher Mark Johnson describe "conceptual metaphors" that are so embedded in our culture and consciousness that they are "reflected in our everyday language by a variety of expressions" [23]. In other words, while conceptual metaphors themselves may remain unspoken or rarely spoken, they are communicated implicitly through the metaphors used in daily life within a given culture [28]. Examples include the conceptual metaphors "Ideas are food" and "Time is money" [23], which inspire a variety of more commonly spoken metaphors, such as "stale ideas," and "saving time". Lakoff and Johnson provide the example of "ARGUMENT IS WAR" as a conceptual metaphor from which various metaphorical expressions have emerged, such as "[Her] criticisms were right *on target*," "He *shot down* all of my arguments," and "You disagree? Okay, *shoot*!". These expressions are not mere aesthetic flourishes. Instead, they reflect our way of thinking about argument as war, which in our culture "is the *ordinary* way of having an argument and thinking about one" [23]. Although wars and arguments are literally different from one another, Lakoff and Johnson claim that "ARGUMENT is partially understood, structured, understood, performed, and talked about in terms of WAR" [23].

As a thought experiment, Lakoff and Johnson ask us to imagine how different our everyday expressions would be if the conceptual metaphor "ARGUMENT IS WAR" had been replaced with "ARGUMENT IS DANCE" [23]. With this re-envisioned conceptual metaphor, the argumentative move of a "counterattack" might be referred to and thought of as "a pirouette." Similarly, we might describe another move during an argument as "altering the melody" or "creating a parallel structure," while moments of agreement might be described as "harmonizing" with the other "dancer" or "partner," as opposed to agreeing with an "opponent." As referenced in section 4.3 of this paper, engineers think and express themselves in terms of war-based metaphors, as product designers communicate how they plan to *target* a specific demographic, and *capture* a percentage of those *target* users.

2.4 Categories of metaphor

In this study, the term "metaphor" is used broadly to refer to many metaphorical forms of nonliteral similarity comparison. In addition to the aforementioned definition of metaphor (section 2.1), this study examines the following subtypes of metaphor:

- *Personification* ascribes human drives, attributes, and behaviors to nonhuman entities, in order to "make sense of phenomena in the world in human terms" [23]. Examples include: "This *fact argues* against standard theories," "*Cancer* finally *caught up* with him," "The *past is taunting* her," and "The ideas in the book *gave birth* to a new approach."

- *Similes* compare one domain to another using the word "like." When similes make nonliteral comparisons they are considered a type of metaphor [29]. For example, "Lemons are like limes" is a literal similarity comparison, whereas the simile "His heart beat like a sledgehammer" is metaphorical [29]. The inclusion of "as" or "like" in similes is critical, as Stewart [30] writes, "A simile tells us what things are like, and leaves them as they are in our literal understanding. There is no transformation of our understanding of objects, no awareness of the different possibilities of standing, as there may be with metaphor."

- *Metonymy* occurs when one entity is used to refer to a separate entity associated with it [31]. For example, in the sentence, "The *Times* hasn't arrived at the press conference yet," the entity of the *Times* stands for the reporter from the *Times* [23]. Similarly, when a reporter says, "The White House has promised to veto the bill," the White House is a metonym for the president and his administration. Unlike other forms of metaphor, metonymies rely on *literal* similarity between the domains of the metonym and the entity it refers to. For this reason, Sapir [26] described metonymy as "the logical inverse of metaphor… [with] two terms that occupy a common domain but do not share common features."

- *Synecdoche* is a specific type of metonymy, in which one part of an entity represents the *entire* entity [23]. For example, in the sentence "We need some *more hands* on the project," *hands* refer to *people*.

- *Analogy* is a broad category encompassing any figure of speech involving a comparison of domains [32], and therefore, metaphor is "a species" of analogy [3]. Readers of this paper who completed the SATs (Scholastic Assessment Test) in the U.S. prior to 2005 are likely familiar with the extended analogy form of one comparison juxtaposed with another (*a* is to *b*, as *x* is to *y*). Most often, we encounter analogy as a form of reasoning ("analogical reasoning") aimed at persuading an audience. For example, a common refrain in U.S. political campaigns involves variations of the following analogy: "My opponent is a Democrat, and Democrats raise taxes. I'm a Republican, and Republicans don't raise taxes. So vote for me and I won't raise your taxes!" In engineering, analogical reasoning is a common strategy during the design and iteration process. Analogical reasoning, "a form of inference that allows us to derive implications from single cases even when we do not know all the factors involved," enables engineers to make comparison-based predictions [33]. For example, when selecting materials and equipment for new aircraft, U.S. Air Force engineers follow a comparative analysis procedure, which involves identifying materials used in existing aircraft and other contexts to justify their selection decisions [33]. Novice designers, including undergraduates, often follow a similar process. During one of the undergraduate presentations examined in this study, a student justified the choice of a particular type of cable in their product by stating that the cables "are the same type as used in bikes," in order to emphasize their reliability and durability.

Delving deeper into the specific content of metaphors reveals additional categories of metaphor that intersect with the aforementioned subtypes, including the following:

- *Perceptual metaphors* connect entities in different domains that share physical properties [34]. For example, in the simile "the clouds look like a patchwork quilt," the physical property (i.e. appearance and perhaps even assumed texture) of a patchwork quilt is mapped onto the clouds. Another example can be found in The Beatles' song, "Lucy in the Sky with Diamonds," in which John Lennon sings of "a girl with kaleidoscope eyes." In Lennon's lyric, the physical properties of a kaleidoscope (i.e. colors, movement, and light) are mapped onto human eyes. Likely due to their connection with the material world, children as young as five years old have been shown to comprehend perceptual metaphors as well as adults [34], and perceptual metaphors are often the first type of metaphors spoken by children [35] ctd. in [34].

- *Nonperceptual metaphors* are based on similarities across domains that cannot be experienced by our senses, yet function in a similar way [34]. For example, branching off from the conceptual metaphor "the mind is a machine," in a moment when I'm performing below my expectations I might say: "My gears are moving slow today." This nonperceptual metaphor, also referred to by Lakoff and Johnson as an *ontological metaphor*, enables an audience to view my non-physical emotional state as a physical entity [23]. This example can also be categorized as a *psychological-physical metaphor*, one of the most common forms of nonperceptual metaphor, in which "physical attributes are used to refer to psychological states" [34]. Since nonperceptual metaphors are based largely on our existing knowledge of physical objects, young children have a more difficult time comprehending nonperceptual metaphors in contrast to perceptual metaphors [34].

- *Orientational metaphors* ascribe spatial orientation to a concept based on culturally-dependent associations with up-down, in-out, front-back, on-off, deep-shallow, central-peripheral [23]. For example, the conceptual metaphor "happy is up" [23], deeply rooted in Western culture, inspires a host of related orientational metaphors, such as: "I'm feeling really low these days," "Hiking gives me a natural high," "She is so uplifting," "He's a downer," "Their contributions brought the conversation to new heights," and "After sleeping I'm functioning at a high level."

- *Lexicalized metaphor*s are metaphors that appear "as familiar and sensible as literal language" [19]. Examples include: "kick the bucket", "a shooting star", "romance is dead", "a kind heart", "a warm person", "they fell in love," and "time is money." Akin to clichés, lexicalized metaphors are so common and entrenched in a given culture that they become sources of "polysemy—they allow words with certain specific meanings to take on additional, related meanings… For example, consider the word *roadblock*. There was presumably a time when this word referred only to a barricade set up in the road. With repeated use as the base term of metaphors such as *Fear is a roadblock to success*, however, *roadblock* has also come to refer to any obstacle to meeting a goal" [3]. Lexicalized metaphors also contribute to the frequent use of metaphors as verbs in everyday communication: "A common example is the use of 'fell' in the sentence: 'He fell in love.' Lacking a word to express the thought underlying this utterance, the verb "to fall" is used metaphorically to refer to entering the state of being in love" [24].

2.5 Metaphor in engineering

The success of undergraduate students and professionals around the world is becoming increasingly dependent on more than technical expertise. Largely in response to industry needs, written and oral communication has been identified as a critical area for undergraduate engineers, and accreditation boards and universities recognize the need to continue developing curricula that prepares students for a profession filled with communication opportunities [13], [36]–[38]. To address this challenge many universities are working to strengthen engineering students' communication knowledge and skills through institution-wide initiatives (e.g. [39]), departmental-wide pedagogical shifts (e.g. [40]), and experimental class-specific interventions by instructors.

The majority of oral communication interventions described in the literature primarily aim to instill conceptions of professionalism [41], guiding students in areas such as presentation delivery (e.g. [42]), slide design (e.g. [43]), rehearsal and revision (e.g. [44]), and peer review (e.g. [45]). Amidst this body of published work there are scant efforts to improve engineering undergraduates' knowledge of how to present technical concepts effectively to diverse, lay audiences. As a caveat to this claim, it is important to acknowledge that instructors are engaging in novel oral communication interventions that are not shared in scholarly publications. In addition, there are initiatives in the literature that imply that engineering students are engaging in oral communication with nonspecialized audiences, though the details of these communication activities and any associated pedagogy are not described explicitly. For example, students in the Engineering Ambassadors Program at Manhattan College prepare engineering-related lesson plans and present them to middle and high school students [46], which likely involves some degree of translating technical concepts. Another example includes a University of Queensland course that brings together undergraduate engineering and journalism students to collaborate on a multimedia design and communication project, which involved interdisciplinary communication among student teams [47]. However, in these types of examples the specific ways in which students communicate with nonspecialized audiences using rhetorical devices such as metaphor, along with any associated pedagogy in this area, is not described, as other pedagogical goals and outcomes are emphasized. Ultimately, the literature reveals a gap in educators' understanding of engineering students' rhetorical abilities, along with a corresponding lack of widely-practiced pedagogical approaches that prepare undergraduate engineers to translate technical information to diverse audiences.

Despite these gaps in the literature, the value of using metaphor to translate technical engineering concepts for nonspecialized audiences is increasingly visible in the world of professional engineering. Research has shown that metaphors are used intentionally by professional engineers in the workplace and academia for ideation [32][46], design [7][29], iteration [33], teaching students about technical engineering concepts [4][7][10][21], and communicating with fellow engineers, other scientists, government agencies, and the public [11][16][28]. The preponderance of evidence that "metaphors are necessary and not just nice" [49] in the world of professional engineering further supports the value of assessing students' translation abilities, and exploring pedagogical approaches that teach students how to generate and use metaphor effectively when communicating technical information to diverse audiences.

3. Methods

3.1 Presentation context, audience, and purpose

In the senior capstone course in the Department of Mechanical Engineering at MIT, eight student teams, each composed of 15-20 students, invent, model, test, and build an alpha prototype [50]. The lead faculty member prescribes several design milestone presentations, though the student teams are self-directed: students brainstorm and invent original product concepts and lead their own weekly meetings. Each team elects two students to be system integrators (SI), who convene meetings, coordinate agendas, and work to share knowledge among various task forces. Other students are elected to serve in the roles of safety, information, tool, and financial officers. In addition to two lab instructors, a communication instructor is embedded within each team to provide feedback and suggestions before and after milestone design presentations. The capstone course is designated by MIT as "communication intensive," and each student is expected to participate in one milestone presentation throughout the term. At the end of the semester three to four students from each team present their final prototype at a large event on campus, akin to a product launch (Figure 1).

Figure 1. The final prototype launch event. The auditorium typically reaches maximum capacity of more than 1,100 in-person attendees. In addition, approximately 15,000 unique IPs accessed the live webcast in 2016.

The audience for the annual event is large and covers a wide spectrum from mechanical engineering professionals to members of the public. As defined in the course materials [51]: "The final project milestone is a formal presentation that is attended by the entire class, all instructors, course sponsors, and guests from product development firms." Students are asked "to prepare a polished technical presentation that is intended for a diverse, but educated, technical, non-technical, and business oriented audience." Each team is expected to demonstrate their prototype working on stage, which often serves as the narrative climax of the presentation. The suggested time limit for each presentation is 7 minutes, and presentations typically run between 7.5-10 minutes.

The event welcomes in-person and online attendees. The auditorium where the presentations are held each year typically reaches maximum capacity with more than 1,100 in-person attendees. In 2016, approximately 15,000 unique IPs (Internet Protocol addresses) accessed the live webcast [50].

In preparing their final presentations, students often watch recorded presentations from prior years. The course faculty encourage students to focus on the following information in their presentations: the core problem or need that the product aims to solve or fulfill, key design features, user experience, technical innovations, and a preliminary business plan to bring the product to users (Figure 2).

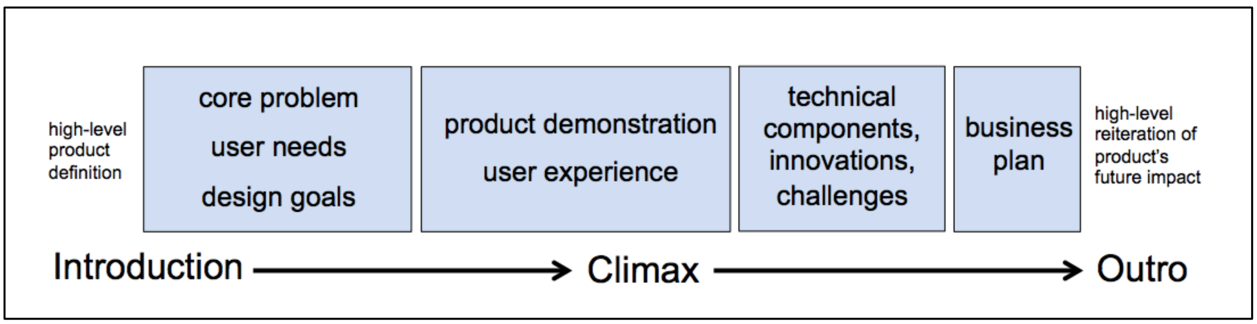

Figure 2. Approximate overview of presentation content and structure. While each team's product and specific presentation content is unique, the shared presentation objectives combined with students' access to previous examples result in a fairly consistent structure among most presentations. The width of the blue rectangles corresponds roughly to the amount of time dedicated to each section of the presentation.

3.2 Metaphor identification

The source texts for this study include fifteen final presentations that occurred from 2013-2017, all of which are publicly available online via the course website and the video-sharing website Vimeo [50]. This study focuses exclusively on students' oral communication, as opposed to visual slide content, use of props, and nonverbal communication within the presentations. Instances of metaphor were transcribed and categorized based on subtype (section 2.4), as well as rhetorical purpose.

4. Results and Discussion

4.1 Translating technical functionality with metaphor

The fifteen presentations contained the following types of metaphors, in order of frequency: personification (36 instances), perceptual metaphor (13), metonymy (9), analogy (5), nonperceptual metaphor (3), and simile (2). The complete list of metaphors spoken during the presentations is provided in Appendix A. Students employed metaphors most frequently during the more technical sections of the presentations, which included the product demonstrations and descriptions of technical components. For example, while demonstrating Animo, a wearable wrist device that uses vibrations to help reduce hand tremors, the presenter explained: "*Animo chooses* the optimal vibrational setting with the best results." Referring to "Animo" as performing the specific technical function, whereas in actuality the function is performed by specific components within the product, is an example of metonymy. The reliance on the product name conveys a sense of cohesiveness among the various parts within Animo. Moreover, personifying Animo as being able to "choose" characterizes an automated process in sentient terms, which imbues the product with life. Following the product demonstration, the presenter explains how the product works at a very high-level, stating that the vibration "*tricks* the brain into thinking that the wrist is already tremoring." This instance of personification ascribes human-like intelligence to the product via the ability to "trick" the user's brain. This reflects an attempt to translate a complex technical and physiological process in an easily digestible way using human terms.

Another example of translating technical material with metaphor occurred during the presentation of Rhino, a product for re-pointing brick buildings (re-pointing is the process of replacing weathered and decayed mortar from in between bricks to maintain a building's structural integrity.) In explaining the mechanical components in the product, the speaker describes "a guidance *fin* which *follows* along behind the bit to keep center within the joint." Using perceptual metaphor, the presenter compares a technical component that is unfamiliar to many in the audience with a more familiar structure that shares similar physical attributes—an anatomical "fin". This example also includes personification, as the guidance fin "*follows* behind the bit," as though the fin possesses the agency necessary to follow another object. These uses of metaphor aim to explain the structure and function of specific design elements in familiar terms.

The relative abundance of metaphors during the more technical sections, compared with the other sections of the presentations, reveals students' attempts to translate complex material for their diverse audience. However, the metaphorical translations mostly focus on translating very high-level design features and functionality, rather than internal technological components or underlying scientific concepts that enable the product to function. Although students' high-level translations are easy to digest for the public, the lack of depth might be hindering many in the audience from understanding the complexity and innovation within these products, and improving their scientific and technological literacy.

Moreover, despite many presentations containing metaphors in the technical explanation section, 6 out of 15 presentations contained no creative translations when sharing technical details. For instance, consider the following statements from several presentations: "[Our product] can deliver a shock of 120 Joules," "The first boost converter is more effective at low voltage charging, and the other at the high voltage charging," and "The geometry of the release [plug mechanism] makes it so that even a small force can actuate it, but it can still stay shut under even 30 pounds of string tension." While a portion of the audience will understand these explanations, without comparative explanations many non-experts in the audience could be confused about the purpose, significance, and proper interpretation of this type of information.

4.2 Describing use context and user needs with metaphor

During the introductory sections of the presentations students primarily described the use context, the problem that their product aims to solve, the user profile, and a high-level definition of the product. For example, during a presentation of TouchLess, a product that attaches to a bathroom stall door to make the stall door touch-free (i.e. motion-activated), the presenter declared: "Pathogens are *responsible* for two-thirds of healthcare related infections." In this metaphor, pathogens are personified as bearers of responsibility, an attribute that implies a sense of human-like consciousness and intent. This opening metaphor contributed to an introduction filled with pathos, attempting to generate fear and disgust among the audience to instill the severity of unhygienic conditions, and in turn, build support for a solution that enables humans to avoid touching bathroom stall doors.

Another example can be found in the introduction for Otto, an automatic braking system with the functionality to stop a longboard (an elongated skateboard used for transportation) as soon as the rider steps off the board. The presenters use personification to characterize the problem that Otto aims to solve: "*A runaway longboard* can quickly become a broken one." In this case, the problem with current longboards is that they do not stop when the rider gets off. As the introduction continues, the presenter again refers to "*the runaway longboard*." This personification evokes the human-like agency and uncontrollability of current longboards as being capable of running away. Similar to the prior examples, this metaphor attempts to convey an intellectual and emotional understanding of an unfamiliar problem for an audience of mostly non-longboarders.

Overall, the metaphorical explanations in the introductions demonstrated audience awareness, specifically the students' recognition that many in the audience did not belong to their product's target user group and were likely unfamiliar with the use context of the product, along with any associated problems and needs.

4.3 Lexicalized metaphors in preliminary business plans

In the closing sections of the presentations, presenters shared their preliminary business plans to bring their product to market. These closing sections featured the least amount of metaphorical explanation. This is likely due to the relatively brief amount of time devoted to these sections, together with the fact that information was very high-level and typically involved more accessible language of commerce. The majority of figurative language in this section comprised the use of lexicalized metaphors as verbs, such as the following statements: "The value proposition that we are *delivering* to our customers," "A steadily *growing* market," "We think we can *capture* 1% of this market in this first year," and "We plan to *grow* until we *capture* 0.2% of the market."

Amidst the ubiquitous use of such lexicalized metaphors, there was one instance of novel metaphor use. In the closing section of the TouchLess presentation, the presenter stated: "TouchLess *sends a message* to every single customer that *the restaurant cares* about hygiene and cleanliness." This statement contains personification with a lexicalized metaphor ("*sends* a message"), along with personification with metonymy ("the restaurant *cares*"). This metaphorical language aims to convey a sophisticated point, namely, that individual users will benefit from TouchLess through improved hygiene, and restaurant owners that purchase TouchLess will benefit from their patrons' enhanced sense of appreciation regarding the perceived owners' sense of concern for their patrons' well-being.

4.4 Endorsing the value of design decisions with metaphor

Among the metaphors used in the fifteen presentations, endorsements of value were the most common rhetorical goal. In the context of the students' presentations, "value" refers to the ways in which the product's design meets users' needs, involving issues of comfort, reliability, efficiency, safety, as well as how a design solves the users' problem. For example, a presenter of Revive, a portable cell phone-powered AED (automated external defibrillator), remarked: "Revive can *go places* that other AEDs can't, like in the glovebox of your car, on a family hike, or on the sports field." In the literal sense Revive cannot "go" (i.e. travel) anywhere on its own, and so the use of personification imbues Revive with the freedom of agency to travel everywhere, including on a family hike. This metaphorical statement endorses the value of portability—the key value proposition of the product—while differentiating Revive from "other AEDs."

Oftentimes, statements of value were embedded within attempts to educate the public about a technical feature using metaphorical language. For example, one team used a perceptual metaphor to tout the value of the discrete housing of their design. The presenter of Strum, an acoustic guitar attachment that digitally transposes a guitarist's playing in tablature form, stated: "Our current saddle contains six sensors and twelve wires in the space *about the size of your pinky*." The use of the perceptual metaphor ("about the size of your pinky") allowed the audience to compare two objects that share physical properties (e.g. size), in this case, comparing the less familiar object ("saddle") with the more familiar "pinky." In addition to translating a technical attribute in familiar, human terms, the statement is an endorsement of the product's discrete design, which does not interfere with the user's need to play the guitar with no physical alterations that would impact comfort and technique.

5. Conclusion

Metaphors attempt to make the unfamiliar familiar and the strange relatable by evoking imagery that connects with an audience in accessible, memorable ways. Although metaphors are widely used by undergraduate instructors, most students receive no explicit instruction on how to translate technical concepts for a diverse audience. In the presentations examined in this study, students exhibited an organic use of metaphor, primarily personification, in order to educate their audience and achieve rhetorical goals. Recognizing the lack of explicit pedagogy on creative translation, together with the imposed time limit of the students' presentations, the quantity of metaphorical translations of technical design features reflects an impressive effort by students to shape their communication for their target audience. However, six of the presentations contained no metaphorical translations of technical information, which, together with instances of technical material that was not translated, suggests an opportunity for explicit pedagogical guidance on ways to educate a diverse audience effectively while preserving technical accuracy.

Future interventions may involve pedagogical experiments aimed at providing students with authentic experiences in creative translation, such as a course in which students present their projects to several different audiences each with different levels of expertise. In part, the associated pedagogy could aim to make explicit the instructors' own use of metaphor during their teaching, which would enable teachers and students to engage in meta-discussions of the metaphorical language used in the classroom. Rather than viewing metaphors in the isolated context of the classroom, however, a challenge for any intervention will be situating creative explanations within the broader landscape of engineering discourse and society. Since metaphors reflect individual and cultural perspectives and values, emphasizing audience awareness, technical accuracy, and the ethical implications of generating and propagating metaphors will be useful. A pedagogical intervention could enable a future study in which undergraduate engineers are interviewed about their process of metaphor creation and rhetorical goals. In addition, the effectiveness of students' metaphors could be evaluated by surveying their target audience to gauge their comprehension of technical content presented with (and without) creative explanations.

The incorporation of creative translation interventions into undergraduate engineering curricula faces logistical and intellectual obstacles. For example, one obvious challenge to these types of interventions involves limited time and space within already bloated curricula. As Chong et al. [52] at the University of Toronto states diplomatically: "Our faculty's engineering calendar provides a fairly restrained argument for the benefits of immersion in the liberal arts." Building departmental support for creative translation work may also require a shift in our definition of "the professional engineer." For instance, oral communication preparation traditionally emphasizes skills associated with aesthetic definitions of professionalism [41]. However, the ongoing tension between science, policy, and the public suggest the need to expand our conception of professionalism in a way that includes the desire to improve scientific literacy among the public. STEM graduates undoubtedly will play a role in the future of science communication, and as engineering educators we should recognize our role in shaping this future. We can ask, "How will our students tell stories in ways that are meaningful for their target audience, whether they are communicating to colleagues, experts in related fields, potential investors, government agencies, the press, students, friends, or family?" At one extreme, a professional engineer may be able to speak about engineering concepts and developments only at an expert-level of complexity. Moreover, when asked about their work, the expert engineer may skip over the jargon entirely and simply utter: "It's complicated, you wouldn't understand." For non-experts, particularly the public, the stories told by this engineer will be confusing, intimidating, and potentially misunderstood. Such communication distances the audience from science itself, and denying the opportunity to learn about new topics and enhance scientific literacy. As Hartz and Chappell [53] argue:

> We've become a point-and-click society, rarely considering what goes on behind the screen. One school of thought says you don't need to know how a car's transmission works to make it go. True, of course, but this kind of limited thinking, when magnified to encompass larger issues, leaves individuals more bewildered and less powerful in shaping the course of their own lives. If, by habit, we come to prefer—and demand—simple constructions to complex questions, eventually we are bound to get incomplete and ultimately incorrect answers.

As educators, whether our individual focus is on teaching engineering concepts or engineering communication, we can contribute to the inevitable role our students will play in educating those outside of the academy. Such an effort might involve educating future engineers on ways to use deliberate, purpose-driven metaphorical language when communicating to specialized and non-specialized audiences.

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Appendix A: Metaphors spoken during fifteen student presentations (excludes many lexicalized metaphors)

Product: Animo, a wearable wrist device that uses vibrations to help reduce hand tremors.

- "*Animo chooses* the optimal vibrational setting with the best results." (Metonymy; Personification)
- "This stimulation… *tricks* the brain into thinking that the wrist is already tremoring." (Personification)

Product: Contour, an adjustable prosthetic socket using granular jamming technology for below-the-knee amputees.

- "These grains are able *to flow* around the limb forming a perfect fit over the leg." (Perceptual metaphor)

Product: GloveStop, a product to remove and dispose of laboratory gloves that reduces the risk of contamination.

- "With only *the footprint of a standard lab trashcan*." (Personification; Perceptual metaphor)

Product: Glow, an interactive yoga mat designed to help users learn new poses and techniques.

- "A new user profile stores calibration information, like John's height, that *the mat* will use to *tailor its instructions* perfectly to his own body proportions." (Metonymy; Personification)
- "Glow will begin its *teaching* routine." (Personification)
- "*Glow takes* the readings from these sensors." (Metonymy; Personification)

Product: Laser Kites, a game for children that brings the fun of laser tag to the magic of flying kites, where the user shoots an invisible beam of light to knock the opponent's kite out of the sky.

- "IR sensors are *hit* by the *blaster*." (Personification; Metonymy)
- "When the microserver rotates it opens *a claw*, and this releases a peg that is attached to the string." (Perceptual metaphor)

Product: Ollie, a therapeutic robotic otter companion for elderly patients with dementia.

- "Animals have a calming effect… they are very *grounding*." (Orientational metaphor)
- "Ollie is a *social robot*." (Personification)
- "Ollie *understands and interprets* the different ways you interact with him so it can respond in meaningful ways. So if you pet his belly he might *hug* your hand." (Personification)
- "Ollie's *dimensions were inspired by that of a baby* to evoke a caregiver impulse." (Analogy; Personification)
- "Capacity touch-sensing circuits that allow Ollie *to feel* when someone is touching *him*." (Personification)
- "A Linux computer *talks* to our boards." (Personification)

Product: Otto, an automatic longboard braking system with the functionality to stop a longboard as soon as the rider gets off.

- "*A runaway longboard* can quickly become a broken one." (Personification)

- "when the board is in its *resting* riderless state" (Personification)

Product: Petra, a rappelling device with a safety feature to prevent cavers and climbers from falling off the end of their rope.

- "In order to get down into the abyss, Austin will need to rappel hundreds of feet from *the mouth* of the cave." (Personification, Perceptual metaphor)

Product: Poseidon, a device that projects a laser at the bottom of a pool that moves at a swimmer's desired pace to assist with training.

- "Poseidon *taps into* that natural instinct by *competing with you, pushing you, making you faster*." (Personification)
- "We chose this setup because *it's often used in other laser-scanning* applications." (Analogy)
- "Much *like our athletes*, Poseidon is also *high-endurance*." (Simile; Personification)

Product: Revive, a portable cell phone-powered AED (automated external defibrillator).

- "Revive can *go places* that other AEDs can't, like in the glove box of your car, on a family hike, or on the sports field." (Personification)

Product: Rhino, a product for re-pointing brick buildings.

- "a guidance *fin* which *follows* along behind the bit to keep center within the joint" (Perceptual metaphor; Personification)

Product: Robin, a discrete wearable pin for people with hearing loss that gives them feedback about their speaking volume with vibration patterns.

- "We created Robin to *empower* those who are hard of hearing." (Personification)
- "Robin will *tell* you to speak up if you are talking too quietly in a situation with ambient noise." (Personification)

Product: Strum, an acoustic guitar attachment that transcribes the music played in a tablature format.

- "Tablature is a very powerful thing for guitarists because it *tells* them exactly where to put their hands to make a certain sound." (Personification)
- "Our current saddle contains six sensors and twelve wires in the space about *the size of your pinky*." (Perceptual metaphor)
- "The microcontroller contains detection algorithms that allow *us to infer* where the finger is placed." (Metonymy; Personification)

Product: TouchLess, a product that attaches to a bathroom stall door to make the stall door touch-free (i.e. motion-activated).

- "Pathogens *are responsible* for two-thirds of healthcare related infections." (Personification)
- "The *door* automatically *recognizes* her presence, closes, and locks." (Metonymy; Personification)
- "Using arrays of sensors with finely-tuned thresholds in conjunction with a microcontroller that acts as the *brains* of touchLess, our product can *interpret* the user's motions." (Personification)

- “The door can only exert a maximum of five pounds of force – *a gentle nudge*.” (Perceptual metaphor)
- “TouchLess *sends a message* to every single customer that *the restaurant cares* about hygiene and cleanliness.” (Personification; Metonymy, Personification)

Product: UpBeat, a set of lighting attachments for guided drum learning on a drumset.

- “The dock is the *brains* of UpBeat.” (Personification)