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Define "Engineering Design": Understanding how freshman students develop their understanding of engineering, design, and engineering design

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Abstract

Freshman engineering students often begin their studies with limited, imprecise, and minimally informed conceptions of “engineering design.” A deep understanding of this term, however, is vital to an informed awareness of what engineering practice might involve and what engineers see themselves as doing. Textbooks can provide authoritative definition for the student, but these formalisms are (1) challenging for freshman students with limited engineering experience to engage with and (2) fail to capture the complexity of engineering design practices, especially in different disciplines and cultures. In this paper, we examine the efficacy of an activity, developed for a freshman engineering design course that is intended to deepen and enrich students’ understanding of these terms by asking them to categorize various artifacts as works of engineering design. Starting with a simple binary question - yes or no - they move to a planar assessment - and finally to a comparative exercise as complications are introduced into the artifact set. Analyzing their pre and post-activity definitions and student reflections on the activity allows us to explore the impact of the exercise on the students’ understanding of and engagement with the concept of “engineering design.”

1. Background and Introduction

Freshman engineering students often begin their studies with limited, imprecise, and minimally informed conceptions of engineering, design, and engineering design. Researchers interested in promoting STEM education and enhancing engineering recruitment have explored these conceptions[1-5], and have used their findings to (e.g.) develop new communications and outreach strategies. They do not appear to have used this information to develop pedagogy and classroom activities intended to influence student conceptions. As undergraduate students progress through their education, they construct, generally implicitly, their engineering identity. Researchers interested in the study of engineering as a profession have focused on the identities that form, not on pedagogical strategies to promote or direct that formation.[6-8] In their design-focused studies, engineering students are exposed to formal models of engineering design, and there is a body of research exploring changes in how students practice engineering design as they progress through their studies. Such research involves mapping student activities to a model of design chosen by the investigators; students are not asked to describe, explain, or justify their approach to or beliefs about engineering design.[9-13]

Many introductory engineering design courses and resources, acknowledging this lack of considered understanding of “engineering” and “design”, begin with a definition of “engineering design” that serves as a basis for further activities. However, though many authoritative textbook definitions for “engineering design” exist, these formalisms have two central issues. First, though carefully constructed, they are still “just words” and are far removed from the lived experience of freshman students. As such, students have difficulty engaging with the subtleties embedded in the definitions, and often only grasp the most basic or surface aspects of the concept. Second, they offer a simple, authoritative response to defining a term and activity that at a minimum varies by discipline and in practice is fluid and dynamic, changing alongside the social and cultural expectations and responsibilities of engineers and designers. Developing a deep and fluid understanding of engineering design is an important part of an engineering education, because it enables a cognitive awareness of the profession that should inform a large part of their learning over their undergraduate career. Achieving such a goal at the freshman level presents a significant challenge, but would produce significant benefit by allowing such an awareness to inform all of their future learning. While many studies have examined how students engage in engineering design, none have looked at how students understand engineering design, and how personal definitions can influence undergraduate students’ perspectives on their studies and the profession.

Typically, in defining engineering design, instructors rely on textbooks which arrive with rich, well thought out, and thorough definitions of engineering design. Such definitions include:

> “Engineering design is the systematic, intelligent generation of specifications for artifacts whose form and function achieve stated objectives and satisfy specified constraints”[14]

> “engineers ... apply their scientific and engineering knowledge to the solution of technical problems, and then to optimize those solutions within the requirements set by material, technological, economic, legal, environmental and human-related considerations.”[15]

> “Engineering design is the communication of a set of rational decisions obtained with creative problem solving for accomplishing certain objectives within prescribed constraints.”[16]

While commonalities exist within the above definitions, each one focuses uniquely on different aspects of the process, and reveal a specific ideology underlying their understanding of engineering design. The first, for example, focuses on the requirements definition part of the process while the last emphasizes the justification of decisions. Figure 1 shows in visual a summary of the relative frequency of the terms used in the definitions of “engineering design” provided by 11 university textbooks, which will later be compared to the definitions provided by the students . [14-24]

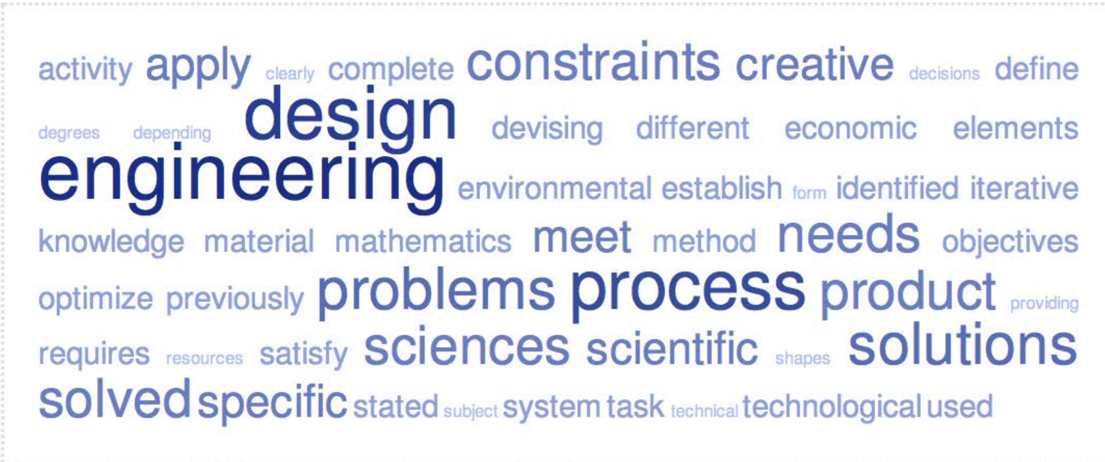

Figure 1– Relative frequency of the terms used in the definitions of "engineering design" provided by 11 university textbooks.

Aside from engineering design textbooks, important, authoritative definitions also come from accreditation agencies such as the Accreditation Board for Engineering and Technology (ABET) in the United States and the Canadian Engineering Accreditation Board (CEAB) in Canada. ABET, for example, sees Engineering Design as:

> "... the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and the engineering sciences are applied to convert resources optimally to meet these stated needs."[23]

CEAB's definition, though equally authoritative, differs in both structure and focus, highlighting rather different traits:

> "Engineering design integrates mathematics, natural sciences, engineering sciences, and complementary studies in order to develop elements, systems, and processes to meet specific needs. It is a creative, iterative, and openended process, subject to constraints which may be governed by standards or legislation to varying degrees depending upon the discipline. These constraints may also relate to economic, health, safety, environmental, societal or other interdisciplinary factors."[24]

One might argue that students should be introduced to this multiplicity of definitions. But while these definitions are rich and multi-faceted, they also demand a strong engineering design vocabulary and experience to be truly understood, something freshman students lack. Further, they may imply a certain ideology of engineering design, or may be intended for specific purposes, such as defining accreditation requirements, and may not be the most useful to students trying to understand the complicated range of activities encompassed by engineering design. The definitions also tend to imply a rational, idealized, vision of engineering design practice, distinct from that which is actually used by practicing engineering designers.

In this project, we explore and experiment with how freshman engineering students in the first year design sequence in the Engineering Science program at the University of Toronto negotiate an understanding of "engineering design," within the context of their first design course, Praxis I. Details on the structure, logistics, and pedagogical foundations of the Praxis sequence can be found in "Assessing the design of a rapid product design cycle activity that develops student understanding of engineering design and professional practice" [25].

2. Research Objectives and Study Methodology

Our research has two main investigative purposes. The first is to assess incoming engineering students' understanding of both the composite term "engineering design" and its constituent terms 'engineering' and 'design'. The second goal is to probe the efficacy of an activity, developed for a freshman engineering design course, that is intended to deepen and enrich students' understanding of these terms. This activity requires students to assess whether or not different types of the same artifact – a shoe, bowl, or bridge, for example – constitute a work of "engineering design." In doing so, we hope to uncover their hidden assumptions about and understandings of engineering, design, and engineering design. In examining the students' definitions of engineering design pre- and post-activity alongside teaching team observations, we hope to demonstrate that developing a deeper and dynamic understanding of engineering design in freshmen is both a possible and desirable outcome that will shape the way that they interact with design activities and courses in the future. This paper presents our preliminary findings, including samples of student pre and post definitions and their unsolicited commentary on the impact of the activity on their understanding of engineering design.

The first step in the study involves students providing their own, unresearched and intuitive definitions of engineering design. To acquire this definition, we asked all students to submit a definition of engineering design as part of an initial online journal post immediately after their first engineering class.

The next week students engaged in Studio 1 "Defining Engineering Design" in which students engage in an activity that is designed to prompt debate on what does and does not constitute engineering design, and to enrich understanding of the terms "engineering," "design," and "engineering design" by examining artifacts and debating whether or not they can be considered "works of engineering design."

Immediately following this activity, students were again asked to provide a definition of engineering design. The purpose in this was to determine if student definitions of engineering design changed as a result of the Studio 1 activity, and if so how they changed. We later compared these pre and post-activity definitions in order to identify the impact of the exercise on the students' understanding of, and engagement with "engineering design."

3. Define "Engineering Design"Activity - Studio 1 Rationale

In designing the course's opening studio, we sought to engage in a dialogue with their initial definitions of engineering design and provide a formative experience by appealing to students' lived experiences in the important act of defining engineering design. In the studio students engaged in a series of activities which prompted them to debate, among themselves and with their instructors, what does and does not constitute "engineering design", to what degree, and embodying what characteristics? They were also prompted to explore the constituent terms "engineering" and "design" similarly. The prompting was accomplished primarily by having the students categorize artifacts as "works of engineering design" and then defend their categorizations to their peers and instructors. We intentionally chose objects, and sets of objects that, in their various iterations and manifestations, had both the most obvious characteristics of engineering design – such as use of scientific principles to fill a social or human need – and characteristics that might exclude engineering itself - may not be intended for humans, may not solve a practical problem in a new way – or have traditional engineering requirements as priorities, or might constitute "hackery." Additionally, an appropriate categorization of these objects is not fully possible without additional information – students are encouraged to identify the questions they would like answered and the assumptions they answer.

The activity consists of categorizing these artifacts in three stages. It starts with a simple binary distinction - yes or no - as to whether a work is (or is not) "engineering design", moves to a linear distinction where students have to assess the relative "engineering design"-ness of the artifacts and finally moves toward a more complex planar categorization of objects along separate axes of "engineering"-ness and "design"-ness. The scaffolding that supports these stages is presented in Figures 2 and 3 below. Larger versions of the scaffolds shown in Figures 2-5 can be found in Appendix 1.

Mid-way through the linear distinction more information about the artifacts is provided, such as when it was built, the process employed, who built it, or a performance against one of the artifact's design criteria, alongside linguistic considerations of engineering design and its constituent terms, as shown in Figure 4 and 5 below.

The supplementary information for each artifact was carefully chosen to challenge an assumption that students were likely to make, or had made in previous iterations of the activity. For example many students assumed that the rabbit (Figure 4) was not a work of engineering design, as it was the product of evolution. Having found out that the rabbit had been cloned by human scientists, many students changed their opinion. The group discussion immediately after the facts were presented focused on the assumptions that the students had, or had not made about the artifacts.

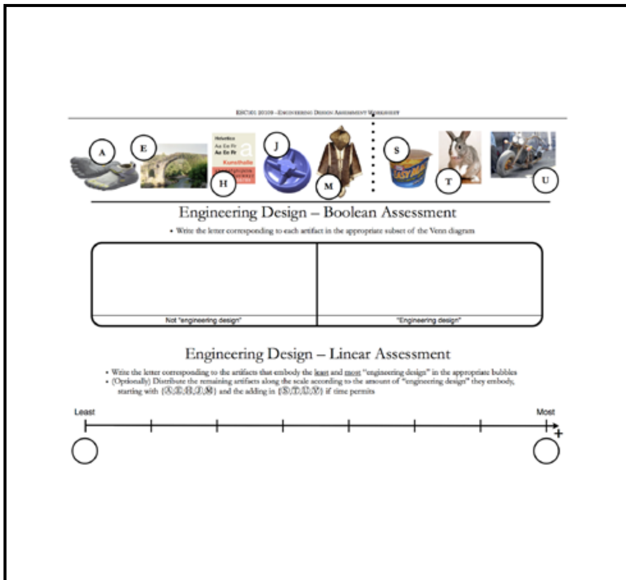

Figure 2: Engineering Design Boolean and Linear Assessments

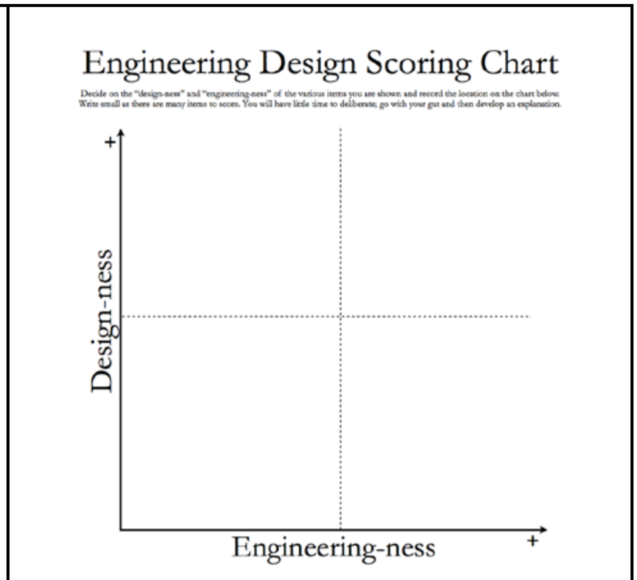

Figure 3: Engineering Design Planar Categorization

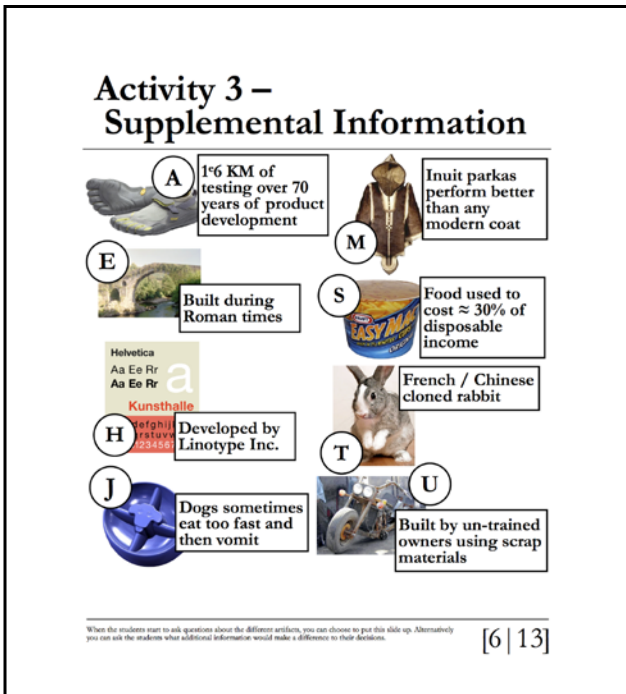

Figure 4: Supplemental Information on Artifacts

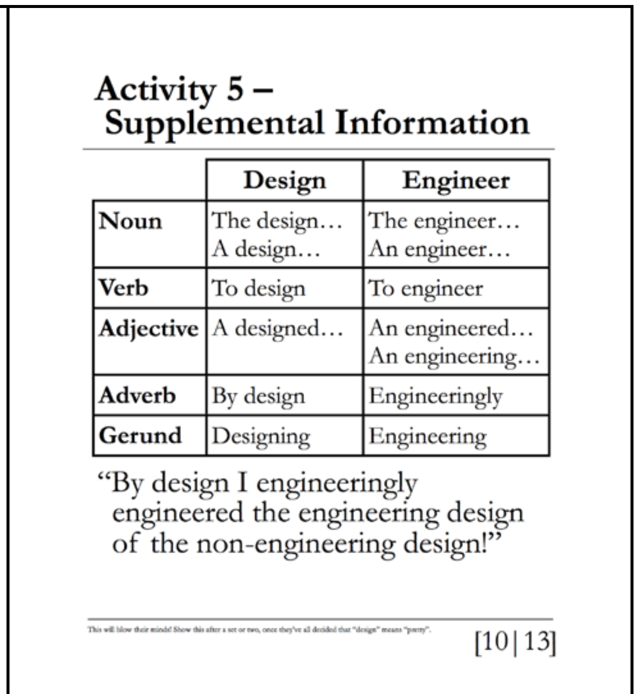

Figure 5: Linguistic Perspectives on "Engineering Design"

The final stage of the activity asks students to explore a set of related artifacts. Each set of artifacts deals with one particular type of design (shoes, motorcycles, bridges, etc.) and presents three different embodiments of it based on different designer/customer/user objectives, as well as different implied processes. We invite students to make informed assumptions about those differences in objectives and processes, and apply those assumptions to help categorize each object as a product of engineering design (or not). Each artifact set was designed to challenge one or more student assumptions about engineering and design, such that the students continually have to refine their beliefs about those terms. This refinement is further complicated by having to justify their new beliefs to classmates.

Figure 6: Artifact Set One - Footwear

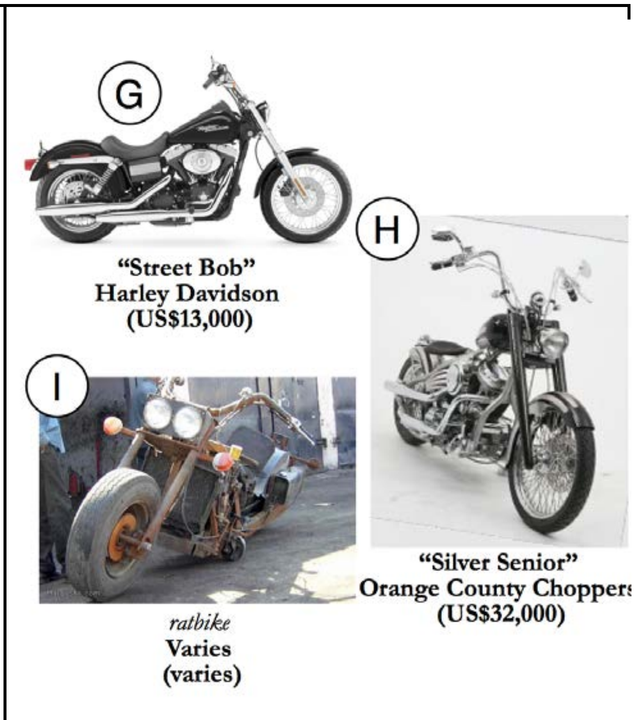

Figure 7: Artifact Set Two - Motorcycles

In the first set of artifacts, shown in Figure 6 above, students are asked to differentiate between a rudimentary sandal developed out of a recycled tire, a Teva Sport sandal, and a Manolo Blahnik heeled designer fashion sandal that are targeted towards different consumers and to be used in different environments. This set of artifacts embodies the following questions and challenges to the students:

- Is there science and mathematics in the Manolo Blahnik heel?
- Is a diagram or plan equivalent to a product when considering engineering design?
- Is the amount of engineering and design related to the difference between luxury, mass-market, and self-produced goods?
- Do the type and variety of materials used affect the "engineering-ness" of an artifact?
- How important is the expertise of the designer when assessing "engineering-ness?"

In a second set of artifacts, shown in Figure 7 above, students were asked to differentiate between motorcycles from Harley Davidson, Orange County Choppers, and a “ratbike” that demonstrate significantly different levels of planning and research behind the product. These examples are similar to the shoes, in that they represent luxury, mass-market, and self-produced products, but change the context to functional machines.

This set of artifacts embodies the following questions and challenges to the students:

- Do the qualifications of the designers (e.g. Harley Davidson engineers vs. Orange County Chopper employees) affect the amount of “engineering-ness” in a commercial product?
- If you have watched the television program “Orange County Choppers”, did “design” take place when they created their motorcycle?
- Is function important when assessing “engineering-ness”?
- Relative to the shoes, does the number and type of parts matter when assessing “engineering-ness”?
- How important is creativity in assessing “engineering-ness” or “design-ness”?

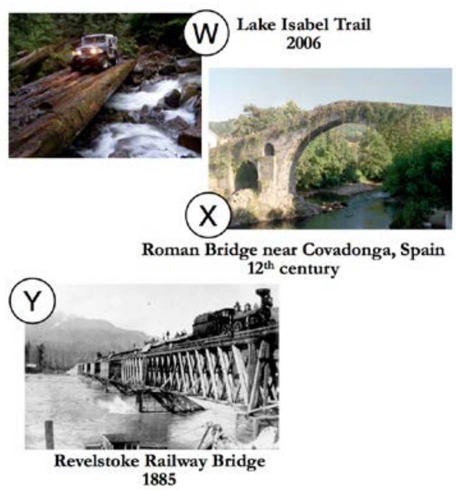

Figure 8: Artifact Set Three - Bridges

In a third set of artifacts, Figure 8 above, students are asked to differentiate between three different bridges with significantly different planning and construction processes: an impromptu bridge constructed on the Lake Isabel Trail, a Roman Bridge, and a late 1800s railway bridge constructed in Revelstoke BC.

This set of artifacts embodies the following questions and challenges to the students:

- Does the “complexity” of a bridge influence how much it embodies “engineering”?

- Do longevity or permanence affect the “engineering-ness” of a bridge?
- Is it possible for the Romans to have practiced “engineering” given that they had no scientific theories regarding forces?
- Is “engineering-ness” related to the use of contemporary materials and theories?
- Is there any “design” present in a bridge?

Students complete these activities individually first then as a team, which first required them to identify their own beliefs around engineering and design, then articulate and negotiate them with their team. Each team is required to place each artifact at one point on the continuums, requiring workable definitions of engineering and design to be negotiated. As these teams began getting a foothold on their definitions, the teaching team continually introduces other criteria or factors that students did not consider to destabilize the team and encourage them to continue re-evaluating their beliefs. Subsequently, each team places their rankings on a class chart, and moderated debates by the teaching staff are initiated between teams with vastly different interpretations of the same item to begin airing some of the criteria with which students assessed the artifacts. The conflict which arises from having students present their beliefs, and challenge/be-challenged-by others requires students to begin appreciating some of their tacit beliefs around engineering and design that they may not have appreciated or acknowledged in their initial understandings and introduces them to other factors which they may not have considered.

By forcing students to think about objects traditionally and not traditionally associated with engineering as potential products of engineering design, or think about objects associated with engineering that have been produced under quite different circumstances, this activity is designed to tease out the more subtle - and possibly tacitly held - aspects of their understanding of the profession and their discipline. It is our belief, that having students rate the artifacts on a continuum of engineering/non-engineering, design/non-design, and explain their positioning of the item on the chart will broaden their understanding of these terms and their beliefs.

Finally, by encouraging the self-production, within a group, of a shared definition of engineering design by which to assess the artifacts, the activity has students move through Perry's middle levels - a multiplicity of ideas, often in conflict - to higher levels of intellectual development - commitment to a carefully thought out and defensible position that the student takes ownership of, and that determines the kinds of activities they engage in over the term (Figure 9).

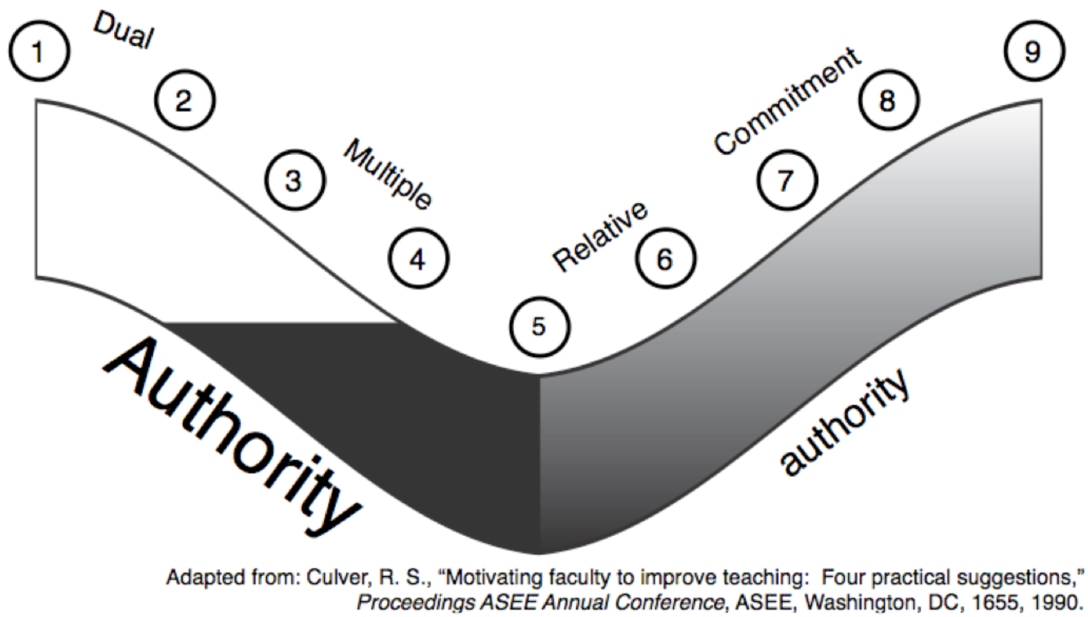

Figure 9: Perry Model of Intellectual and Ethical Development as presented in lecture to students during a debriefing on the activity. The number "1655" on the slide refers to the session number at the conference in which the paper was presented.

4. Analysis and Discussion

The pre-activity definitions, alongside visual word analyses generated from the entire student set, represent an initial baseline against which post-activity definitions can be compared. Anecdotal evidence from instructors on the challenges of leading the activity in the classroom, solicited in post-studio meetings with our teaching team, alongside unsolicited student reflections on the activity, both provide useful and different perspectives on students' engagement with the act of defining engineering design.

4.1 Pre-activity Definitions

Six randomly sampled "Pre" definitions are included below:

1 "To create and/or develop an idea of a machine or process that facilitates a task and/or makes possible a task that would otherwise be impossible."

2 "The practical and theoretical application of science and mathematics to make technological advances via the engineering method."

3 “The process of creating something in order to produce a product that is useful to or improves the efficiency of society in an innovative way.”

4 “Different from the research of the universe done by scientists, [engineering design] is the actual contribution to the human society which can affect and improve our lives.”

5 “Engineering design is the process by which engineers analyze problems and create safe, economical, and efficient solutions for them.”

6 “Engineering Design is the process of developing elegant, practical solutions to real world problems using technical knowledge and skills.”

At first glance, these definitions are brief, and reflect a relatively simplistic, novice perspective, expected from freshman engineering students.

Figure 10 – Frequency analysis of the terms contained within the student provided definitions of “engineering design” before the Studio 1 activity with the terms “engineering” and “design” as well as articles excluded. Increased frequency of occurrence is demonstrated through larger text and darker font.

The qualitative frequency analysis provided in the world cloud shown in Figure 10, above, indicates a relatively small vocabulary, with significant emphasis being placed only on a small number of words. The similarities between the student terms, shown in Figure 10, and the textbook terms, as shown in Figure 1, suggest that there is little benefit in instructors imposing a textbook definition of “engineering design” on their students as student understanding pre-activity is largely consistent with accepted definitions. What the student definitions lack are objectives or criteria (e.g. the ‘X’ in “Design for X”) that are commonly associated with engineering design.

4.2 Anecdotal Observations from the Activity

This activity relies on strong, informed, and highly engaged instructors as facilitators, who have provided valuable anecdotal feedback on how students react to the challenges posed by the activity, summarized below.

Although few students were interested in the activity at the binary stage, with many seeing the distinctions as obvious or straightforward, they did become increasingly engaged as the activity progressed. As they were presented with more levels of “engineering design” and more information that helped to differentiate the artifacts, the students were able to disagree more often with those they were working with. When there were teams of students that had fundamental differences (i.e. whether or not God is an engineer), debates between some students often got highly animated, even resulting in raised voices in the rooms. While this may not be seen as a positive in most classrooms, this kind of engagement in the activity is – for us – highly desirable as this passion demonstrates that students were strongly expressing and justifying their beliefs to others, and spoke to a plurality of often directly contradictory opinions about engineering design in the room.

It remained difficult, however, to engage all students: some were simply not able, at least initially, to articulate their assumptions and beliefs about engineering design. Some of these students did not see “engineering design” as a topic that was open to interpretation as it was already clearly defined by other professors and textbooks. For these students, the key to having them acknowledge their beliefs was to compare their placement of each artifact on the continuums to their definition. In these cases, the justification for placement usually dealt with criteria that were not explicit in their original definition, or even close to the definition presented (i.e. its complicated therefore there is more engineering in it, its old therefore there is more design in it, etc.). Debating with these students to find a way to use their definition to justify their decisions was particularly helpful for having them acknowledge the presence of assumptions that were so implicit even they did not know they existed; creating a discrepancy between the definition they provided and the implicit notion which they used to sort the various artifacts into the provided categories was the key.

Essential to this activity were the members of the teaching team whose job was to continually destabilize the students as soon as they settled on a definition. Destabilization in this context refers to introducing new information, considerations, or examples for which the definition no longer worked. This resulted in students continually re-evaluating their beliefs and their definitions, as the artifacts and information were presented to them, helping to counteract the fixed, textbook style definitions held by some students prior to the activity.

Student rankings of "engineering design"-ness were fairly consistent for the binary and linear assessments. There was some discussion as to the sequencing of the artifacts around the mid-section of the linear assessment; in most teams the same three artifacts were the ones in the middle. In terms of the planar chart, however, student assessments of the "engineering"-ness and "design"-ness of the artifacts was greatly divergent. What some teams had placed as high on both axes, others had placed low. This created excellent discussion for the class and excellent material for the teaching team to use to elicit student beliefs.

4.3 Student definitions post-activity

As mentioned previously, student definitions of engineering design were also collected following the activity. A representative sample of three post definitions is provided below:

1 "Engineering Design is the combination of intelligent choices, elegant design, and physical and mechanical principles; These three factors are combined to create as effective a solution as possible to any identified problem, such that the solution is efficient, simple, safe, and innovative in a way that benefits the society for which it was designed. It is not the creation of a final, perfect solution, but rather the creation of a solution that improves on past technologies or practices that defines Engineering Design. This constant pursuit of improvement is what drives engineers to continual innovation."

2 "Engineering Design, being the symbiotic combination of both design and engineering, incorporates elements from both words. The engineering portion demands that good "engineering design" be economical, practical, accomplishes a set out purpose, and is rigorously proven. The design aspect warrants for an aesthetic and well thought out blueprint that will aid in the construction and execution of the task or product at hand."

3 "Engineering design is the application of scientific knowledge to create an elegant, sound, efficient and effective solution to a problem. Engineering design however must involve some development of concept to move from the initial idea to the final product, and must not simply be the result of randomness - there must be some specific thought process involved in the evolution of the design."

Generally, as seen in the above samples, these definitions were longer and incorporated more vague, varied, and fluid terminology than before, as indicated in the frequency analysis shown in Figure 11, below. Key themes that emerged from assessing the definitions and frequency of the words used in the definitions is that most students at the end of the activity felt that engineering design was a process through which products were created to solve problems. And while this may found the core of most traditional engineering design definitions, the interesting material was in the descriptors of engineering design that surfaced: economical, efficient, elegant, innovative, practical, safe, useful. These descriptors were what the activity aimed to surface as they demonstrated the values that students bring implicitly with them when they begin designing.

Figure 11 – Frequency analysis of the terms contained within the student provided definitions of “engineering design” after the Studio 1 activity with the terms “engineering” and “design” as well as articles excluded. Increased frequency of occurrence is demonstrated through larger text and darker font.

Some students upon completing this activity chose to submit reflections on the activity as well as their new definition of engineering design. Some of these reflections are shown below to demonstrate the level of ambiguity and opposable beliefs we were able to get students to embrace, as well as the critical thinking they engaged in to deduce their beliefs on engineering design and on the objectives of the activity. These reflections are unaltered to demonstrate the students’ thinking processes and modes of expression.

1 “Engineering design has proven to be a stubbornly difficult definition to crack. Though the individual words can be easily looked up in a dictionary, the combination of the two just becomes vexing. After the first studio, I'm more unsure than ever (I guess that was the whole point... but it doesn't mean I have to be happy about it). My current definition of engineering design is that it is the extensive creation process behind everything, which tries to find a solution to a

problem or fulfill a purpose in the most efficient manner possible."

2 "My definition of engineering design has changed as a result of our group and class discussion during the tutorial. While I still believe that at its core, engineering design is the process by which engineers analyze problems and come up with solutions that are feasible economically, efficient, and safe, I have added some side notes to my definition. I believe there are other considerations engineers must keep in mind while designing products. The aesthetics and elegance of the design are also important. In addition, the product should provide some level of innovation. This could be coming up with an altogether new product or simply improving substantially on an existing design."

3 "My first definition of engineering design was very open, it revolved around the idea that we should not set a standard on a phrase that does not necessarily enforce one in and of itself. I was reminded of the countless times I had heard the phrase "this is not music" or "that isn't art", and I believed that what was not engineering design to one person could be considered an excellent example of engineering design to another. I felt that any original product created by humans to fulfill a purpose should be considered an example of engineering design.

While this has not changed, after some thinking (literally hours sitting in meditation), I've decided to add that conscious decisions must have been made to address non-emotional objectives. To reach this step I examined some items to determine whether or not I would consider them examples of engineering design: A painting (portrait or landscape), a piece of abstract art with lines carefully measured to convey a message, typical small statue of person (up to life-size), and the statue of Liberty. I decided that I would only consider the statue of liberty an example of engineering design, and it was because the statue of liberty had to be designed to withstand considerable stresses, while the others were only designed for the purpose of conveying emotions.

Furthermore, we saw today that judging different products based on engineering design will yield different results based on the goals and criteria upon which they are evaluated. As someone who hopes to one day design innovative consumer products, I understand that different engineering design decisions will appeal to different people. In studio 01, our group ranked "Tire Sandals" low on the chart because they lacked strictness of requirements, rigorous calculations, and failed to perform in terms of safety, comfort, or aesthetics in comparison to other shoes. However, considering the low cost of materials and simplicity of production, it would be hugely beneficial in areas where many people cannot afford to buy other shoes.

To conclude, Engineering design applies to original, man-made products that are created to fulfill specific practical (non-emotional) purposes, and has a set of shifting criteria depending on the objective at hand."

4 "Following my experiences in Studio 01, I have come to a second definition of engineering design, after realizing that there are actually two major components to this concept: engineering and design. My first definition was far too narrow, but after the day's activities, I now have a better picture of what engineering design truly is. It all starts with a problem, either given or more likely found, that must be solved. The designer's role in engineering design comes up with an ideal solution to the problem, which can then be communicated with anything from a blueprint to a formal presentation to the engineer. Next, the engineer will figure out how to make this idea a reality, whether he builds it, grows it, or programs it, or does whatever he needs to do. However, this is not to forget the ideas from my previous definition: elegance, usefulness, and economics. These three things must be present throughout the whole engineering design process; not only does the idea have to be useful, elegant, and economical, but the way in which the idea is executed by the engineer must be too. Thus, to summarize, engineering design is the process of solving a problem by first thinking up and designing the solution, then making and engineering a solution, all the while keeping elegance, usefulness, and economics ingrained into the idea and the method of engineering the solution."

In the leadership literature, defining a value-system and set of beliefs is documented as the foundation of authentic leadership; one must be able to understand the perspective from which they are leading to actively engage their followers who may have different perspectives. Similarly, to engage the students in this course in developing individualized, authentic practices of engineering design they must be able to understand and articulate what perspective they are engineering and designing from, as well as how they believe both should be practiced. The core benefit of having students discover their definitions through their experience, rather than having it imposed by an external force, is that it provides them with more tangible and direct evidence when their beliefs and practices are challenged. Allowing students to surface and deconstruct these beliefs first individually, then as a group provides them with the opportunity to see why in group work there may be contentions around how to develop or design a particular product.

As can be seen from the above reflections, the articulation of beliefs which inform the way in which individuals appreciate, interpret, and define entities in their surroundings can be a challenging, and sometimes vexing, activity. Each student above presents different aspects of engineering design that they value, and as a result observe intuitively in artifacts of engineering design. The first student demonstrates a valuing of functionality, efficiency, and process, the second initially focusing on the performance metrics of a design: cost, efficiency safety, but through the activity discovered value in beauty and innovation as components of engineering design. Through appreciating these values, as students move forward in their design work they will be able to acknowledge the types of design decisions they may focus on (such as surface finish or colour in the case of the second student) and as a result of what they do not value, which aspects of a design they might overlook.

As the objective of the activity was to surface these values, as articulated through student descriptors of engineering design, a visual comparison of the two graphical word frequency analyses demonstrates that there are a greater number of descriptors in the post-activity student definitions. While it is unknown whether most students can identify the dependency between these descriptors and their value systems, the reflections provided do give evidence that some of the students did identify this connection through their analysis of these and other artifacts.

5. Conclusions and Future Work

Although this paper tracks the impact of only a single intervention, the students revised definitions and initial reflections already demonstrate a deepening of understanding about engineering design. Their revised definitions reflect a change in relative emphasis and variety of terms associated with engineering design, though not necessarily in kind. One key finding from the activity from the teaching team is that students really struggle to see "design" as "following a process" rather than an attribute of the result of a process, a factor that may influence how the term is introduced to students in the future. With these encouraging preliminary results, we hope that a deeper discourse analysis of the differences between student pre and post definitions will confirm the efficacy of the activity, at least in the short term. Anecdotally, instructors have reported that students can revert back to their initial ideas in the immediately following activities, and need further prompting to reinforce the understanding developed in the activity: we need to figure out how to track the evolution of students perceptions of design over the course, and eventually, longitudinally over their four year academic careers.

Two core goals of an engineering education are to introduce students to the engineering community of practice and to provide students with a means of distinguishing themselves from their peers and competition. Exposing freshman students to the complexity surrounding the concepts of "engineering" and "design", having them start to develop their own definitions, and asking them to demonstrate integrity as they practice as engineers, is a promising approach to meeting these goals.

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Appendix 1. Larger versions of the scaffolds used in the activity

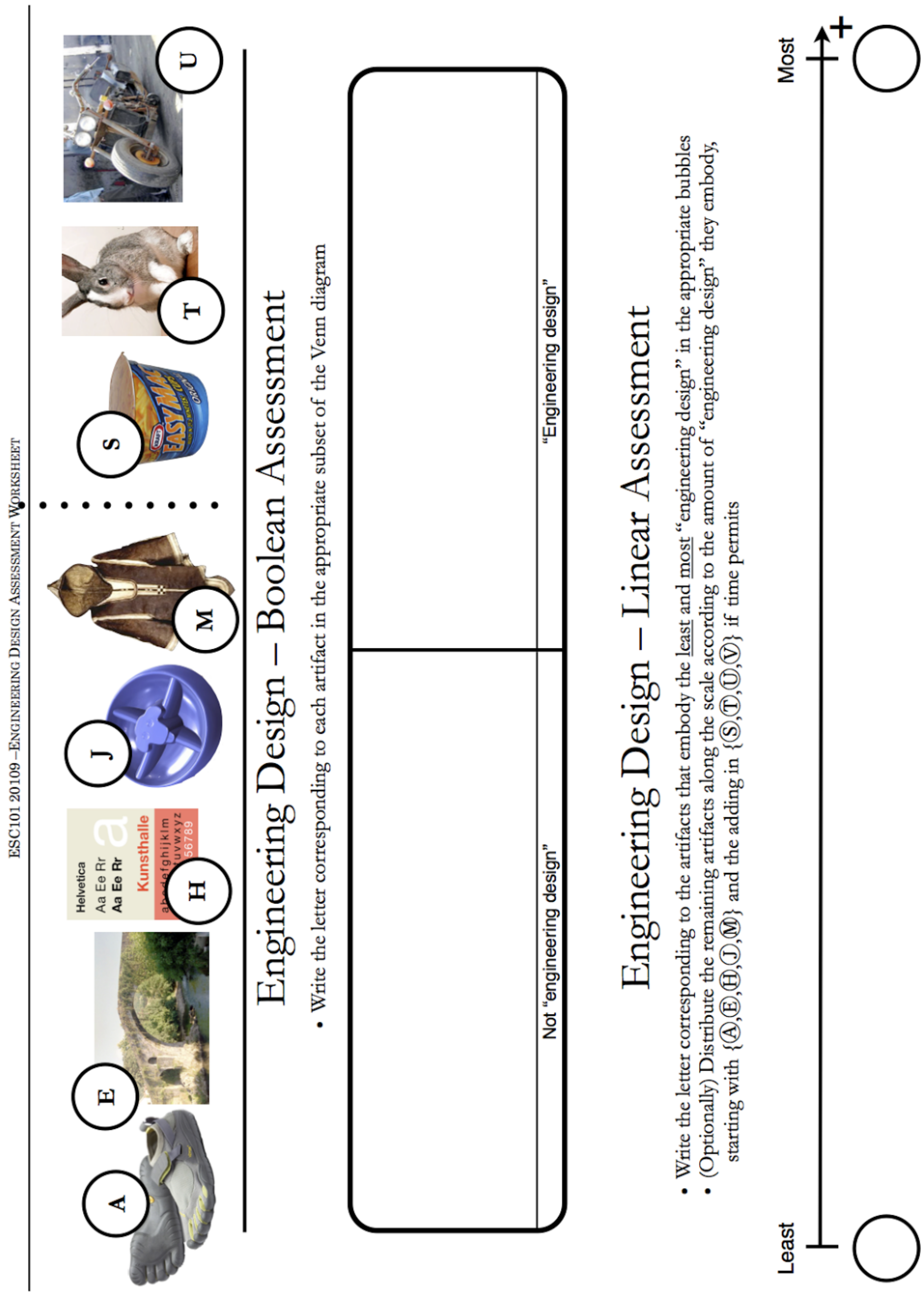

Figure 2: Engineering Design Boolean and Linear Assessments

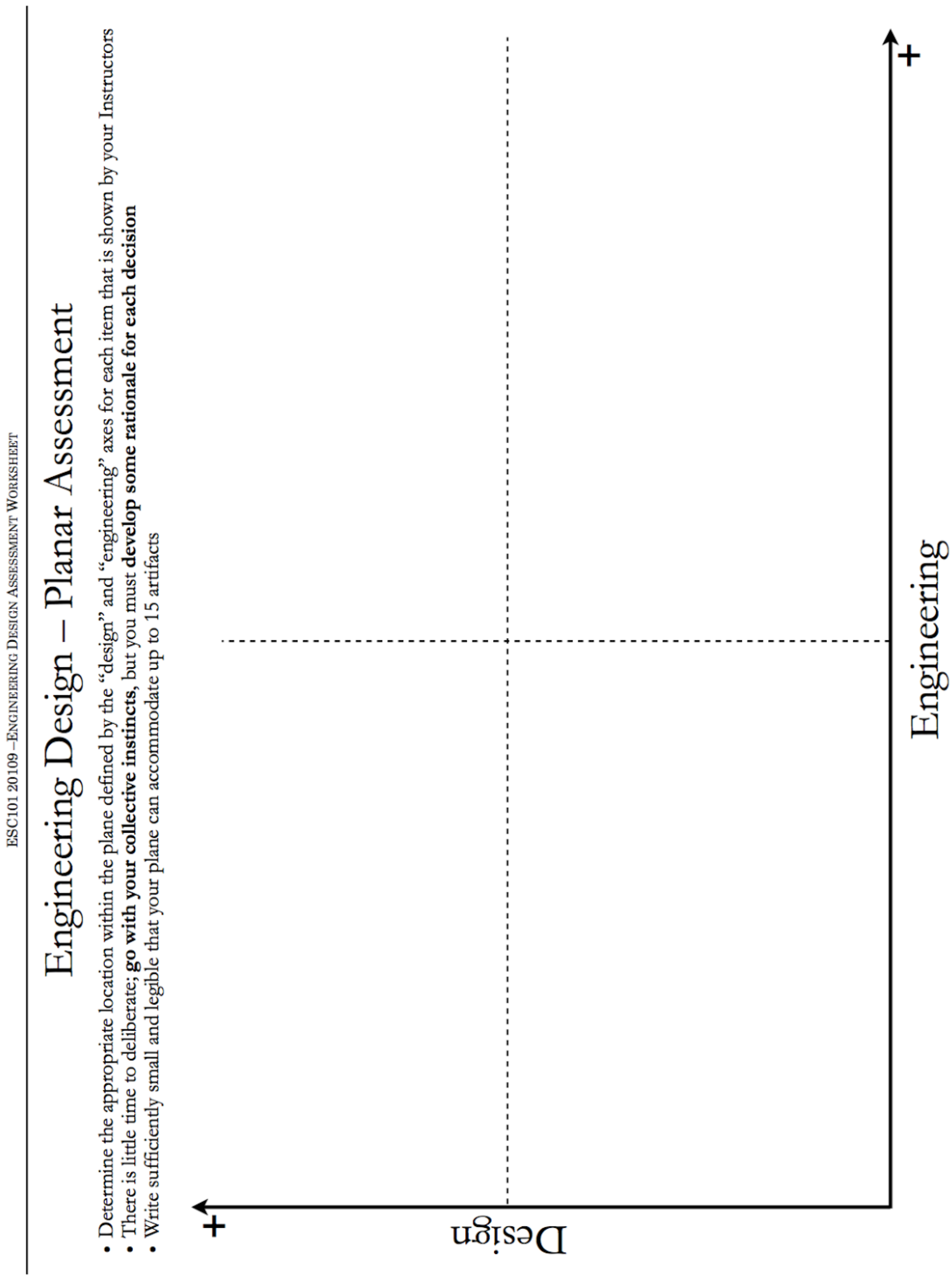

Figure 3: Engineering Design Planar Categorization

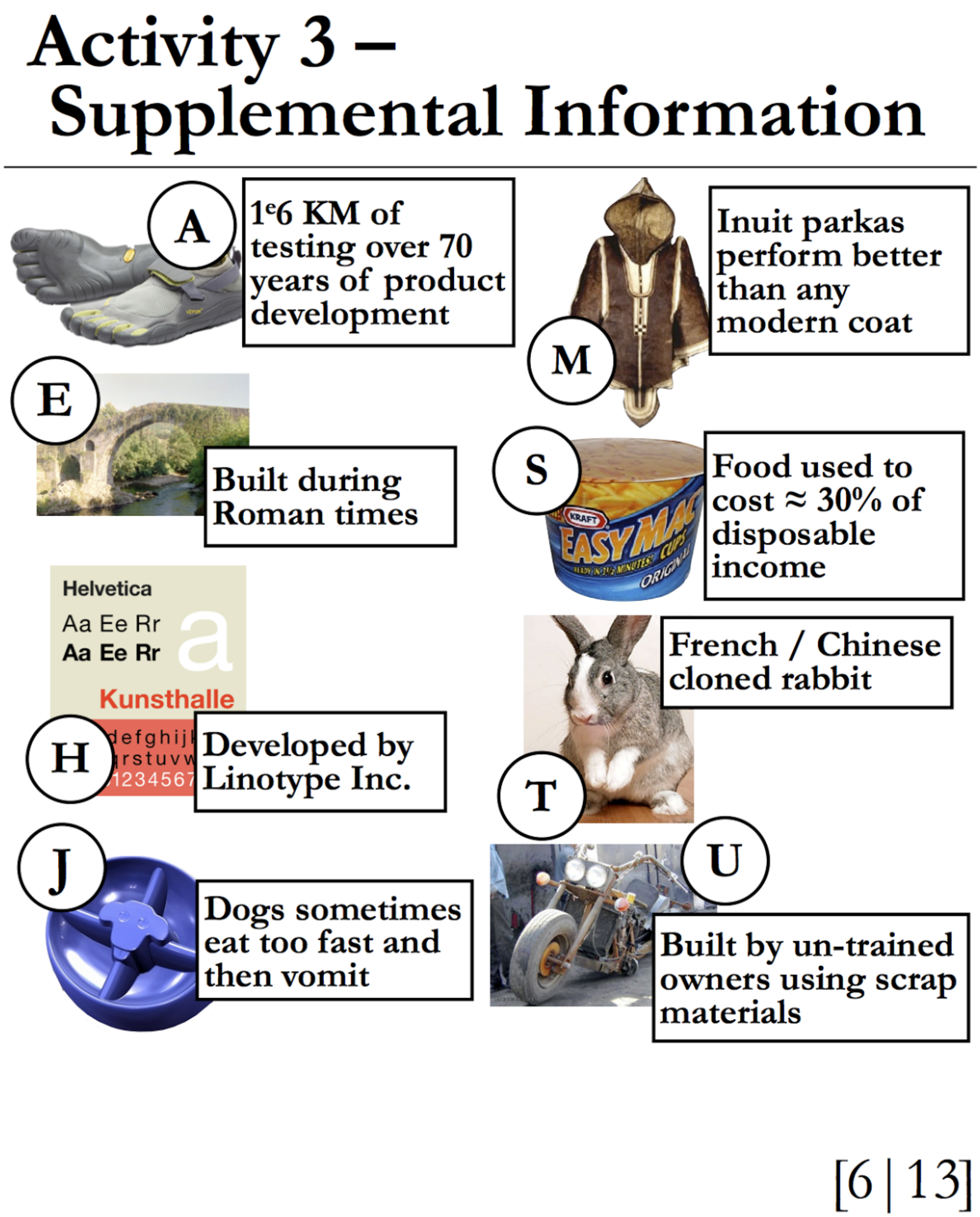

Figure 4: Supplemental Information on Artifacts

Activity 5 – Supplemental Information

	Design	Engineer
Noun	The design… A design…	The engineer… An engineer…
Verb	To design	To engineer
Adjective	A designed…	An engineered… An engineering…
Adverb	By design	Engineeringly
Gerund	Designing	Engineering

"By design I engineeringly engineered the engineering design of the non-engineering design!"

[10 | 13]

Figure 5: Linguistic Perspectives on "Engineering Design"