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Investigating How Mechanical Engineering Students Design and Make the Now and the Future

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**Investigating How Mechanical Engineering Students
Design and Make the Now and the Future**

Introduction

Engineers are uniquely positioned to create solutions that do not yet exist. The National Academy of Engineering's *Changing the Conversation: Messages for Improving Public Understanding of Engineering* report (NAE, 2008) includes specific messaging that engineers design the future. One can invent and integrate technology in new ways to make a future happen. Mechanical engineering students are well placed to become fluent with technology as well as achieving a better understanding of how one might apply that to create something novel and of value. Whether it be more efficient means for transportation that are less impactful on the environment, or a new widget that makes interactions more meaningful, there is a physical scale and scope of impact that mechanical engineers can impart directly with stakeholders and users. Because items imagined can be within the size of consumer products where solutions may be simply created and mocked up (Brandt, 2007), there is a unique opportunity to better understand these students' behaviors in designing and prototyping.

This research project explores how a cohort of senior mechanical engineering students can design and prototype solutions for a problem today, and how their solutions are changed when asked to be placed out into the future. We are curious about the similarities and differences in their approaches along aspects of the design process (cognition) and in the design result (artifacts). This project allows us to explore how engineering students conceive of the breadth of impact of engineering on the future 5-10-20 years out through reviewing their work and classifying their work product.

Context

Within the ME 465 Design Thinking and Innovation for Mechanical Engineers course at the South Dakota School of Mines & Technology, a senior-level mechanical engineering elective course that covered approaches and processes of human-centered design, students were introduced to habits of prototyping through paper prototyping (Brandt, 2007). With simple materials such as paper, scissors, markers, and tape, the utility of prototyping low-fidelity (McElroy, 2016) artifacts, or prototypes, was introduced into a single class session. Students were then asked to apply this approach in a series of open-ended design challenges.

The first framing of the design challenge was to make a greeting card for Mondays. This is a simplified toy problem that fit within the timeframe of one class period. The underlying assumption was that the construct of a greeting card was generally understood and the materials provided were sufficient to accomplish the task. There is also a generally shared ennui and angst about the start of the work/school week. The second iteration of the design challenge activity was to have participants repeat the same design challenge with an additional priming that their solution be placed out into the future 5-10-20 years. By using the same task and participants, with this one change in framing, it was hoped to be able to generate matched pairs of what students imagined for today and for some time off into the future. Additional content as part of this human-centered design course delved into more refined approaches to prototyping.

The context of this senior elective course is routed in design thinking – for students to extend their mechanical engineering design process from one of product development to one also based in appreciating the needs of users and solving problems with people at the center of it. The activity for this study was from one class session that was planned to focus on paper prototyping as an extension of a module on the approaches of rapid prototyping. As such, the time horizon aspect of the design task was ancillary to the specific task of practicing the creation of artifacts with simple materials of paper, scissors, markers, and tape. In addition, the particular task of creating a greeting card was meant to be a bridge into the available materials as well as a means to have a shared appreciation for the emotional latency or meaning for Mondays. Like warm wishes for a birthday celebration, for example, a greeting card for Mondays, or the sympathy of the start of the week was intended to be a shortcut to creating artifacts to communicate that empathetic aspect.

The specific learning objective for this task was to practice paper prototyping as an echo of rapid prototyping. Students were engaged in longer-form design challenges in the class that relied on students applying what they learned in these short-form activities in more in-depth and (hopefully) personally meaningful (and motivating) problems to solve. Subsequent projects throughout the class had student teams tackle reorientation to a space new to them, an ambiguously framed personal transportation project, and an open-ended innovation challenge. These were scaffolded to initially provide the user and problem to solve, then less prescribed design finding and solving work where students could project their own interests, in service to the design thinking learning objectives of the course.

Goals

The goal of this research project is to better understand how the difference in time horizon (now, in the future) made for similar and different aspects of the created artifacts. This also serves as an opportunity to introduce an undergraduate mechanical engineering student to the processes of design research and engineering education research. Within that scope, the research activities served to define a scheme capable of categorizing prototypes of existing technologies and possible future technologies.

Literature Review

Prototyping

The manifestation of ideas into a physical and tangible artifact is prototyping. It is a central activity to designing and engineering. Research has looked at prototypes as content (Lloyd & Snelders, 2003) and conduct (Schrage, 1996) but less frequently through the activity of students in situ. Prototyping can be the practices of a "prototyping culture" (Shrage, 2006) as well as a cyclical part of the design process to learn and refine concepts further (Buxton, 207).

The roles for prototyping have been described as a communication tool (Brandt, 2007) and a means to answer questions (Shrage, 1996) between designers, but also between designers and others. Houde and Hill (1997) identified four types of prototypes, each with an associated use: role (purpose), look and feel (experience), implementation (physical), and integration (system). Nielsen (1989) described three different types of prototypes along a scale of features of services and functionality of features.

Prototyping in Education

Adapting a practice and habit of prototyping can be part of cornerstone and capstone design experiences. Introducing the practice of prototyping within a course supports the learning of the process around design, as well as the end artifact (Lande & Leifer, 2009). The notion of learning professional work, like a "prototyping culture" (Schrage, 1996), can sometimes support course learning goals. Oftentimes though the purpose of learning of a design process, and in particular, the discrete steps and associated values, takes a secondary role to the creation and delivery of a functional system. There is less time than might be desired for reflection (Turns et.al, 2014), especially within the design process, in seeking feedback and actually doing iterative design. Iterative physical prototyping to learn and refine concepts further (Buxton, 2007) may suffer due to time constraints.

Future Time Horizon

Students' futures thinking has been explored, though not within the context of design. Shell and Husman (2001) investigated college students' *future time perspective* through large-scale quantitative means. Benson and Kirn (2015) examined student motivations over a times scale.

Research Methods

This research project used an iterative, emergent thematic analysis (Fereday & Muir-Cochrane, 2006) of classifying artifacts in a qualitative fashion. An in-class activity was collected and subsequent documentation and classification of the activity's prototype creations were undertaken. The data was then analyzed and reviewed qualitatively for patterns from which conclusions were drawn.

Research Question

The primary research question for this research project is "How do students prototype the present and future and how does this impact the way they view the world?" Or conversely, does their worldview shape how they prototype the present and future?

Setting and Context

The setting of the prototypes creations was a class activity in a mechanical engineering senior elective based around design thinking. In one class session the class was tasked with designing a "greeting card for Mondays." After completion they were then asked to create a prototype of a “greeting card for Mondays from the future.” This was part of the course that emphasized rapid prototyping – this activity focused on the skills and benefits of quick paper prototyping to realize an idea and be able to get feedback with an efficient use of time and resources. (Additional design projects during the semester were more in-depth with regard to time, complexity, and completeness.)

Creation and Iteration of a Classification Scheme

In discussions within the research team, a number of possible factors became the basis of the classification nomenclature. For the first iteration the factors deemed important were the following:

- Fidelity Level
- Feels/Looks/Works Like
- Material Amount
- Feasibility
- Build Time

A complete breakdown of the first iteration is in the appendices. Through team discussion the second and final iterations were created. The general factors, listed above, stayed the same, but the description and specificity of some factors were modified. These factors were the Feasibility and Build Time measures. The changes made from the first iteration to the final iteration are displayed in the figures below.

First Set	Fourth Set-balance feasibility and viability
L = Low Fidelity	E = Existing Technology
M = Mixed Fidelity	N = New Technology
H = High Fidelity	I = Inaccessible Technology (Cost&Availability)
Second Set	A = Accessible Technology(Cost&Availability)
F = Feels Like	
L = Looks Like	
W = Works Like	Fifth Set
Third Set	L - < 1 day to build
number of materials used	M - 1 to 7 days to build
	H - >7 Days to build

Table 1: First Iteration of the Classification Scheme

First Set	Fourth Set-balance feasibility and viability
L = Low Fidelity	E = Existing Technology
M = Mixed Fidelity	R = Technology in Research
H = High Fidelity	N = Non-existing Technology
Second Set	IF RELATIVELY EXPENSIVE **AND** 'R' **OR** 'N'
F = Feels Like	I = Inaccessible Technology
L = Looks Like	IF RELATIVELY INEXPENSIVE **AND** 'E' **OR** 'R'
W = Works Like	A = Accessible Technology
Third Set	Fifth Set
number of materials used	Approximate hours to build (down to 0.25 hrs)

Table 2: Final Iteration of the Classification Scheme

As previously stated, the most notable changes between the iterations were the Feasibility and Build Time measures. The Feasibility measure moved from a relatively unspecific classification to interdependent parts that better capture the feasibility of the technology being prototyped. Similarly, the Build Time measure was moved to use a more accurate measurement of time. An explanation is in order to supply more information about each individual measure given the end item measures.

Numbering Prototypes
A numbering scheme was also developing as a unique item number for each separate prototype. Each item number is comprised of five 'dash-codes.' An example of a dash-code used while exploring this topic follows. Having a catalog of prototypes is helpful it reduces needed storage space and with enough pictures and descriptions it is almost like having the real thing. Our lab used a document scanner to take high quality images of the prototypes this project encompassed. Each prototype was then assigned a four-digit number starting at one (0001). The first dash code is simply that number.

Fidelity Level
The classifications for the first set are as follows.

- L: Low Fidelity
- M: Medium Fidelity
- H: High Fidelity

Fidelity describes the level to which a prototype resembles a finalized product, whether ergonomically, visually, or functionally. The higher the fidelity level, generally, the more complex and expensive the prototype. While low, medium, and high may seem nonspecific it is a widely accepted scale in the world of prototyping.

Prototype Style (F, L, W)
The classifications for the second set are as follows.

- F: Feels Like
- L: Looks Like
- W: Works Like

"Feels like" describes a prototype that is made to show a customer what the end-product would feel like. These prototypes may use specific materials or texturing. "Looks Like" describes prototypes that look like a finished product. They focus on the aesthetics of the end-product. "Works Like" describes prototypes that are based around functionality. This does not mean they have to be functional. They can be functional, but they may also have representations of functions, such as fake buttons. Keep in mind prototypes can hold more than one of these descriptors and thus the dash-code would contain each of the qualifying descriptors.

Material Quantity (x)
This dash code is simply the number of materials used within a prototype. The materials should be counted by each type of expendable product used. For instance, a card from the future used scotch tape, eight different colored markers, printer paper, and cardstock, the quantity would therefore be four. This is because eight markers served the same functional purpose and would

count as one. Whereas two different types of paper could serve different functions within the card, thus making it quantity two. The remaining one quantity accounts for the tape.

Feasibility (E, R, N)

The fourth set is by far the most difficult. It has an independent and dependent component. The following are the independent components.

- E: Existing Technology
- R: Technology in Research
- N: Non-existing Technology

"Existing Technology" describes a prototype of a technology, idea, or product that is commonplace. For example, these may prototype products that are publicly available. "Technology in Research" describes prototypes that model things that are known, fairly understood, but are not readily accessible. Perhaps a functional machine, but only built as a one-off for a very specific or particular use. Imagining a jerry-rigged research lab tool is a good way to describe prototypes that fit this description.

"Non-existing Technology" describes models that depict something that does not necessarily exist outside of the mind. Examples of this are the ideas the sci-fi genre has put into place. For example, hyperspace drives. Many people have speculations and ideas on how to build these, but it is something out of the scope of our, humans, existing technology.

The classification chosen here leads to the dependent portion of this set. If the chosen classifier is "R" or "N" the following letter will be "I" for inaccessible technology. If "R" or "E" the following letter will be "A" for accessible technology. "I" is based on the technology being hard to obtain, whether it is from the expense standpoint or the lack of ability of modern science. One can also think about this as the technology being infeasible. "A" is based on the idea of a technology being readily accessible, cheap, or commonplace. If the first letter is "R" the classifier can be either "I" or "A;" this is left to the discretion of the user.

Estimated Build Time (x.xx hrs)

The final dash code is an estimate of how long it took to build. In many cases the full build time is not recorded. Therefore, the cataloger estimates to the quarter hour how long it would take them to replicate the prototype.

Results

Using the senior elective's output from the Monday's greeting card activity we were able to apply the classification scheme to attempt to establish a pattern for prototyping the future. Below are examples of documented prototypes, brief explanations of their significance to this project, and their final classification. An exhaustive list of artifact classifications is in the Appendices.

Figure 1: Prototype of Present Time Monday Themed Greeting Card

Figure 1 is a representative prototype of those created for present day Monday themed greeting cards. Its classification is 0010-L-LW-2-EA-0.25. Regarding the present day prototypes this card and its classification are comparable to the remaining documented.

Figure 2: Prototype of a Drone Carrying an iPad Displaying a Monday Greeting

Figure 2 above displays a prototype which falls in the five-to-ten-year timeline. Its classification is 0025-L-L-3-EA-0.50. This prototype shows the thinking of using existing accessible, albeit possibly expensive, technology to enhance the novel idea of greeting people on Mondays.

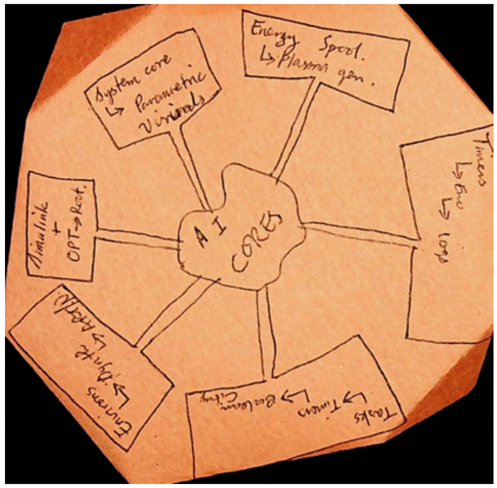

Figure 3: Brain Chip to Alter Brain Function

Figure 3 is a brain chip whose duty is to alter the brain's function to convince the user it is mid-week, rather than Monday. This prototype displays technology that may be twenty or more years from being a functioning future. Its classification is 0032-L-W-2-RI-0.25.

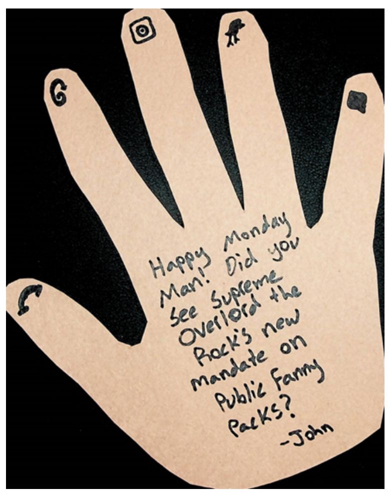

Figure 4: Hand Attached Device Similar to a Cellphone

Figure 4 depicts not specifically a greeting card but a method for receiving such communications. Similar to what is seen in *Total Recall* (2012), this prototype effectively integrates a modern smartphone into the user's hand. This prototype is classified as 0028-L-L-2-NI-0.25.

Findings

The following qualitative findings came from classifying and studying approximately 40 different prototypes created by the class activity. The findings presented are related to the previously discussed results of the classification and study of students' output.

Some consistent portions within each classification of the prototypes are the fidelity level, all scored in the low to medium range. Also, near constant across the board were the number of materials used and time to build, this is because of the nature of the activity. Students were given the same materials to choose from and the same amount of time to complete each portion. The inconsistencies in the prototypes were the points of interest.

Present Day Prototyping

Aforementioned in the Results section were the similarities of the prototype in Figure 2 to the rest of the present-day sample prototypes. This comparability shows how people, specifically engineering students, prototype the present. It is generally done with notions of what is current with little to no deviation from industry standards, or commercially available products.

Future Prototyping

In the opposite manner, the prototypes of future greeting cards can vary wildly from one to the next. For example, the prototypes depicted in Figures 3 and 4. These two prototypes show how some students thought of the short-term future, while others thought of the long-term future. These differences also display how "the future" can be interpreted from student to student, along with levels of optimism about the progression of technology.

It should also be noted that some prototypes fell into the realm between the two previously mentioned styles of prototype. The first being prototypes that are like commercially available products. The second being the future prototypes that have little existing technologies involved, keep in mind the brain chip. This middle ground is identified by the drone and hand-phone prototypes, Figures 3 and 4 respectively. This middle ground uses commercially available technology in an advanced way to do novel things. Like the shift from needing a phone and a camera to now, where every phone has a camera attached, this middle ground combines previously "separate" technologies to do old tasks in a different manner in a mediating innovation manner.

Limitations

How people design and prototype the future is highly individualistic in nature. It is based around how everyone defines what constitutes "the future," their personal background, and their overall knowledge base, to name a few. When this project was based on students with similar knowledge relating to college academics one may imagine seeing similar outcomes of prototyping future greeting cards. This was the case for contemporary greeting cards, but very much the opposite for greeting cards of the future.

The precursor project to our classification scheme shows fundamentally the different ideas and notions even like-minded people have about what constitutes the future, let alone the technology of the future. With all these differences it can be difficult to compare the output of such an activity and relate each idea to the next. This difficulty is what provoked the classification scheme to be developed. It was created to compare the various outputs of prototypes of future things to make it easier to compare different prototypes to one another. And from there it may be possible to further understand how people design the future.

It can be noted that this single-class design activity was brief in nature. The toy project to design a greeting card was convenient to the time allotted in class. Additional work for students allowed for them to dive more deeply into solving more authentic, discovered, real-world type problems over an extended period of time over the run of the course.

Discussion

From this work we see optimism about the evolution of technologies imagined. But there are barriers students must consider how far out of a time horizon they are able to work with. This may have implications for how we might frame and scope design challenges for students and how we might inspire and capture students' excitement for an out-there future for design work in the classroom. Students may be fixated on a short-term or long-term time horizon based on the prompt of priming given with the specific design challenge. This may have implications for how we ask or frame design challenges. Simply projecting a task for today versus tomorrow is an interesting framing that deserves more exploration.

With the findings in mind the team was able to form conclusions and possible theories about the way engineering students specifically prototype for the future. Please note most conclusions are about the future since most of the prototyping had to do with the present which acted as a baseline and the average person prototypes for present times were nearly identically to another.

Summary

Students often use existing commonly available technologies and/or methods to prototype present items. For near future things they may use existing less cost-efficient technologies, such as an iPad carrying drone, seen in the Results section, to do novel activities. For the far future students generally come up with concepts that do not necessarily have known ways to implement them, the brain micro-chip, also shown in the Results section.

It can also be seen how students use empathy to prototype. Framing the activity in the manner chosen students were able to easily tap their empathy to understand how the average person feels about Mondays. This empathy component was evident throughout the prototypes, both present and future.

Implications

Based on the findings and conclusions drawn from them, one can further produce implications for both design and education. In terms of education, the results show the importance of framing a design question. This is seen through how the prototypes differed between present-day and future. Designing the same product based only on the imagined time horizon changed the different artifacts.

Regarding design work, say in a non-classroom setting, the findings presented show how the level of specificity of design criteria affects the outcome. This can be utilized by a team to produce extremely specific designs if a goal were in mind, versus bulk prototypes to attempt to find a possible solution to the design problem. While there are many notable implications, at this point future work with a basis in this project could present new ones and or confirm or correct what has been presented thus far.

The short-term activity for greeting cards may not be a very complex problem. The bridging of something familiar to something ambiguously framed out into the future however, may be a useful yet simple task reframing that is worthwhile to explore in this paper. With all else being homogenous, we find it useful to use this short-term classroom intervention to better get at the paper's objective about how students may design for now and for the future. There are implications here that could very well be extended to more complex systems, and for design challenges of longer duration. That being said, the complexity of designing for a system with a person at the center of it, and understanding what latent or expressed needs someone may have is of considerable complexity, with some variability based on the user and point of view, as well as quite a number of feasible, viable, and desirable solutions. Human-centered design may appear simple but it involves the complexity of people in consideration of a designed solution. This exploration of designing for the future may be extended to more technologically involved and complex systems too.

Future Work

This project offers many avenues to travel down for future work. For example, the group may work with first year students rather than fourth year students. This path may produce insights into how students with less formal education think about and design the future.

Another avenue of interest is working comparable exercises with practicing engineers who are in the later parts of their careers. Their greater experience and generally larger knowledge base could possibly couple together to form quite interesting thoughts on the future and how they would design it. Additionally, more investigation and increased numbers of collected artifacts may allow the research team to build on our qualitative research methods to measure some of our categories quantitatively to confirm our exploratory findings. This may be of interest and translate to engineering educators more broadly.

We have used the end products students have created during a brief classroom design intervention and challenge to begin to explore how prototypes for now and prototypes created for a future timeframe may be approached differently. Connecting what students have made to their own espoused values and beliefs about the future is good fodder for future work and extension to this research project. In addition to capturing what students create it may be useful to interview selected students to explain their process and modes of thinking to arrive at their solutions. It may be possible to concatenate students' perspectives into further classifications of their world views. Connecting student practice as well to the concept of worldviews and/or mindsets is an interesting problem to tackle for future work.

Overall, this topic of interest has only begun to be unraveled. Our group has a solid foundation and looks forward to studying how prototyping the future relates to engineers and engineering students and how they view what the future may be.

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Appendices

First Scheme Iteration

First Four Digits
Prototype number in Catalog

First Set
L = Low Fidelity

M = Mixed Fidelity
H = High Fidelity

Second Set
F = Feels Like
L = Looks Like
W = Works Like

Third Set
number of materials used

Fourth Set-balance feasibility and viability
E = Existing Technology
N = New Technology
I = Inaccessible Technology (Cost & Availability)
A = Accessible Technology (Cost & Availability)

Fifth Set
L - < 1 day to build
M - 1 to 7 days to build
H - >7 Days to build

Sixth Set

investment
cost of changing - emotional, money, time

Example Classification
0124-M-FW-4-EA-M

Second Scheme Iteration

First Four Digits
Prototype number in Catalog

First Set
L = Low Fidelity
M = Mixed Fidelity
H = High Fidelity

Fifth Set
Approximate number of hours to build (down to 0.25 hrs)
time/personal time investment
resource investment
fidelity=== precision vs quality

Example Classification

0124-M-FW-4-EA-M

Second Set		
F = Feels Like	experiential	
L = Looks Like		
W = Works Like		**NOTES/IDEAS**
		investment cost of changing - emotional, money, time
Third Set		
number of materials used	how it might be used	building type? Work on second set, more specificity.

Fourth Set-balance feasibility and viability

E = Existing Technology	Publicly on the market
R = Technology in Research	Newly developed/developing technology
N = Non-existing Technology	New ideas, something that doesn't explicitly exist

IF RELATIVELY EXPENSIVE **AND** 'R' **OR** 'N'

I = Inaccessible Technology	infeasible/ practical vs impractical ingenuity

IF RELATIVELY INEXPENSIVE **AND** 'E' **OR** 'R'

A = Accessible Technology

Final Scheme Iteration

First Four Digits	**Fifth Set**
Prototype number in Catalog	Approximate number of hours to build (down to 0.25 hrs)

First Set
L = Low Fidelity
M = Mixed Fidelity
H = High Fidelity

Second Set
F = Feels Like
L = Looks Like
W = Works Like

Third Set

number of materials used

Fourth Set-balance feasibility and viability
E = Existing Technology
R = Technology in Research
N = Non-existing Technology
IF RELATIVELY EXPENSIVE **AND** 'R' **OR** 'N'
I = Inaccessible Technology
IF RELATIVELY INEXPENSIVE **AND** 'E' **OR** 'R'
A = Accessible Technology

Activity Artifact Classifications

0001-L-LW-2-EA-0.25	0011-L-LW-2-EA-0.25	0021-L-W-2-EA-0.25	0031-L-LW-2-EA-0.25	0041-L-LW-3-EA-0.5
0002-L-LW-3-EA-0.25	0012-L-LW-4-EA-0.25	0022-L-LW-2-EA-0.25	0032-L-W-2-RI-0.25	0042-L-LW-2-EA-0.25
0003-L-LW-3-EA-0.25	0013-L-LW-4-EA-0.25	0023-L-LW-2-EA-0.25	0033-L-LW-3-EA-0.25	
0004-L-LW-4-EA-0.25	0014-L-LW-3-EA-0.25	0024-M-FL-4-RI-0.5	0034-L-L-3-EA-0.25	
0005-L-LW-3-EA-0.25	0015-L-LW-2-EA-0.25	0025-L-L-3-EA-0.50	0035-L-LW-2-EA-0.25	
0006-L-LW-2-EA-0.25	0016-L-LW-2-EA-0.25	0026-L-LW-3-EA-0.25	0036-L-W-3-RI-0.5	
0007-L-LW-4-EA-0.25	0017-L-LW-2-EA-0.25	0027-L-LW-3-EA-0.5	0037-L-LW-2-EA-0.25	
0008-L-LW-2-EA-0.25	0018-L-W-2-EA-0.25	0028-L-L-2-NI-0.25	0038-L-W-4-NI-0.25	
0009-L-LW-2-EA-0.25	0019-L-LW-2-EA-0.25	0029-L-L-4-RI-0.5	0039-L-W-3-EI-0.25	
0010-L-LW-2-EA-0.25	0020-L-LW-2-EA-0.25	0030-L-W-3-NI-0.25	0040-L-W-2-NI-0.25	