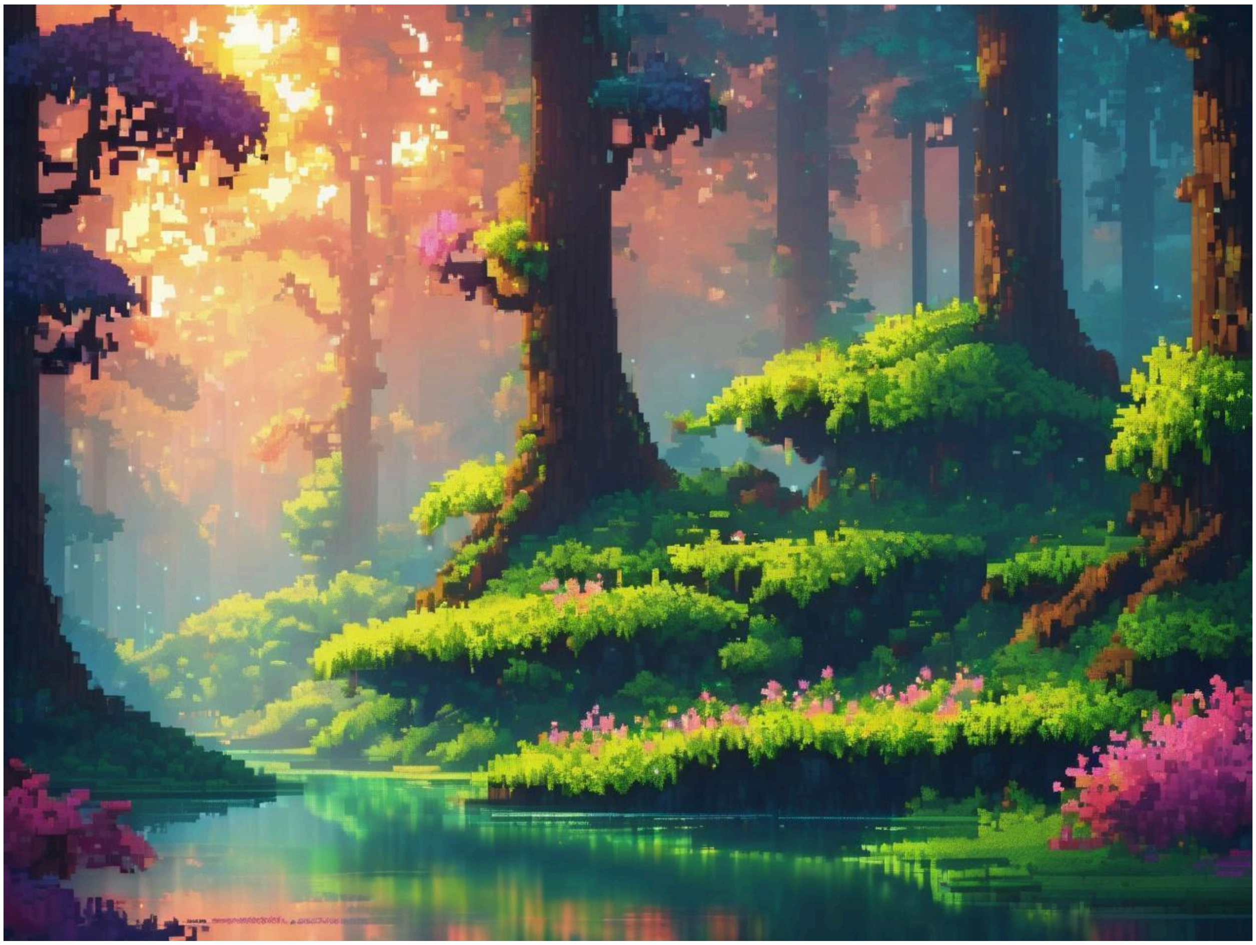
A Guide To Engineering Design



A Handbook Written by Jaival Patel

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1.0.0 Introduction

The handbook is created to serve as a guide on how to conduct Engineering Design. It is written in reference to the author's (Jaival Patel) experiences in his first year of Engineering Science at the University of Toronto.

The handbook is laid out in a manner to understand how Jaival Patel undergoes Engineering Design including:

1) His positionality and perspectives on Engineering Design.
2) Tools, Models, and Frameworks used in the process.
3) Impacts of each tool, model, and framework used on applied projects conducted.

The reader might be wondering why this is written on an online document instead of a fancy website. The reader should be reminded that the purpose of the handbook is to reference my future self and my colleague on how to approach Engineering Design. Having it on an online document has two advantages:

- **Strict Formatting**: Due to the strict margins and line spacing of the template, there is only a certain amount of text that can fit on one page. Moreover, there is frequent usage of converting information through bullet points to impose conciseness. Everyone also has a lot of things going on in their lives, and so, no one wants to spend their time reading extra text.
- **Simplicity:** As will be discussed in the author's values, the author likes designs to be simple as it makes it easier for the stakeholders to interact with them as they are not overwhelmed by various components of the designs. In this case, having a white document with black text allows the reader to easily grasp information about the author as an Engineer. There is no extra color to distract them from the content.

2.0.0 Position

The author is both an **Engineering** and an **Engineering Student**.

- As an **Engineering Student:** The author is learning the theory (i.e., calculus, molecules and materials, etc) and practices (CAD, programming, etc) to be able to address opportunities successfully.
- As an **Engineer:** The author is applying the knowledge taught from their Engineering courses in design opportunities at UTAT where the author is developing a test stand for the Liquid Propulsion Rocket, as well as their programming expertise at his Co-op Lunr developing ground-computer software.

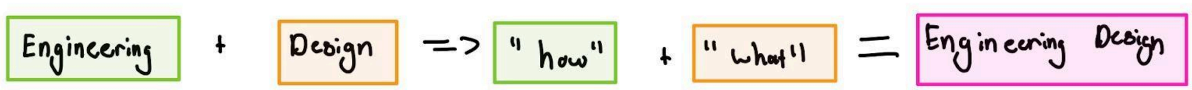
By having spent time in both perspectives, the author has started to grasp what Engineering Design truly is. However, from their perspective, to understand what Engineering Design is requires an understanding of what Engineering and Design are separately.

Engineering: The process of bringing abstraction to reality using knowledge either documented, observed, or through intuition.

The author's definition of Engineering arises from the phenomenon of comparing engineering designs. When evaluating different engineering projects on which one is the "most engineered", it becomes difficult to evaluate each project based on intentionality, impact, and if they have constraints, criteria, etc. This is mostly because each engineering project is made with the intention of a designer (rather small or big), where their decisions such as creating certain constraints, using certain methodologies (or models), and criteria revolve around the design space they have set. For example, consider the project of the lemon battery powering a hypercar [2]. This was more impressive than a Lithium Ion battery although they achieve the same purpose - why? Because the lemon battery was built from scratch with materials at home. It was the process that stood out rather than the end product.

Design: Design is the "what". It is the intention, constraints, and criteria of the idea the designer has in mind.
The thoughts of "what", "constraints and criteria to ensure it is impactful", "what it should achieve", etc, are all thoughts that a designer has before manufacturing their idea because, by natural tendencies, they have the desire to make their idea the best as possible [7] - thus naturally creating such thoughts and analyses of how to achieve such a task. Now, such thoughts define the characteristics of what their final idea will look like in reality, which lines parallel with the dictionary definition of design: *something that is made, such as a building, book, machine, etc* [6].

Engineering Design: Engineering design is the combination of the "how" and "what." It is the practice of planning, ideating, and recursively improving the idea while manufacturing it in the process.



The author's formula for Engineering Design

The author's definition spotlights the essence of what engineering and design are, as well as how they work together based on the two definitions above. It connects the thoughts (the perspective of the designer) of the "what" with their pursuit of making their idea into reality - the "how".

3.0.0. Biases and Values

This section refers to the author's biases and values relating to Engineering Design. It should be noted that not all of them have been stated, but rather only a few important ones.

3.1.0 Biases

Just like everyone else, the author does have a few biases that have impacted his perspectives on the topics that are included in this handbook.

- As an Engineering Student, he is new to formal Engineering Design. Therefore, he may not have full exposure to various tools, models, frameworks, knowledge, and practices that may be described in the handbook due to the lack of experience.
- With his limited experience, he has assumed that Engineering Design is a linear process where once one begins brainstorming and chooses a specific solution to an opportunity, they cannot go back to the brainstorming process (as it would be wasting a lot of time). It should be noted that this was an initial bias coming into the field of Engineering and has been addressed through various projects that will be discussed in the handbook.

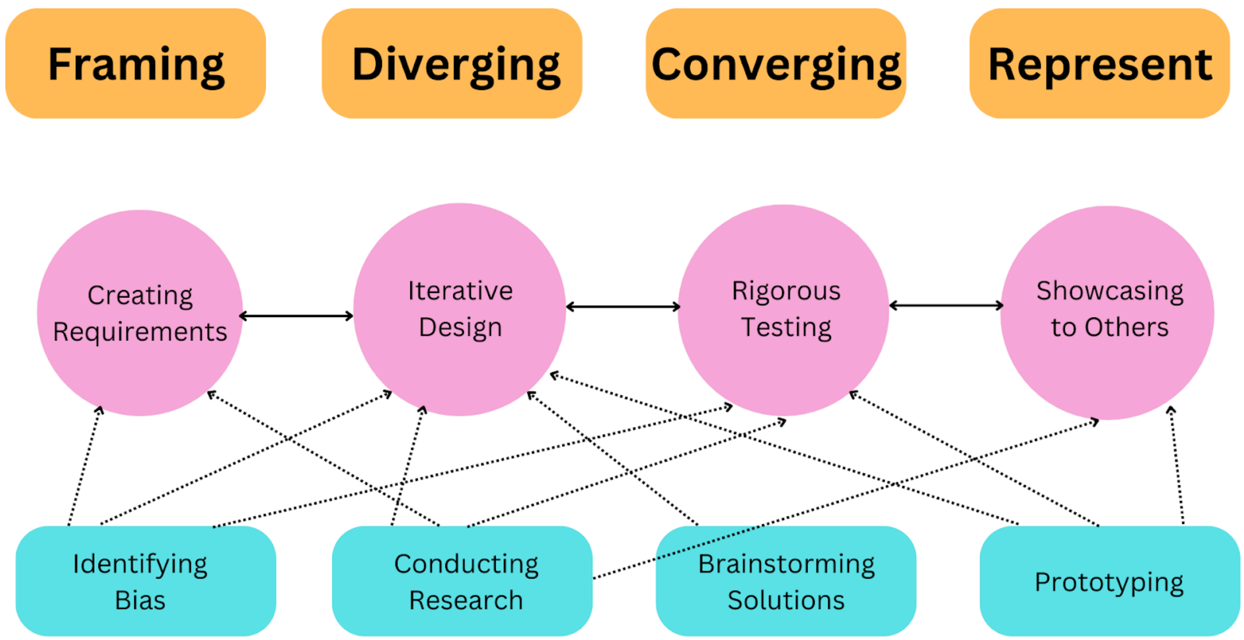
3.2.0 Values

The author has 4 main values:

- **Simplicity**: Just like Leonardo DaVinci once said, *"Simplicity is the ultimate Sophistication"*. Keeping the design "simple" allows designers to be organized so that they can track changes, as well as see where improvements have to be made on the design (rather than looking through each feature/component, which may take a long time). Simplicity also positively impacts the stakeholders. If the design was complex and had a lot of features (i.e., had a lot of buttons), the stakeholders would be distracted from the actual solution, not addressing the actual opportunity since they never get to access the solution itself.

    - This has mainly affected the author’s design choices where he has often gone for a mechanical solution rather than an electrical one as he does not want the stakeholders to be distracted by all the electrical components instead of the solution itself. Such choices will be seen further in the handbook in the examples.
- **Recursive Design**: It should be noted that due to his bias of Engineering Design being a linear process has slowly been addressed over time, he has developed a value where going back a few steps in the design process is essential for effective rescoping (will be mentioned later in the handbook).
    - This allows the engineering designer to stay on track with their ultimate purpose with their idea while simultaneously exploring various areas of the design space.
- **Leadership**: This may sound counterintuitive, but the author likes to take the leadership position for most group-related Engineering Design projects. He likes to guide and motivate others to pursue challenging tasks that will give outstanding results. These results often come in the form of great design decisions and character development.
- **Responsibility**: The author does the tasks that are required and attends all group meetings. It is simple, but yet crucial in successfully submitting Engineering Solutions on time. He expects his colleagues to do the same.

4.0.0 Engineering Design Process



Graphical representation of the author's Engineering Design model.

The author's Engineering Design can be categorized using the modified FDCR process [5]:

- **Framing**: establishing the design space (i.e., what to consider as the opportunity). What is the opportunity? What are the requirements associated with the opportunity?
- **Diverging**: Coming up with ideas to address the opportunity. There are rigorous methodologies that allow for a productive session of coming up with ideas.
- **Converging**: How can one choose the best ideas as a solution? Some may develop proxy tests, prototypes, more research, etc, to narrow down their set of ideas. If one cannot converge further, re-framing is needed where more requirements or an expansion of the design space needs to be made.

- **Representing**: How can one deliver the solution in a manner that is concise and comprehensible to everyone?

The author's design process is non-linear. Oftentimes, he may repeat a process multiple times, go back a step during the process, etc, as expressed in his values above with *recursive design*. This philosophy is also indicated by the "double-headed" arrows on the diagram above.

It should be noted that the turquoise boxes above in the diagram represent the main actions that occur at each step of the process. Each step in the design process is approached with a different mindset.

Requirements Model: The mindset here is to be like a baby. Babies have incredible curiosity - they wonder about everything they see, hear, and touch. When establishing a design space, one must understand what the opportunity entails completely. If not, they will introduce biases that may hinder the accuracy of your proposed solution in the end. As a result, one may ask as many questions as possible about the opportunity

- What does the opportunity entail?
- How did the opportunity come to be?
- Does the opportunity impact any other stakeholders?
- How do the stakeholders feel about the opportunity?
- How would the stakeholders go about solving this opportunity?

By doing so, they will be able to create effective requirements that can guide them in the right direction. It is almost like learning Math proofs. One must ask a lot of questions to understand what the proof is about (i.e. what does this lemma say, why does the author use a certain theorem rather than another, etc) - Engineering Design is the same.

Iterative Design: The mindset in this stage is similar to an Engineering Student. How can one learn the most about my product? What theories, tools, and tests can be used and developed to learn more information about the behavior of my design? Just like an Engineering Student, this process requires one to be open-minded as lots of information from varying resources (i.e., Interactions with stakeholders, research papers, experiments, etc) may go against or with the arguments developed on why their design may be effective.

Presenting to other people: The author approaches this section like an artist. How can one communicate the main message on the canvas without being there to explain it to the audience? Or in the context of Engineering Design, “How can one communicate how the design addresses the opportunity without them being there to explain it to the stakeholders?” Typically, this involves slideshows with smaller text, but more visuals (as 65% of individuals are visual learners [1]) as well as, intentionally creating a simple design to make it easier for stakeholders to intuitively understand (reflecting the value of *simplicity*).

Example: Praxis II Showcase Poster. The author wanted to reflect on the main ideas of how his Engineering Design (Sync Tube) addresses the opportunity of canoe synchronization.

Praxis II Showcase Poster.

Although many posters had complex diagrams of molecules interacting with each other and physics equations, the author decided to display an image of how the design is used (in the middle of the poster), and 5 bullet points of its features to give an idea to the stakeholder of how it functions rather than how it was developed.

Sync Tube final design [left] and electrical design on [right]. Note the excess amount of components that are being added such as the circuit board and the amount of power it is taking.

Moreover, Sync Tube is a mechanical design. The author's team (Victor Weng, Nick Wang, and Joshua Chung) initially had an electrical design to present, but they realized that a lot of people were caught up with the gimmicks of battery usage and electrical power, instead of the solution. Therefore, they stuck with the mechanical design to primarily present, which allowed the stakeholders to care more about its intention of creating an audio queue where they were intrigued with its results.

5.0.0 Overview of Projects

Throughout the handbook, the author will reference a few projects they have started in 2023/2024:

- **Praxis I - Clip on a Cup (Dharsh Nagrani, Adam Kabbara, David Li, Jaival Patel)**: A body clip that can be applied anywhere on the body to hold coffee cups to reduce spillage while traveling around campus.
- **Praxis II - Sync Tube (Victor Weng, Joshua Chung, Nick Wang, Jaival Patel)**: A shoulder attachment with a metal tube and ball. The ball rolls down a horizontal 3D-printed tube and collides with the metal tube making an audio queue as a signal for rowers to move their paddles.

It should be noted that the design process for each project will also be presented as a reference.

Projects outside of the course that make an appearance:

- **UTAT - Liquid Test Stand**: Developing Test Stand for liquid propulsion rocket cold and hot flow tests.
- **Lunr - Ground-Control Software**: Developing ground-control software with Go, Python backend, and Flask Frontend.

6.0.0 Framing

Framing is the foundation for starting Engineering Design. It is defining the "space" which one considers to be an opportunity to work with.

Empty Space in the Universe. A symbol of choosing the "space" (an opportunity) in a cluster of stars (other opportunities).

Different designers may have varying assumptions and perspectives on what should be the design space, but this is what Engineering Design is as expressed previously - the reflection of the designer (view **2.0.0 Position** for more information). It is also the reason why there are many solutions to one opportunity.

Although a design space can be arbitrary, to make a design for an opportunity, it is important to understand its stakeholders, create requirements, and study existing solutions. These give one an idea if they have the expertise to pursue an opportunity and if it is worth their time as an Engineer. This can be quite daunting at first to understand an opportunity, but there are varying tools to assist one during this process including:

- Requirements model

- Research tools

6.1.0 Requirements Model

Requirements model is the first step one should take in understanding their design space. It consists of the following components:

- **Stakeholders**: Who are the communities, individuals, and figures that are associated with the opportunity at hand? What are their perspectives on the opportunity? What are their values?
- **Objectives**: What should an optimal design do? Can be split up into two different types:
  - **High level**: General and basic requirements that first come up when thinking about objectives. They are often the "common-sense" ones.
  - **Low Level**: More specific objectives that require a little more thinking. At times, it may also require one to look at reference designs or research handbooks.
- **Metrics**: A quantifiable measurement that can be made for every design. Is used to compare each design during the converging process.
- **Criteria**: What is the ideal result of the quantifiable measurement? What "should" the result be relative to the opportunity?
- **Constraints**: The maximum or minimum result a design can make. It is satisfied for each metric and often requires Standards to define.

Example: Sample Requirements created for Sync Tube in Praxis II and Clip on a Cup in Praxis I (image below for reference). Note the conciseness of the metrics as well as the constraints. This ensures that the author can measure the effectiveness of the design more easily against the requirements.

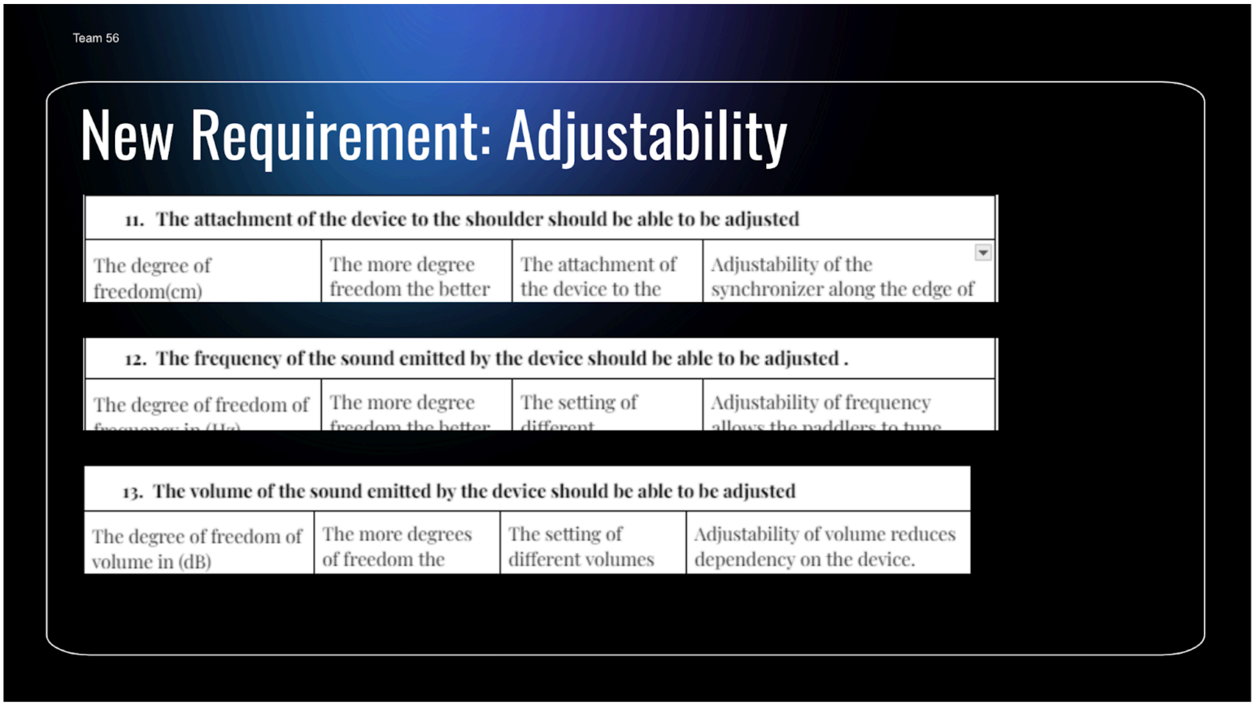
Metric	Criteria	Constraint	Justification
3. The frequency of the sound amplifier must be distinct from the ambient environment			
Frequency (hertz) calculated using the frequency formula which relate to material stiffness)	Frequency difference between ambient frequency and device frequency larger the better	Must be greater than 100 Hz(ambient frequency) less than 2000 Hz(hearing discomfort level)	The frequency generated by the design must be distinct from surrounding frequencies of the environment.
4. Sustainability: The design should not produce excess waste(harmful material to recycle)			
The mass (g) of environmental harmful materials which could pollute the water.	N/A	The amount of harmful waste produced should be none	The design should not produce any pollutant that could contaminate the water source.
5. Effectiveness: The device should produce an instantaneous signal as the paddle strikes the water			
Time (ms) that is produced by the synchronizer as the paddle strikes the water	The less time duration when the device produces its signal after the paddle make contact with the water, the better	The time interval between the signal and the paddle contact less than 1 second	In order to ensure synchronicity, it is important that the device be precise in producing a signal during the exact moment of the paddles down stroke.
6. Safety: The design must not introduce additional risks in its use			
Must pass Section 4 of Canoe Kayak Canada's Safety Code. Code[13] Unit: None	The more checks passed, the better.	All requirements in Section 4 met	For our design to be used it must be cleared by the governing bodies of the sport and must also be made sure to be safe for use, doing this will increase confidence in our design and allow for its widespread use throughout the sport

#	Objective	Metrics	Criteria	Constraint
1	Will not spill from ranges of common movements on route to destination (I.e., jumping downstairs, running. Sitting, standing, acceleration/deceleration, anything causing the beverage to slosh).	% of spilled liquid (mL/mL)	The less the spillage the better	% spillage must be reduced during movements in all three axes (x, y, z)
2	Totally hands-free	Yes or No	If yes, better	Hands must not be occupied by the coffee cup at all. The coffee cup should be on the body.
3a	Support diameters of typical disposable hot coffee cups	millimeters (mm)	57mm minimum to 89mm maximum at least	Larger range is better supported diameters the better
3b	Support the heights of typical disposable hot coffee cups	millimeters (mm)	89mm minimum to 178mm maximum at least	Larger range of supported heights the better
4	Must be able to withhold loads without causing excessive strain in any body parts.	Newtons (N)	Greater loads withheld the better	Must hold loads in 3 axes without
5	Liquid in cup must have a minimal displacement in all axes when subject to impulse or jerk.	Frequency of being faced with impulse (percentage) during normal activity	Less the better	

Sample requirement model for Sync Tube from Praxis II [left] and requirement model for Clip on a Cup from Praxis I [right].

It should also be noted that often, one may have to remove certain requirements or add to advance their progress in their design. This usually occurs when the designer is at a stalemate and requires reframing of the opportunity.

Example: For the reframing for Sync Tube, the author's team decided to add a requirement to support their design in addressing the opportunity (image below for reference). Since Sync Tube is designed to help synchronize all beginner rowers, the author's team must take into consideration different-sized athletes, which they only recognized during reframing. As a result, to incorporate this consideration, they needed to add a new requirement reflecting adjustability to further progress their design, which was communicated in Showcase as seen on the slide below.



One slide from our Showcase presentation for Sync Tube portraying a new requirement post reframing.

6.2.0 Research

Although the design is unique to the designer's perspective of the opportunity, not everything must be unique - one of which is research. Research is used to solidify arguments about why one's design may be valid, spark ideas, identify potential issues that may arise with a feature of the design, and expand one's conscience in the design space.

There are two types of research:

- **Primary**: Through experiments and interacting with stakeholders. It is the act of personally seeking information without a documented source.
- **Secondary**: Research from documented sources including research papers, books, articles, etc.

However, it should be noted that with the ease of communicating any type of information, one may be subjected to false information especially when conducting secondary research.

6.2.1 CRAAP Test

That is where the CRAAP test is handy. CRAAP is a tool to evaluate how reliable a source may be.

- **Currency**: When was the information dated? Has the information evolved since then?
- **Relevance**: Does the source satisfy your needs?
- **Authority**: What is the background of the author and is it legitimate? Do they have the experience required to write about the topic?
- **Accuracy**: How do you know the information is correct? Has it been validated from an experiment or cited?
- **Purpose**: Why did the author write it? Do they have a purpose outside of communicating the right information that may not align with your desires?

Example: The CRAAP Test was symbolized in the Design Brief in Praxis I where the author's team wrote about the darkness at the Robarts Cafeteria. Note how they explicitly mentioned the *Canadian Center for Occupational Health and Safety* along with the citation to portray that the CRAAP test was conducted by checking the authority of the author.

> **2.1 Opportunity**
>
> The primary opportunity addressed in this brief is the development of a lighting solution tailored to meet the specific needs of both cafeteria workers and students at UofT. The significance of this opportunity is underscored by research from the Canadian Center for Occupational Health and Safety, which highlights the positive impact of proper lighting on eye health and workplace productivity. Although traditional lighting systems, such as fluorescent and incandescent lights, have been the standard, they come with inherent limitations that require innovative solutions. [1.1]

Opportunity section in Design Brief from Praxis I.

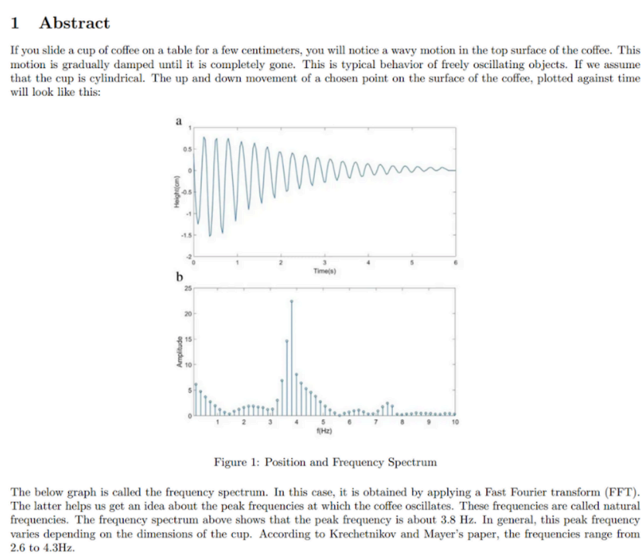
6.2.2 (Modified) Scientific Method

When it comes to talking about the scientific method, the first thing that comes to people's minds is scientific experiments. While this may be true, it can also be used in primary research if experiments are being done to validate the results. There are 7 steps to part of the scientific method, but the last one is modified [4]:

1. Ask a question
2. Perform Research

3. Establish a hypothesis
4. Test the hypothesis by conducting an experiment
5. Make an observation
6. Analyze the results and draw a conclusion
7. Compare results to theory and similar experiments done in academia (instead of presenting the findings as originally documented in the Scientific Method)

Example: For Clip on a Cup in Praxis I, the author's team developed an experiment to track the motion of a liquid and analyze it with a Fourier Transform to see how well it can stop liquid from sloshing around. They did initial secondary research, which is written in the Abstract, and conducted their experiment. After getting some results, they compared it to academia (or more specifically, the cited paper in the Abstract) in Section 6 of the experiment document, which was their analysis section. Steps 6 and 7 of the Scientific Method were combined.



1 Abstract

If you slide a cup of coffee on a table for a few centimeters, you will notice a wavy motion in the top surface of the coffee. This motion is gradually damped until it is completely gone. This is typical behavior of freely oscillating objects. If we assume that the cup is cylindrical. The up and down movement of a chosen point on the surface of the coffee, plotted against time will look like this:

Figure 1: Position and Frequency Spectrum

The below graph is called the frequency spectrum. In this case, it is obtained by applying a Fast Fourier transform (FFT). The latter helps us get an idea about the peak frequencies at which the coffee oscillates. These frequencies are called natural frequencies. The frequency spectrum above shows that the peak frequency is about 3.8 Hz. In general, this peak frequency varies depending on the dimensions of the cup. According to Krechetnikov and Mayer's paper, the frequencies range from 2.6 to 4.3Hz.

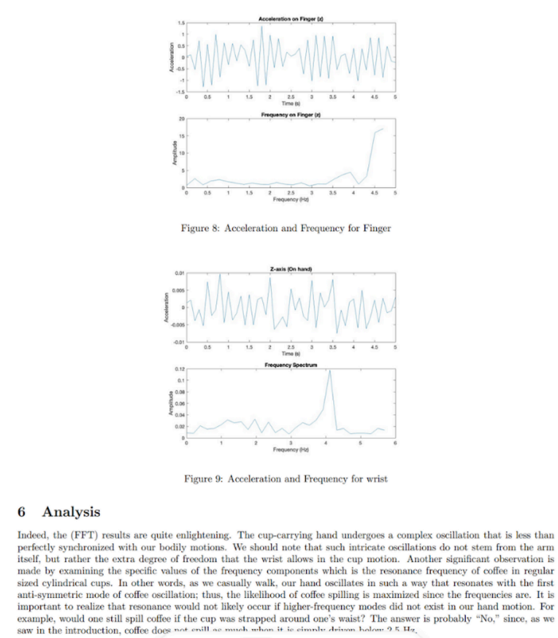


Figure 8: Acceleration and Frequency for Finger

Figure 9: Acceleration and Frequency for wrist

6 Analysis

Indeed, the (FFT) results are quite enlightening. The cup-carrying hand undergoes a complex oscillation that is less than perfectly synchronized with our bodily motions. We should note that such intricate oscillations do not stem from the arm itself, but rather the extra degree of freedom that the wrist allows in the cup motion. Another significant observation is made by examining the specific values of the frequency components which is the resonance frequency of coffee in regular sized cylindrical cups. In other words, as we casually walk, our hand oscillates in such a way that resonates with the first anti-symmetric mode of coffee oscillation; thus, the likelihood of coffee spilling is maximized since the frequencies are. It is important to realize that resonance would not likely occur if higher-frequency modes did not exist in our hand motion. For example, would one still spill coffee if the cup was strapped around one's waist? The answer is probably "No," since, as we saw in the introduction, coffee does not spill as much when it is simply driven below 2.5 Hz.

Abstract of experiment [left] and Analysis [right]. Experiment to find sloshing amounts in diverging process in praxis I.

7.0.0 Diverging

As mentioned previously, the main goal of Diverging is to generate as many ideas as possible. The ideas do not have to be the final, but they have to be relevant to the opportunity to remain productive. Although this may sound easy to do, several challenges arise that can negatively impact one's next steps if not taken into consideration:

- **Anchoring**: Diverging is about creating unique ideas. However, it is often easy to revolve around the previous ideas without noticing. Be careful!
- **Bias**: Prevent bias and assumptions from affecting design choices.
- **Inclusiveness**: Ensure everyone's ideas and perspectives are taken into consideration.

7.1.0 Diverging Tools

To take into account the challenges mentioned above, various diverging tools can be considered. There are over 15 tools, however, the ones mentioned in this handbook are the ones used by the author more frequently in such contexts [3]:

- **Brainstorming 6-3-5**
    - Helps with inclusiveness
- **Random Input**
    - Helps with anchoring
- **Mimicry**
    - Helps with bias

The handbook will also discuss the limitations of each tool, how to use them, and their overall significance in the Diverging stage.

7.1.1 Brainstorming 6-3-5

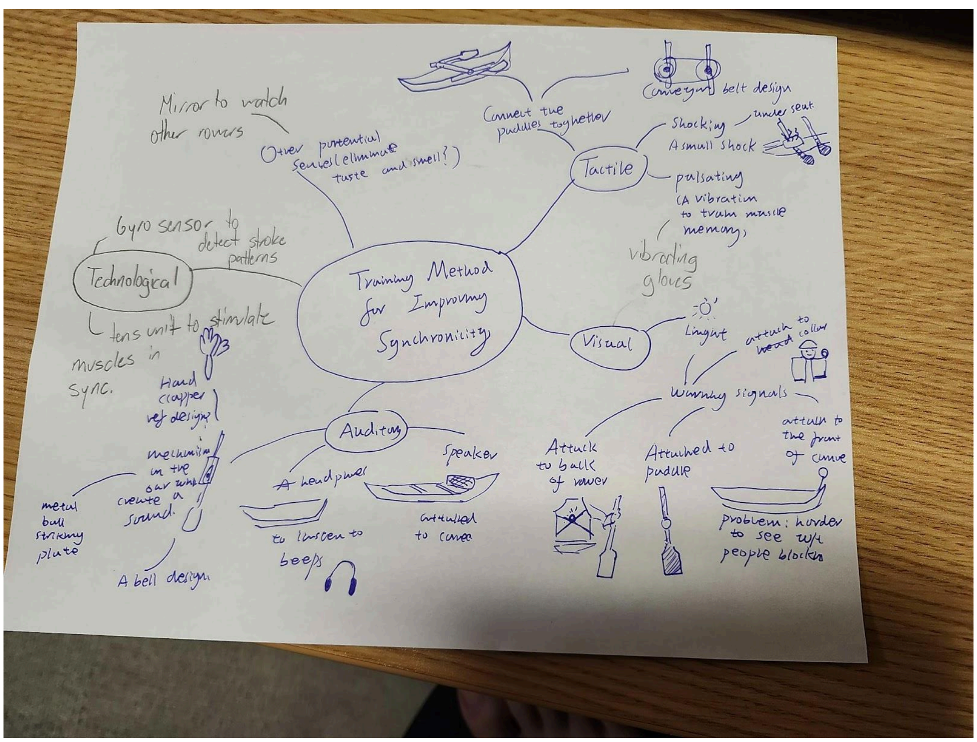
Traditional brainstorming can only have one person speak at a time, or a group of people focus on one idea. As a result, although there may be 4 brains at work, there is only one idea which everyone has to agree or disagree upon. This phenomenon can be unproductive in a diverging stage because the whole purpose is to create as many ideas as possible, but since there can only be one idea communicated, there is a high probability that the other ideas that have not been communicated can be forgotten.

Brainwriting 6-3-5 attempts to eliminate the output of one idea. Instead, each member writes their ideas and every few minutes, everyone “rotates” and expands the ideas of another person.

Methodology

- Within a 5 - 10 interval, each person writes ideas or creates drawings portraying their ideas. This can be done on a piece of paper or online document. No one talks during this instance.
- After the time interval, everyone rotates counter or clockwise such that they have a new set of ideas to expand on.
- Repeat Step 1 until you have visited everyone’s ideas.
- Discuss with the group common occurrences of ideas, which ones were liked and didn’t like.

Example: Brainstorming 6-3-5 done in the initial diverging phase in Praxis II. The author’s team were diverging about ways to improve synchronicity.



Brainstorming 6-3-5 Sheet on ways to create signals for paddle synchronization.

Takeaway: Note how no design involves a body attachment. This was due to the author's team's initial bias that there cannot be any weight on the body as it can prevent strain. However, it was the opposite after further research that there can be no weight on the paddle resulting in our diverging to be somewhat incorrect. Therefore, brainstorming 6-3-5 is subjected to bias and may be inaccurate if biases are not acknowledged and verified.

7.1.2 Random Input

To remove the risk of repeating ideas, the author's team used ChatGPT to generate random objects to spark ideas. These objects were broad but still relevant to the design theme. However, depending on the complexity of the opportunity, the objects that the computer generates can be very random for this method to work. It should be acknowledged that many of the ideas will be bad but will allow one to generate a lot of ideas - the entire purpose of the Diverging stage.

Methodology

1) Find a random object generator like chatGPT.
2) Create a prompt such as "Generate 20 random items related to canoeing"
3) For each object, every member records an idea using the item.
4) Once all objects are complete, discuss the ideas and new perspectives that have arisen from the opportunity.

Example: For choosing a Community to write an RFP about, the author's team was struggling to find community ideas (image below for reference). As a result, they asked chatGPT if it could generate some words for them to spark communities that are related to that domain. For each word, whoever had an idea for a community was assigned to contact them as seen on Google sheet.

Community	Link	Contact Email	#	Idea From
Bike Brigade	bikebrigade.ca	info@bikebrigade.ca		Victor
Young Immigrants in Toronto	Newcomer Youth Engagement Program - Strides Toronto	Kasthuri Jeyaraj (she/her) kasthuri.jeyaraj@stridestoronto.ca Poni Modi (she/her)poni.modi@stridestoronto.ca	437-423-2134 416-525-9280 General Inquiries: 416-438-3697 416-321-5464	Victor
Toronto Indie Game Developers	Canadian Game Devs	contact@canadiangamedevs.com		Joshua
Toronto Writers' Co-operative	Toronto Writers' Co-operative | Toronto ON | Facebook	towc@live.com		Nick
Toronto Film Critics Association	Toronto Film Critics Association - | Toronto Film Critics Associatic	Contact - Toronto Film Critics Association | Toronto Film Critics Association		Joshua
Toronto Urban Sketchers	Urban Sketchers Toronto | Facebook OR https://uskto.ma	toronto.urbansketchers@gmail.com		Victor
Toronto Knitters Guild	Toronto Knitters Guild – Celebrating the Joy of Yarn	info@torontoknittersguild.ca		Paival
Toronto Beekeepers Cooperative	Toronto Beekeepers Collective (torontobeekeeping.ca)	info@torontobeekeeping.ca		Paival
Toronto School Street Guardians				Paival
Ontarion Long Term Care..				Joshua
Live Your Retirement			6472563490	Nick
			8886094754	Nick

Excel sheet of contacting communities that were thought of based on Random Input.

Takeaway: Random Input works for initial diverging as it is very broad. However, if Random Input was used for round 2 of diverging, it would not be as impactful as more specificity is required to generate relevant ideas.

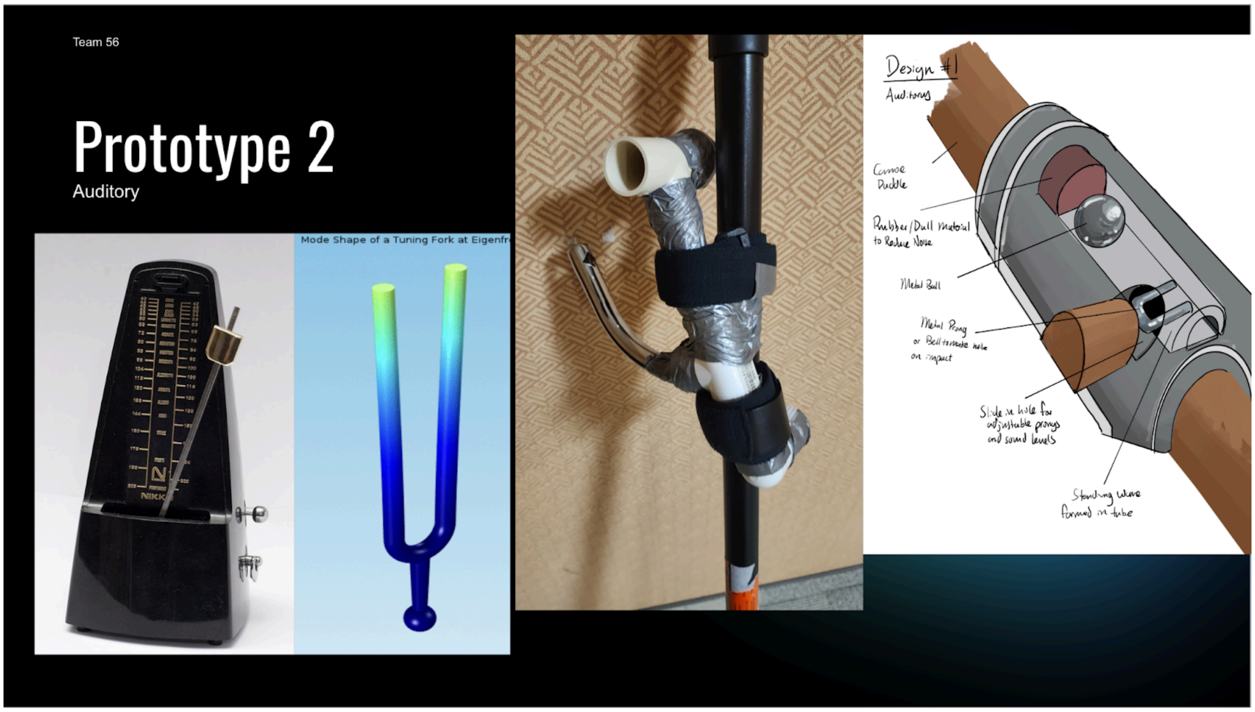
7.1.3 Mimicry

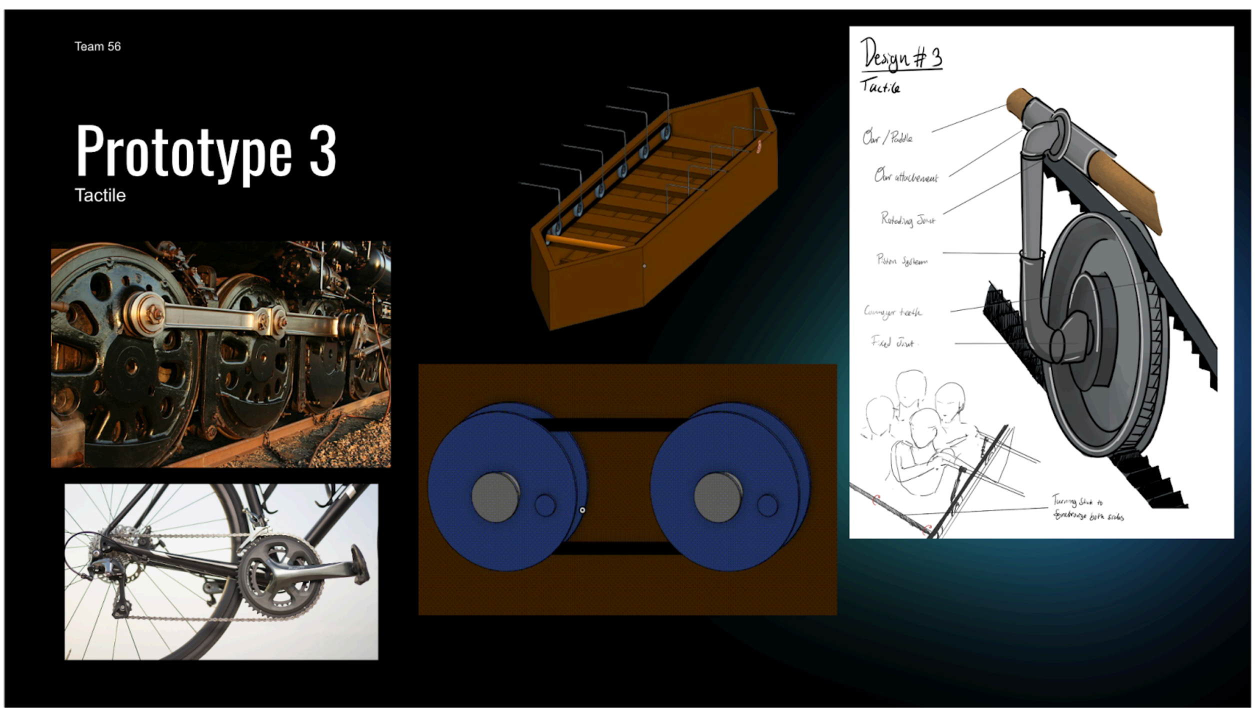
Similar to Biomimicry, the method entails looking at the outside world and taking inspiration from it. This can be from past engineering designs, paintings, sculptures, architecture, etc.

Methodology

1. Identify key requirements of the opportunity. But ensure they are generally such that it allows you to find other objects. Being too specific can discourage one from looking at objects and taking inspiration due to them not being "relevant enough"
2. Observe the surroundings. Every 5 minutes, one must change their location.
3. For everything new that one observes or that sparks their interest, write it down. Describe how it looks, how it performs, and how it interacts with its environment.
4. Every 20 - 30 minutes, discuss with the team how certain objects' features or behaviors can be replicated in the design to achieve its purpose.

Example: The author's initial prototypes at Beta for Sync Tube, which were inspired by the Tuning Fork (i.e., the metal ball hitting certain areas of metal tube to produce different frequencies) as well as a gear system (i.e, from trains and cycles) for a possible automated rowing machine.





Prototype 2 (above) and Prototype 3 (below) of the initial Sync Tube Idea presented at Beta.

8.0.0 Reframing

In the first attempt, it is difficult to have a perfect framing process. However, it does not need to, which is always the initial bias a new Engineer will have - something the author had personally (as expressed in the **Values and biases**) but does get addressed with experience.

A good divergence will reveal flaws in the initial framing of the opportunity including:

- Too broad or narrow scoped design space
- Assumptions that were hidden and not addressed or known.

One will commonly start to recognize the need for reframing after their first rounds of diverging and converging, and maybe even sometimes, after multiple iterations to ensure their design is on point with the requirements and stakeholder needs.

Example: After Beta, for Sync Tube, part of the author's reframing included re-defining their stakeholders. Initially, they considered all rowing athletes but the design space became too large because they had to consider various stroking patterns making it difficult to converge on designs. As a result, to make progress in the design process, they had to converge down to beginners as they were all taught the same rowing technique initially. Image below for reference.

Slide from Showcase indicating a reframing of stakeholders to narrow the opportunity to improving synchronization paddling for beginners.

9.0.0 Converging

Converging is the "elimination" of ideas. As mentioned earlier in the handbook, it is the filtration of bad ideas. The process can be split into 3 sections:

- **Prototyping**: building physical prototypes from initial designs.
- **Testing**: Creating proxy tests to meet the criteria. The test can be as simple as drawing on a piece of paper to going to the lab and heating it to 1000 degrees Celsius.
- **Iterating**: Using results from tests and observations during prototyping, to modify and update the design.

9.1.0 Prototyping

Process in which the initial design concept can be built into reality. It is split into 2 types:

- **Low-fidelity:** Prototypes from everyday materials such as paper, pencils, markers, etc.
- **High-fidelity**: Prototypes from specific materials and built using specific tools like woodwork, programming, and CADing. Typically requires some type of investment either time or monetary.

Tip: One should always try to prototype the most *unbelievable* aspect of the design. This is to truly test if the design is feasible or not in reality when it comes to addressing the opportunity. It is normally done as a low-fidelity prototype to ensure that if there are changes that must be made, it can be done much easier.

Initial low-fidelity prototype for Sync Tube from Metal and plastic tubes, fabric straps, and a broomstick.

Higher-fidelity prototypes are recommended to be done if the low-fidelity one works. It is not always a good idea to go straight to high fidelity without testing if the actual concept works - it will waste resources and a lot of time! However, once one does get to the stage of higher-fidelity prototyping, multiple tools can be used as mentioned earlier in this section. The author will focus on 3 main tools that have been commonly used in his designs:

- 3D Printing
- Programming
- Mathematical Models

9.1.1 3D Printing

3D printing is a good way to build an accurate representation of one's idea into reality. Moreover, computer models can be good but are complex when it comes to producing accurate results since there are a lot of variables to consider to model reality. 3D printing bridges the gap of accuracy and difficulty, by allowing one to test any part in the real world.

3D casing for a final prototype for Sync Tube.

9.1.2 Programming

Every time a design uses a digital component, programming is required to ensure it works in relevance to the design. Most of the programming that was required was with hardware integration (i.e., Arduino), which made a lot of the "unbelievable" aspects of the design.

Though there are two fallbacks with electrical components and programming

1. If hardware is being used, it can add excess weight which may not be ideal.
2. If it is a software-only project, there are a lot of security protocols that need to be written compared to a mechanical design - wasting a lot of time.

Example: Similar to earlier, note the excess weight on the electrical design compared to the mechanical one for the Sync Tube (image below for reference). The motherboard and batteries had a significant amount of weight that was being added, which was not ideal for a shoulder strap as it would cause excess strain to the shoulder.

Mechanical design of Sync Tube (left) and Electrical design of Sync Tube (right).

9.1.3 Mathematical Designs

There are certain relationships between variables that cannot be found online mostly due to the lack of applications. However, although there is a lack of applications, it does not mean that it cannot be used at all! Additionally, for complex designs, a mathematical model is sufficient to understand how feasible a concept is concerning its variables defined.

Example: Flexural Stress Model referenced for the Canoe Paddle that was used to identify the optimal placement of the original Sync Tube attachment on the paddle in Praxis II (image below for reference). By doing further research, it was known that the results of the Young's modulus from the model were too large for the paddle resulting in damaging it, which led the author to make Sync Tube into a shoulder attachment in our second round of diverging.

The frequency is a function of the dimensions of the bar and its Young's modulus.

You need to know what mode of oscillation you are exciting in your bar - there is a hug difference between the flexural and longitudinal modes.

If the rod is bending, you can find the formulas here. The derivation goes on and on... but you should be able to use the formula on the first page (for free-free):

$$f = \frac{1}{2\pi}\left(\frac{22.373}{L^2}\right)\sqrt{\frac{EI}{\rho}}$$

In this formula, I is the second moment of area of the rod - see the wiki article for an explanation and to find the appropriate value for the shape of your rod.

If you have a higher mode, you can find the position of two fixed nodes and use the fixed-fixed equation instead.

And if you have longitudinal vibration, the answer is much simpler - you just have to look at the transit time of the sound wave from end to end. One round trip corresponds to the fundamental frequency, so

$$f = \frac{v}{2L} = \sqrt{\frac{E}{4L^2\rho}}$$

$$E = \rho\,(\,2\;L\;f\,)^2$$

Source extract that portrays relevant equations for a flexural stress Model for paddles.

10.0.0 Testing

During testing, the ultimate goal is to evaluate each design concept against various metrics, and they meet the constraints and criteria defined. However, some obstacles may arise:

- Lack of resources and technology to create a proper test apparatus and method.
- Easy to skew the results towards initial biases and assumptions if the tests are not rigorous.

Such obstacles were addressed with the Modified Scientific Method (view **6.2.2 (Modified) Scientific Method** for reference) expressed above as well as Designing Proxies.

10.1.0 Designing Proxies

As an Engineering student, the author will not always have access to the apparatus and resources of professional engineers when testing for industry standards. At times, tests are required to validate a final product from being completed, and thus, there must be alternative methods to test.

These tests include building a custom apparatus with everyday materials while making a conscious effort to reduce any biases present.

Example: Sample Proxy test conducted for Clip on a Cup in Praxis I before Design Critique (image found below for reference). The author's team put a liquid sensor in the cup to track the motion of liquid and analyze the amount of motion on a computer while moving around. They conducted the test for different holding grips of the coffee cup. The only materials used for the test were an Arduino Liquid Sensor, a Coffee Cup, and Water.

3 Scenarios Tested

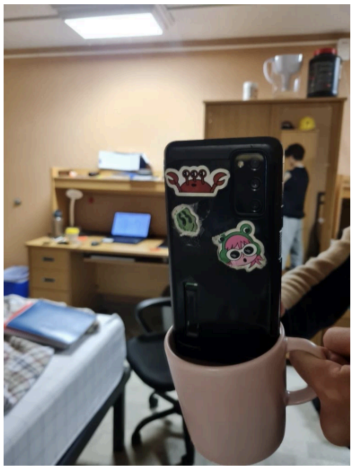


Figure 2: Finger held

Figure 3: Wrist Held

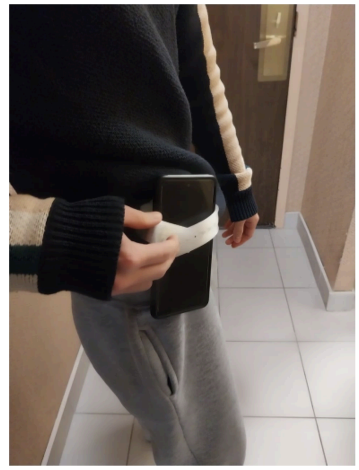


Figure 4: Waist Held

4 Procedure

From experience, we know that our carrying hand is usually strong enough to be essentially unaffected by the coffee's impact on the cup. This subtle insight immensely simplifies the situation: instead of analyzing both directions of influence, we can limit ourselves to one. In other words, we interpret the coffee-cup system as a forced harmonic oscillator. The driving force, which is synchronized with the carrying hand's motion, is directly exerted on the liquid from the inner walls of the cup. If the driving frequency corresponds to the resonance frequency of coffee, the sloshing amplitude reaches its maximum and leads to spilling. Thus, the question that we must investigate is clear: which mode of transport leads to frequencies which coincide with the natural frequency and cause spillage?

By fixing an accelerometer (or, equivalently, a smartphone) to the top of the mug, we record all three directions of acceleration. Since the mug is a hard body, we expect the acceleration measured on any part of the mug to be equal.

4.1 Set up

I used an app in the play store called SensorRecord (any sensor recording app will do). The app will record real-time XYZ coordinates from the phone's accelerometer sensor. The coordinates system used by most Android phones is represented by the figure below:

Extract of sloshing Proxy Test in Praxis I to validate a Clip on a Cup design.

11.0.0 Iterating

Iteration is the process of narrowing down the set of ideas and diverging from those sets of ideas. Note that this process particularly has inspired the author's value of *Recursive Design* as well as addressed his bias that FDCR is linear. The author's Engineering Design method includes **Iterating**, which means that for many of his projects, he has rediverged after converging, which slowly started to convince him that FDCR is non-linear.

The Iterating process consists of:

- **Multivoting**: A voting system used to decide which design choices should be accepted for the next iteration.
- **Pugh Chart**: Comparing designs against requirements and each other.
- **SCAMPER**: Acronym to help combine different features of various designs to rediverge.

11.1.0 Multivoting

At the start of the converging phase, all ideas can look attractive. This is because one does not know initially how to make a rigorous judgment of what they should proceed with first, and thus, they create a vote.

methodology

- Given n ideas and m people, each person gets n/m votes rounded to the nearest integer down.
- Each person casts a vote for their desired design choice. If they like it a lot, they can give multiple votes.
- Each vote is documented privately, and once everyone is done, all votes are recorded publicly.
- The top m ideas are pursued.

Example: Multivoting was used by the author when choosing the RFP to pursue for Beta and Showcase (image below for reference). Notice that many of the votes differed for each RFP as it was based on either what the author's team had experience in like to work in, or that it was an RFP from a known colleague. As a result, there was no factual support and reasoning as to why votes were placed for a certain RFP and instead, it was their biases that were making the decisions for them.

	RFPS										
	A	B	C	D	E	F	G	H	I	J	Total
JH	1	2	1	2	2	2	2	0	0	1	13
NI	2	1	1	2	1	2	2	2	1	2	16
VI	2	0	2	0	2	1	2	0	0	0	9
JV	2	0	2	1	2	1	2	2	0	0	12
Total	7	3	6	5	7	6	8	4	1	3	50

Multivoting on Excel Sheet for different RFP Choices.

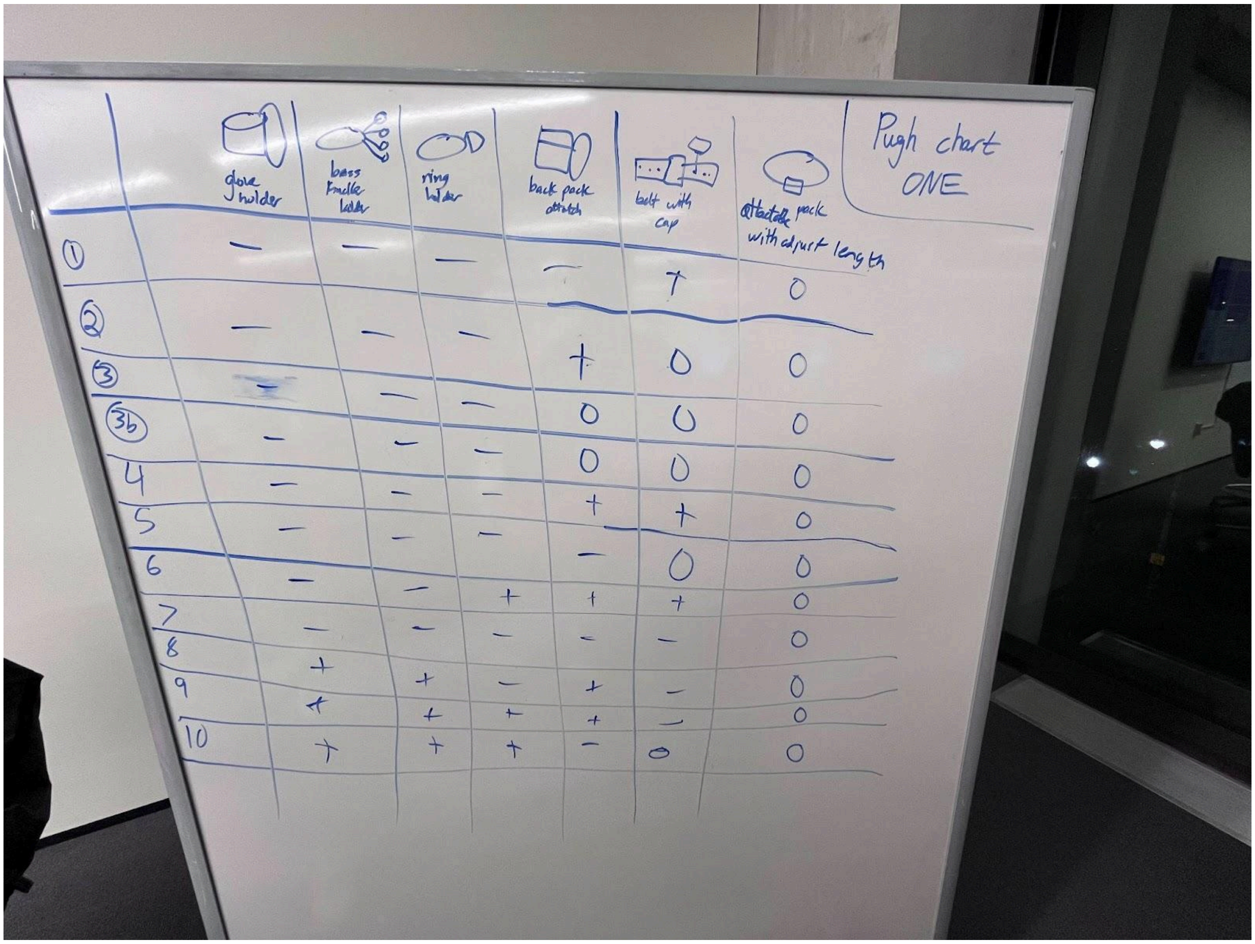
Takeaway: This method is the least rigorous, and should only be used in the initial stages. This is because bias plays a huge role in what idea one chose since they did not have the information to make rational decisions.

11.2.0 Pugh Chart

A rigorous method to determine the best designs using information from research and testing.

Methodology:

1. Select various designs to compare with. These can be from diverging or reference designs.
2. Create a table with designs on one axis and requirements on the other.
3. Using the constraints and criteria, write down if each design did “better” (+), “worse”(-), or the “same”(0) compared to the other designs.
4. Analyze the table to make your final judgment. If two columns have the same amount of (+), (-), or (0), requirements need to be prioritized to make a judgment.



Pugh Chart made to compare different designs to reduce Spillage of Coffee cups in Praxis I.

It should be noted to not sum the +s, -s, or 0s although it may seem tempting. This is due to the fact of losing information about the significance of each requirement as you are normalizing them. If one would like to do so, they can use the Pairwise Comparison, which is similar to a Pugh Chart, but they add the results and compare the totals.

	Walking on UofT campus	Running on UofT Campus	Jumping on Uoft campus	"Athletic movements" (I.e, flips, running football routes, skateboarding...)	Frequency of Drinking Coffee (I.e., attending second cup on second floor at Myhal)	Time spent in crowded areas or enclosed room	Methods to hold the coffee while transporting	Time spent drinking coffee overall	Sum
Engsci Students	+	+	+	+	0	+	-	+	5
Engsci Faculty	-	-	-	-	0	-	+	-	-5

Pairwise comparison made to study different stakeholders for the author's framing of the Coffee Cup Spillage Opportunity in Praxis I.

11.3.0 Scamper

It is very rare that the design one thought of first is the design that makes it to the end. Often, one will want to look at reference designs or other diverged ideas to generate some inspiration to improve their current designs.

Scamper has the following acronym:

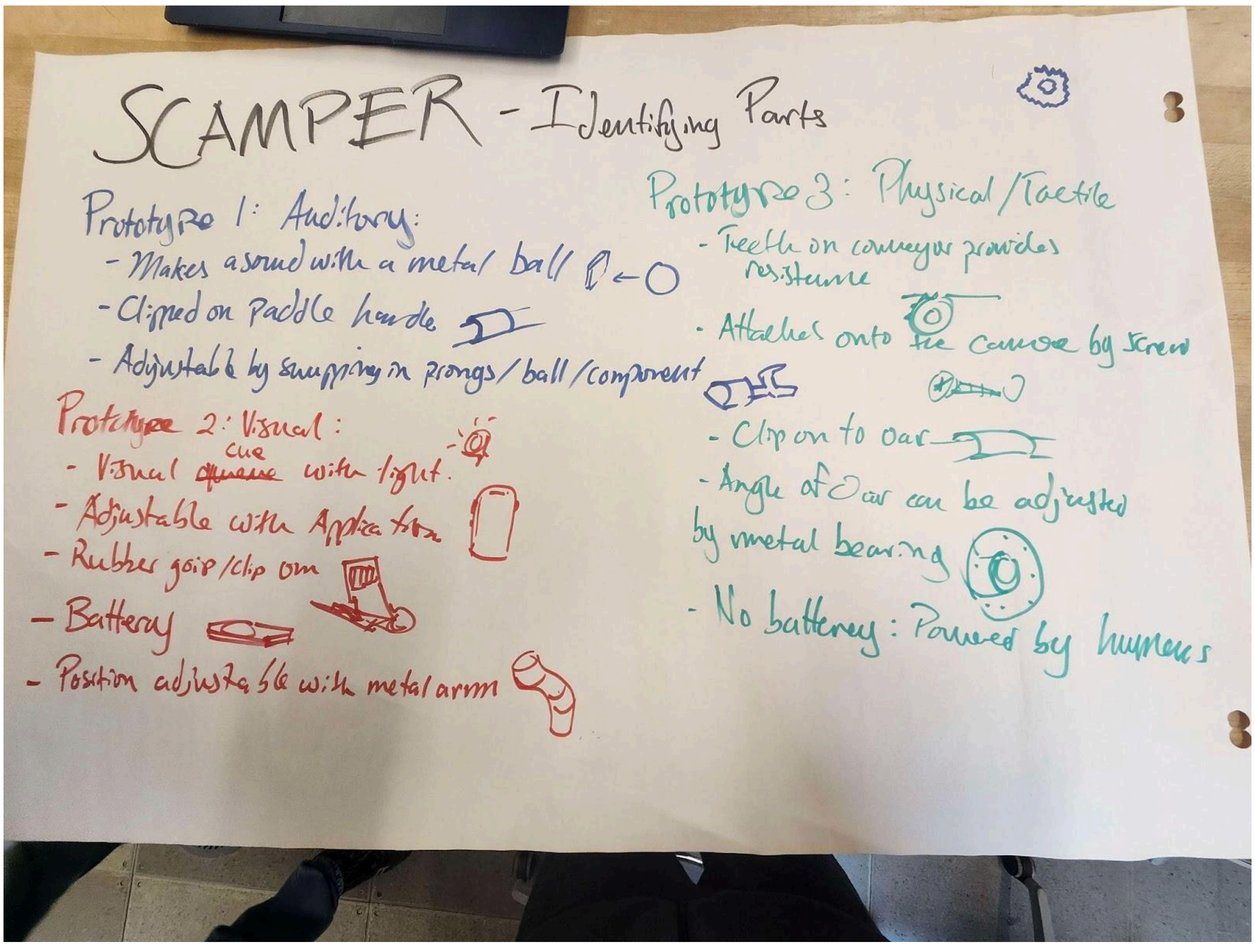
- Substitute
- Combine
- Adapt
- Modify
- Put to another use
- Eliminate
- Reverse

One can ask the following questions as a guide to take into consideration each element

- **Substitute**: Can some feature of the current design be implemented somewhere else?
- **Combine**: Can we combine two designs into one?
- **Adapt**: Can we take an existing design and adapt it to the design?
- **Modify**: Can we modify a part of the opportunity? Would the design chosen function differently in such a case?

- **Eliminate**: Are there features of the design that can be eliminated?
- **Reverse**: Imagine reversing the purpose of the design (i.e., making it fail its constraints). Can we take anything from that?

Example: Scamper done in Praxis II studio after initially converging to find ways to synchronize a team of rowers. Brief notes were made and was a quick process based on preliminary secondary research.



Initial Scamper to think of methods to create audio queues as signals to start rowing.

Takeaway: Note that Scamper is very brief. In the previous example, only short notes were taken and the author's team did not carefully think through all the components. As a result, it should only be used when the ideas are more narrow.

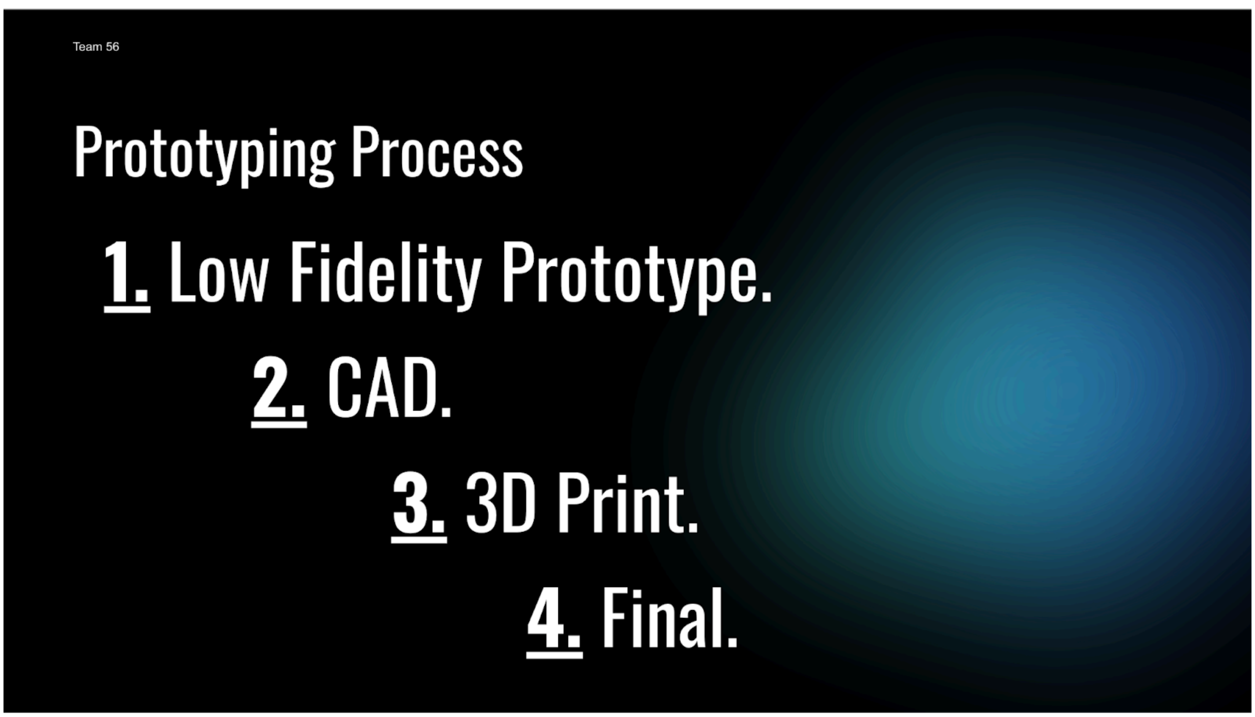
Using it when the ideas are broad will not be as significant and one will not have much information to compare the designs with.

12.0.0 Presenting

After all the hard work has been done in performing good engineering design, it is important to communicate it effectively. To communicate in such a manner, one must ensure they have their research and proxy test results ready to reference to solidify their argument on why their design can successfully address their opportunity.

Takeaway: If doing a slideshow, the key idea is to ensure there are not many words on the slides, but rather, points to guide the audience about what one will talk about for the design.

Example: One slide from the author's Showcase Slideshow presentation of our Sync Tube design. Here the author's team was explaining the entire prototyping process with less than 10 words on the slideshow. This allowed them to have the attention of the audience on them rather than the slides.



Slide from Showcase Slideshow summarizing prototyping process of Sync Tube.

13.0.0 Conclusion

Engineering Design and methodologies to undergo the process vary individual by individual as expressed in the Position. This handbook reflects how the author undergoes an engineering design from defining an opportunity to choosing the final design.

The author is still an Engineering Student, and therefore, will continually learn new methodologies, testing protocols, theoretical models, etc, to expand his skillset. As a result, the position and content described in this handbook are not the final version of the author as an Engineer.

A forest leading into a world of unknowns

Much more is to come…

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