The Engineered Imagination: Student Engineer Handbook

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Last Updated: April 30, 2021

Author Note

Underlined gray text is indicative of an internal link.

Table of Contents

1. Introduction and Position

1.1 My Engineering Design Philosophy

My name is Hamza Dugmag, and I am an engineering student at the University of Toronto. I always knew I wanted to pursue engineering; I enjoyed mathematics and science and wanted to apply them in the real-world to tackle challenging opportunities. However, I am very impressionable on the types of problems I want to solve and the tools I want to use in my work. Therefore, Engineering Science was the obvious choice to pursue; I could learn about my values and interests in the first two years to make a confident decision on where I want to employ my skills. I have embraced this notion of exploring all the resources around me to develop a self-awareness about what I enjoy and what has not worked, which is a key focus of this handbook revolving around my engineering activities.

Before delving into my engineering work, I believe it important to ask why we want to build things and solve problems in the first place. How do we make the jump from *enjoying* math and science to *applying* math and science? Personally, I see engineering as an art because it effectively encompasses the human experience. According to Northrop Frye – a literary critique who also studied at the University of Toronto – literature is about conveying a world we want using the world we have, not about the actual words on a piece of paper [1]. Similarly, I believe engineering is a form of creative expression, one that uses numbers and microcontrollers instead of words and colors. However, instead of dreaming of such a world (as many novelists do), engineering provides the opportunity to build one. Ultimately, this world I want is shaped by my values and interests. My philosophy closely resembles the Hoover Dam model, which I have used as inspiration for my personal design process [2].

1.2 Purpose and Structure of this Handbook

The purpose of this personalized engineering handbook is to organize and reflect on my first-year engineering activities to develop a self-awareness about my design process and guide my future work.

This year, I have collaborated in various teams on many unique and exciting projects. In addition to improving my communication and interpersonal skills, I have refined my personal engineering design process and leveraged numerous tools and models. Thus, this handbook is organized into 4 logical sections:

1. My position as a student engineer and my relationship to design. This effectively establishes the reference point on how I have evaluated my work.
2. First year engineering projects. This portrays how I have put what I learned into practice and allows me to evaluate my engineering decisions and tools in specific contexts.
3. My unique design process focused on specific engineering activities which I find valuable.
4. An assessment of the tools, models, and frameworks that I used throughout first year.

Ultimately, in addition to acting as a checklist for rigorous design, this handbook can remind me about how I approached specific engineering activities and help me select an appropriate tool to use.

1.3 Personal Values

1.3.1 Attention to Detail

My engineering work is influenced by my values. Firstly, I am committed to organization and aesthetics throughout the entire design process, especially when representing my work. I have developed my own standard for clean representation and believe every design team should convene before a project to develop a set of style guidelines. Although I agree with the notion of "form follows function," I am confident that function follows form to an extent. Neatness structures my ideas, maintains my motivation, and improves my efficiency. I start taking my work more seriously this way. Although this consistency may be an artifact of my obsessive compulsiveness, I try not to be a perfectionist because I will never be satisfied otherwise. I have learned to interpret this as a desire to strive for excellence and ties in with my intentionality. By excelling in my work, I become more confident and aware of my actions.

Moreover, I have engaged in various experiences involving graphic, product, and branding design. So, I have an extensive awareness of how a product looks and is perceived by the stakeholders. Since I also see engineering as an art, I enjoy complimenting visual art in my prototypes. I believe that in addition to a product's main purpose, its visual functionality is equally as important because it allows the design team to express their values through a different creative avenue.

For me, the most exciting part of the design process is taking a candidate design and creating engineering drawings and 3D models, such as during the CIV102 project. I am really interested in product design and looking for ways to compliment a product's usability. This includes everything from architecture to user interface design. My value for aesthetic implies that I try to simplify the design as much as possible, while maintaining its technological complexity. I keep in mind that on the user's side, this can also reduce the design's failure rate.

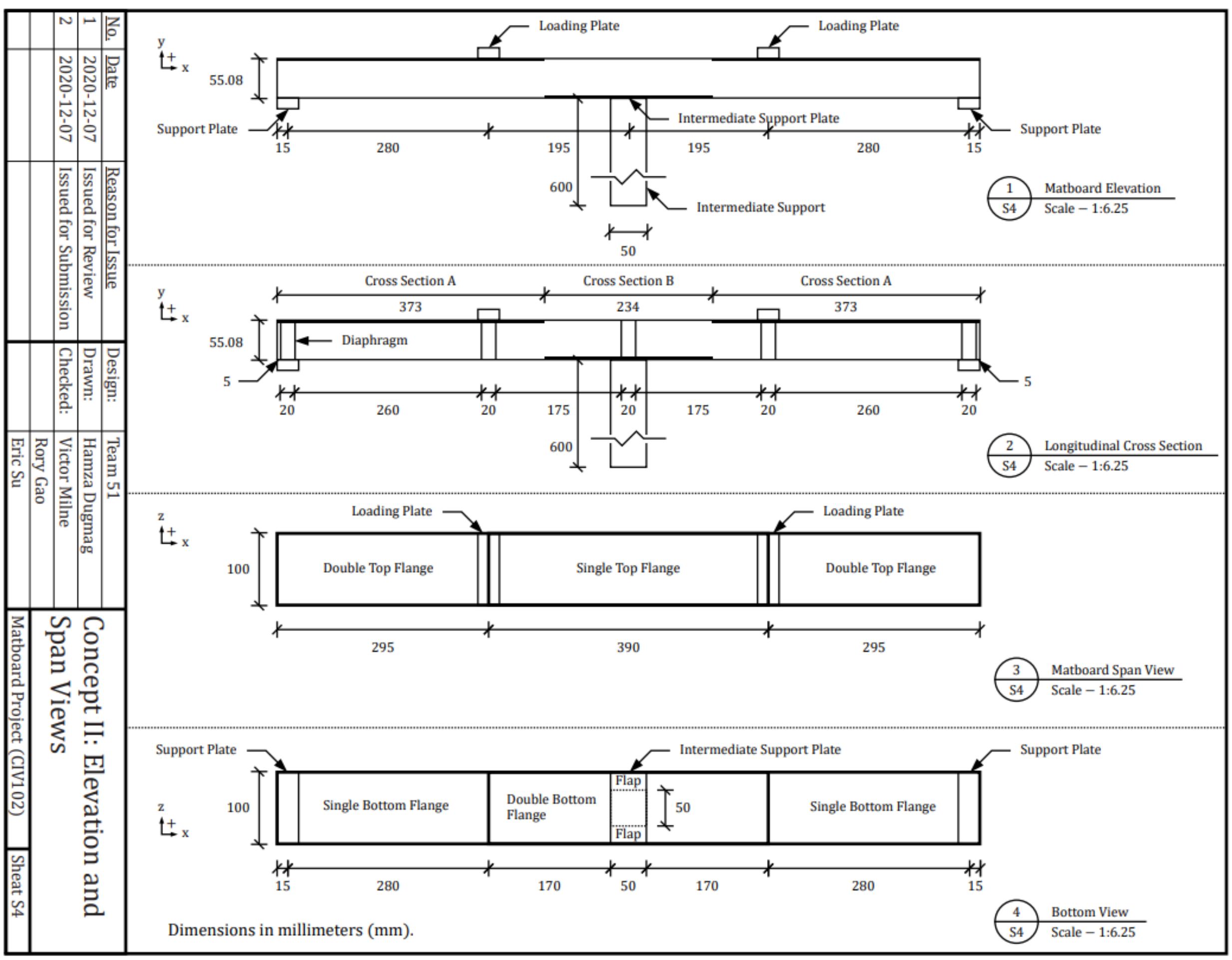


Figure 1. My CIV102 bridge project technical drawings created in *Affinity Designer*.

1.3.2 Designing for Accessibility

My mission in engineering (the world I want) is to increase accessibility to education and scientific technologies. I aspire to become a teacher. A motive for pursuing graduate school is to become an educator and a role model for students. Specifically, I want to reach out to less fortunate communities around the world and introduce them to interesting fields. One of my inspirations was the *Paperfuge*, a centrifuge that costs less than a dollar to build and does not require electricity [3].

As a prospective engineer, I plan to use my skills to reduce the barrier to education and inspire others. On a design project, this implies that I would advocate for cost efficiency, improving ease of use, and designing for simplicity. From this, I have learned that I have a commitment to service and prefer to engage in participatory design instead of feeding my knowledge to a heartless corporation. This value manifests itself in the types of communities I would like to work with: ones that share my mission of achieving well-being for everyone involved. For example, in ESC102, my team and I decided to work with skiers in Italy to improve the effectiveness of ski airbags. We designed for accessibility by developing a hands-free device that can also be used by snowboarders.

1.3.3 Open-Mindedness and Risk-Taking

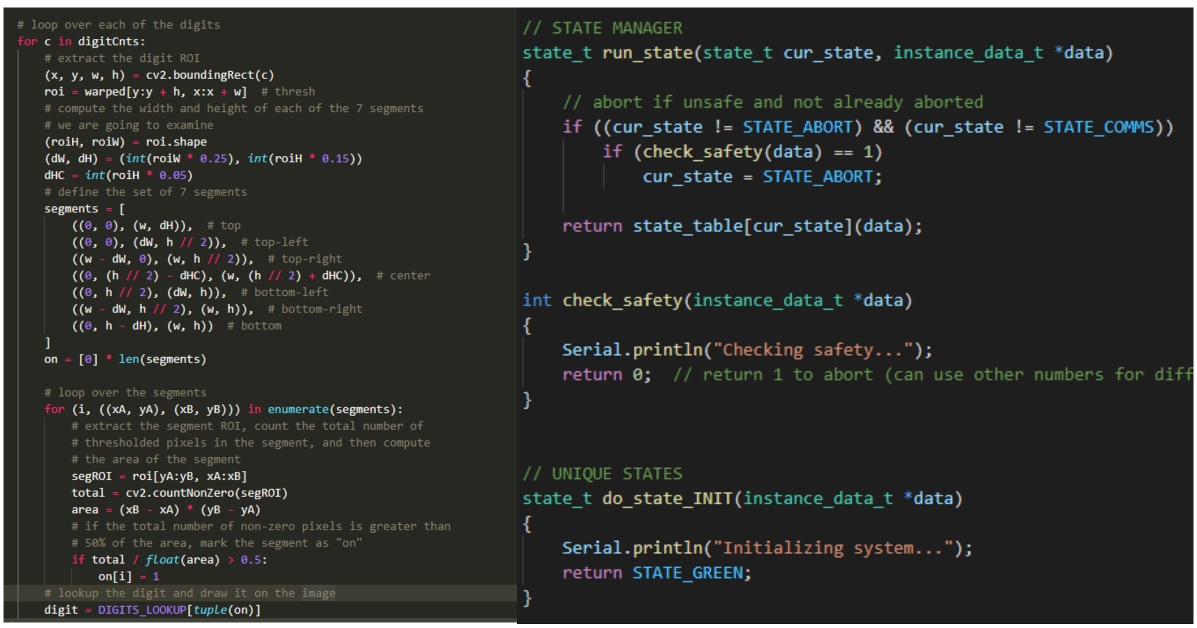
Furthermore, as an impressionable student, I enjoy exploring different processes, tools, and ideas, and working in diverse teams. From this, I have interpreted that if I want to be a life-long learner, then each new project should be a challenge. I do not prefer to recycle old ideas or heavily engage in selection-style design. I see each project as an opportunity to help the community, but also grow as an engineer. I aspire to approach each design activity with the mindset of learning something new and being resilient when facing change. Essentially, I enjoy engaging in *Creative Design* [4].

Lastly, I recognize that being a part of a diverse team comes with appreciating our different backgrounds and values. If our design processes are shaped by our values, and each team nurtures a unique set of values, then the final design is ultimately an artifact of the team members. Thus, I strive to constantly seek and evaluate the perspectives of my peers. If our goal is to use engineering to bring kindness to the community, then we should equally be responsible for respecting each other on the team, even in the face of conflicting arguments.

1.4 Skills and Interests

1.4.1 Programming

One of the reasons for choosing engineering was that I was already equipped with the skill and interest for programming. Having applied this skill outside my courses in game development, data analysis, embedded systems, and machine learning, my design space is much wider since I am not limited in terms of the software-side implementation of my designs. I have used programming to prototype a computer vision model for my ESC101 Critique as well as a finite state machine for the University of Toronto Aerospace Team (UTAT).



Figures 2-3: Snippets of the ESC101 Critique prototype (left) and UTAT state machine (right).

1.4.2 Graphic Design

Moreover, I am very passionate about visual art and graphic design. Last year, I was the Marketing Lead of a youth group focused on bridging the gap between high school students and the technology industry. I extensively developed my branding and graphic design skills and aspire to contribute this artistic mindset in engineering design, especially when presenting our process and final recommendation. Paired with my value for attention-to-detail, I can effectively use this skill to produce technical drawings, sketches, slideshows, brochures, and more. I also want to experiment with showcasing our design on a website or a video.

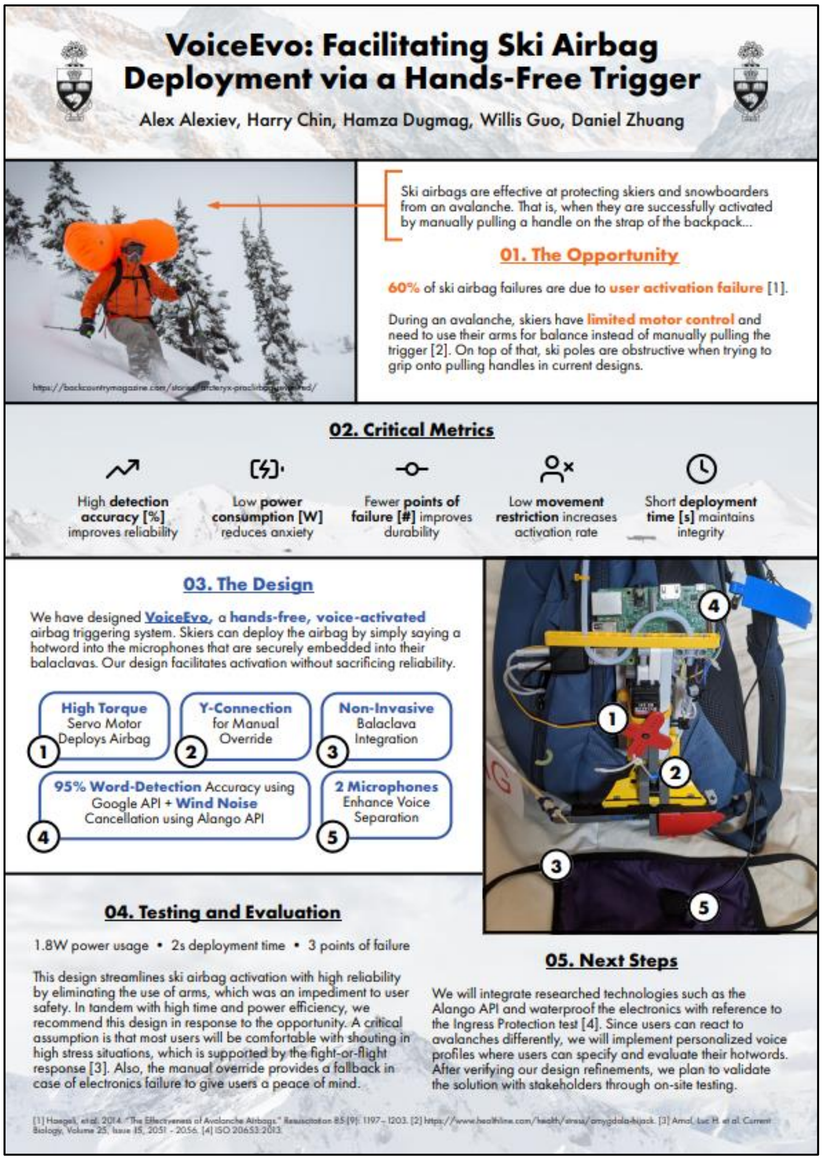


Figure 4. The ESC102 Showcase one-pager I designed with branding in mind.

1.5 Biases and Assumptions

1.5.1 Technological Solutions

Since most of my extra-curricular activities and skills revolve around microcontrollers and programming, I am biased towards technology-based and automated solutions. This is also difficult to avoid since most industries are adopting technology and many of the designs that I am inspired by incorporate software. This was evident during ESC102 when my team was forced to reframe the opportunity to allow automated solutions for ski airbag triggering systems because everyone was interested in programming. This bias may be detrimental since there is an increased concern for points of failure, reduced accuracy, and redundancy systems. However, I believe that I was implicitly assuming that “engineering” must incorporate a software or electrical component.

Note: Not all strategies will be relevant to you. Choose Wisely.
Consider your Team’s Positionality

Reinterpreting / Modifying RFP	
Options	Notes
Reframe	
Rescope	Can use automated solutions (R1). We value accessibility: accommodate for skiers and snowboarders

Figure 5. Rescoping of the ESC102 opportunity that I proposed to the team and was accepted.

Fortunately, I have now become more self-aware and recognize my value for exploring new engineering strategies and design ideas. So, since I have extensively experimented with technological solutions, I plan to scope some of my future projects to non-technological designs if appropriate.

1.5.2 Idealized User Behavior

One of the key assumptions I made in my first-year projects is that the primary stakeholder will perfectly interact with the final design. For example, we assumed that the skiers using our voice-activated airbag system will always shout whenever they have been caught in an avalanche. We selected our design before conducting any research on how different skiers react in high-stress situations. After raising this concern to my teammates, we fortunately found reputable sources that justified our design. However, there may have been an element of confirmation bias in play.

Ultimately, I have learned that a critical component in most designs is the stakeholder. Thus, in addition to designing a functional and reliable product, attention must be paid towards refining the user experience.

2. Personal Engineering Design Products

The following discussions on the engineering design products that I learned from the most showcase the process for selecting these designs with reference to the respective tools and models. Each product highlights a specific component(s) of the engineering design process.

2.1 Process: Improving Ski Airbags via a Voice-Activated Trigger (ESC102)

The Praxis II is my most recent team-based project where we (myself, Alex Alexiev, Daniel Zhuang, Willis Guo, and Harry Chin) tackled the opportunity to "Reduce Injury by Improving Ski Airbags" [5]. It was also the most iterative project: we had two stages of framing, one for diverging, and three for converging, where we learned more about ourselves, the opportunity, and our candidate designs at each stage. Ultimately, we designed a voice-activated trigger that activates a servo motor and deploys the airbag:

Figure 6. Final prototype built by Alex Alexiev presented at Showcase.

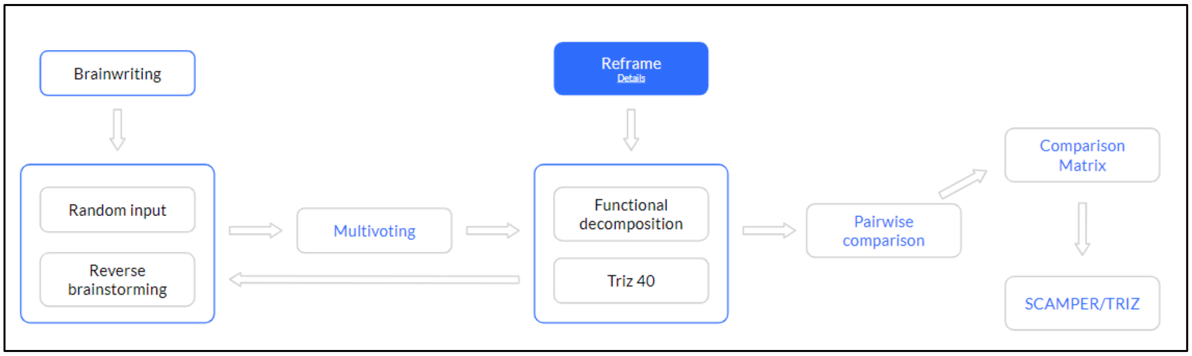


Figure 7. Our engineering design process for this project.

Our initial reframing mainly consisted of revising the given Requirements Model and adjusting it according to our values and interests. For example, we expanded our design space by allowing for automated designs because everyone on the team was interested in technology. We removed some requirements we believed were irrelevant and revised others for more rigorous measurement.

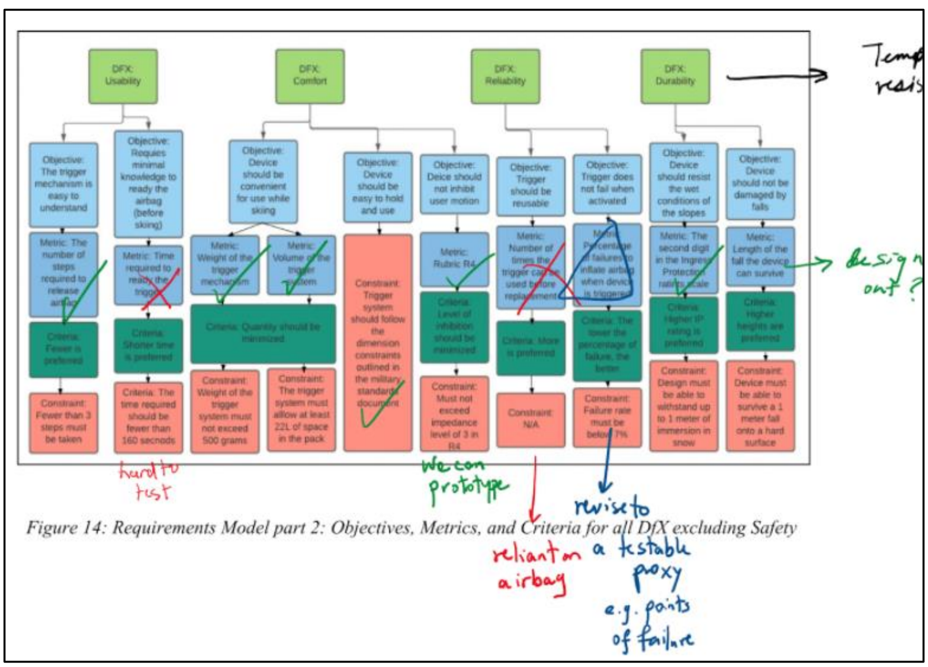


Figure 8. Revising the requirements model as a team. Handwriting by Daniel Zhuang.

The exciting part was diverging and rapidly coming up with potential ideas, where we used tools like Brainwriting and Random Input. We found that Random Input was not as effective as initially thought because the online word generator tool barely provided relevant words to work from [6]. On the other hand, since Brainwriting required us to brainstorm individually at first, it allowed us to reveal implicit biases we had about the design space to each other. For example, most of the designs involved skiers using their hands and arms to activate the airbag. However, my design proposed using a mouthguard sensor that can be triggered using the user's teeth. This allowed the entire team to identify that the skier can use other body parts to activate the airbag, especially since their arms would be occupied by ski poles and are required to maintain their balance when in an avalanche.

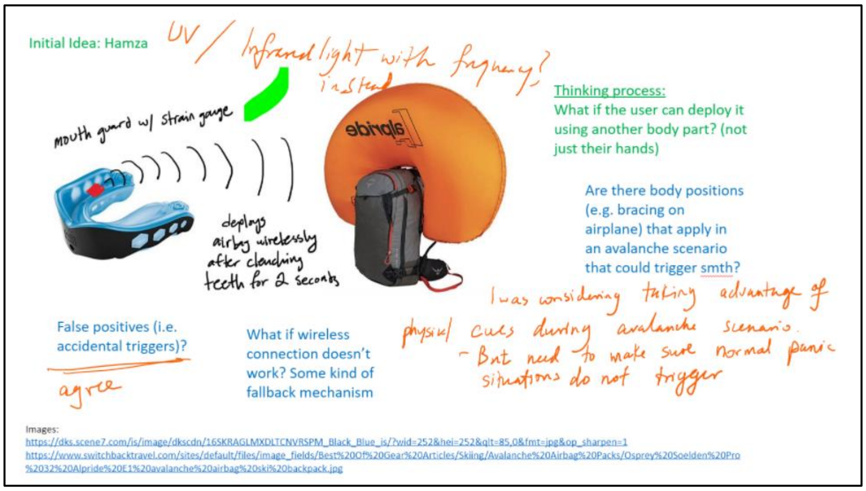


Figure 9. Brainwriting: my mouthguard idea expanded upon by my teammates' annotations.

After coming up with 22 different initial designs, we used Multi-Voting to select our top 6 choices. This initial converging did not involve any rigorous testing or research, rather, it was based on what we personally found to be the most interesting to move forward with. Thus, it was mainly dictated by the team's values.

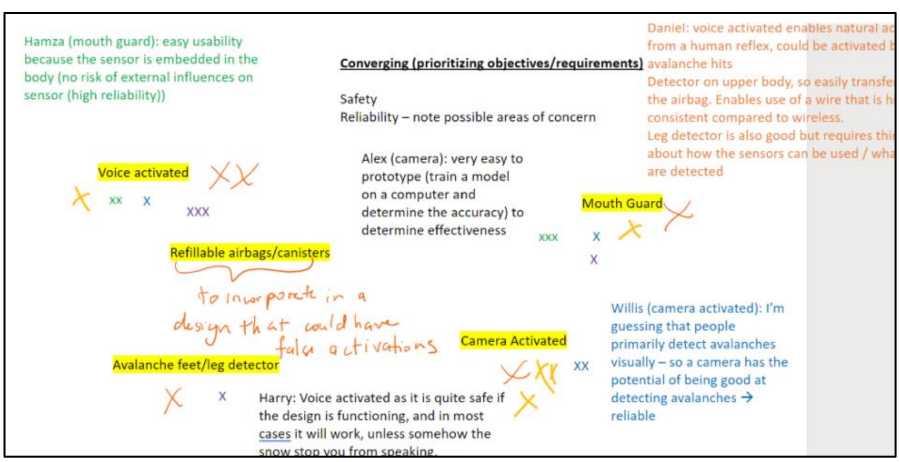


Figure 10: Snippet of initial team convergence using Multi-Voting.

After doing more research about the opportunity, we found that most ski airbag deployment failures are due to user error because skiers lose fine motor control, and their hands may be trapped in snow [7]. So, we reframed the opportunity once again to focus on designs that do not require hand motion.

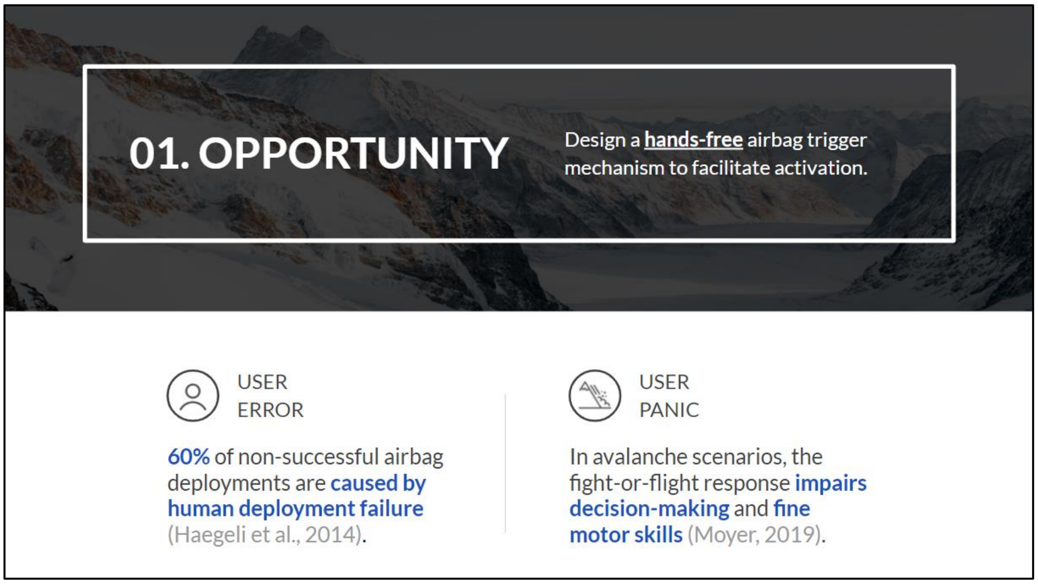


Figure 11. Our second reframing as researched and communicated by Willis Guo.

Although the lack of hand motion does not imply no user involvement, we deduced that it may imply an automated activation of the airbag. Thus, to approve the reframing, we rapidly prototyped automatic Bowden cable pulling mechanisms.

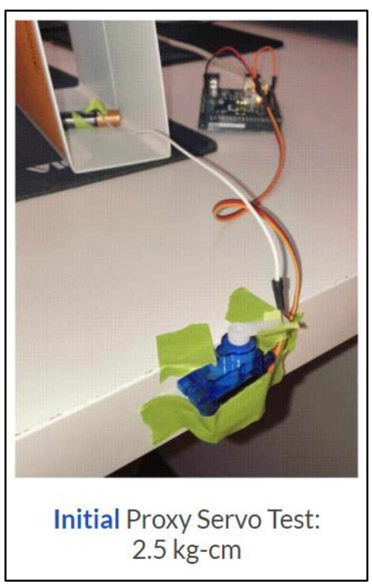


Figure 12. My proxy test for a servo motor automatically pulling a Bowden cable.

With our new reframing and top 6 designs ready, we speculated how they would match up to the requirements and converged to 3 designs using Pairwise Comparison. The last three designs underwent prototyping and rigorous testing using researched measurement protocols. Finally, a Measurement and Comparison Matrix was used to set up our Toulmin argument and select the final voice-activated design.

We were far from done because we still needed to spec the design in detail. For example, to select the microphone position, we conducted more research and testing to determine the optimal placement which reduces the volume of background noise detected. We also used SCAMPER to increase the number of microphones to 2 and improve sound separation.

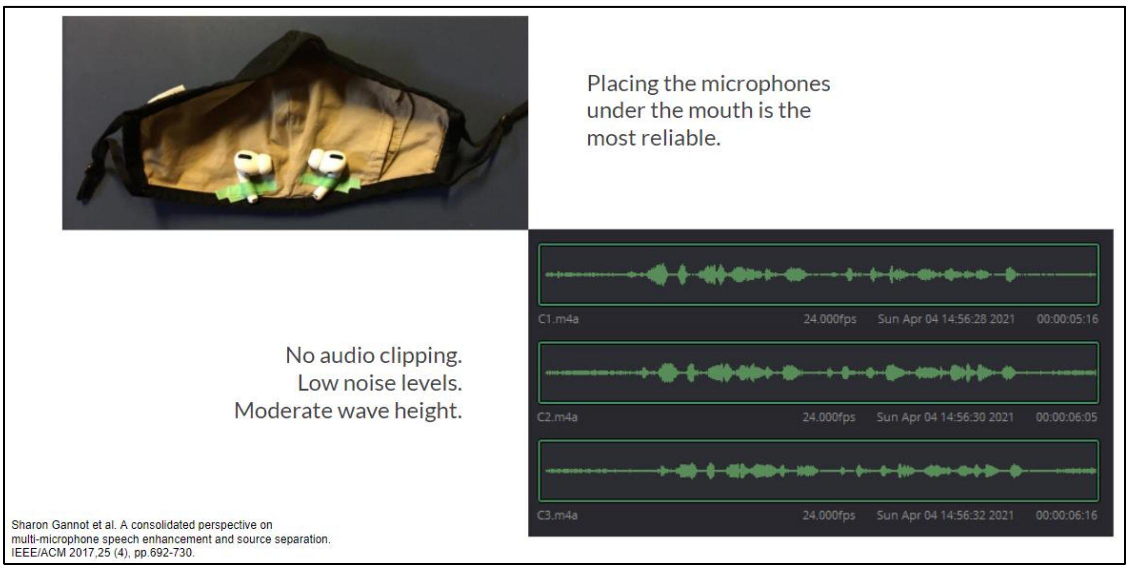


Figure 13. My microphone placement prototype and testing results.

Finally for showcase, we wanted to brand and polish the design. The consistent slideshow, refined prototype, informative one-pager, and beautiful front slide allowed us to communicate our design clearly and professionally.

What I Learned

- Prototypes and proxy tests can verify if you are on the right track (e.g., testing if the Bowden cable can be automatically pulled).
- Design refinement after selection increases credibility of the design as it is more detailed.

What I Would do Next Time

- Convene with stakeholders after each major milestone to ensure that we are on the right track for addressing the opportunity (e.g., initial brainstorming, testing, design refinement).
- Conduct more reframing research in the beginning to brainstorm more relevant ideas and save time.

How this Project Influenced my Personal Engineering Process

- The numerous convergence and reframing stages conveyed that engineering design is a circularly iterative process. Each convergence acts as a more critical filter than the previous. The loop ends once we reach a final design, at which it is refined and polished for presentation.
- Reframing is dictated by our values and research.
- Design refinement and branding is required before presentation as they increase the team's ethos.

2.2 Prototyping: Mitigating Carpal Tunnel Though Ergonomic Typing (ESC101)

For our Critique project in ESC101, my team (Andrew Castro, Joy Lai, Liam Mendoza, and Natalie Volk) and I worked on designing a typing device to reduce the effects of carpal tunnel in the workplace. After using Tournament-Style Selection and Multi-Voting to initially converge to our top 5 designs, each team member prototyped and tested one candidate design.

I prototyped a touchscreen keyboard which aims to reduce the force exerted by the user's wrist when typing. I utilized various representations for my prototype:

- Rough sketches convey the main features and functionality of the design before converging.

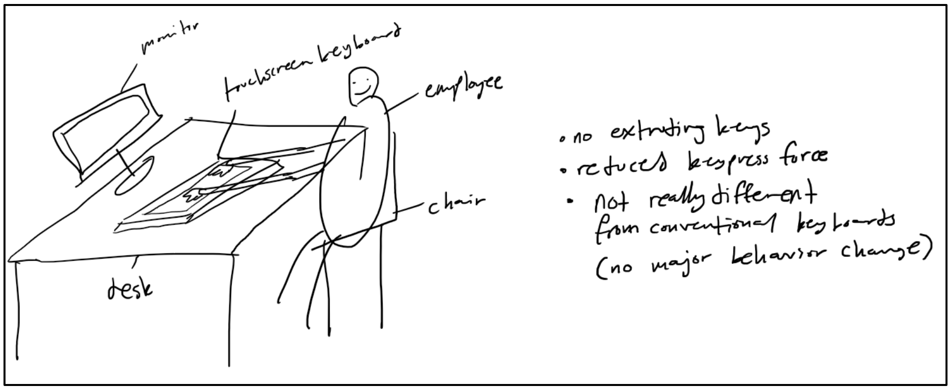


Figure 14. Rough sketch of the design during the initial diverging process.

- Technical drawings portray how the components interact with one another.

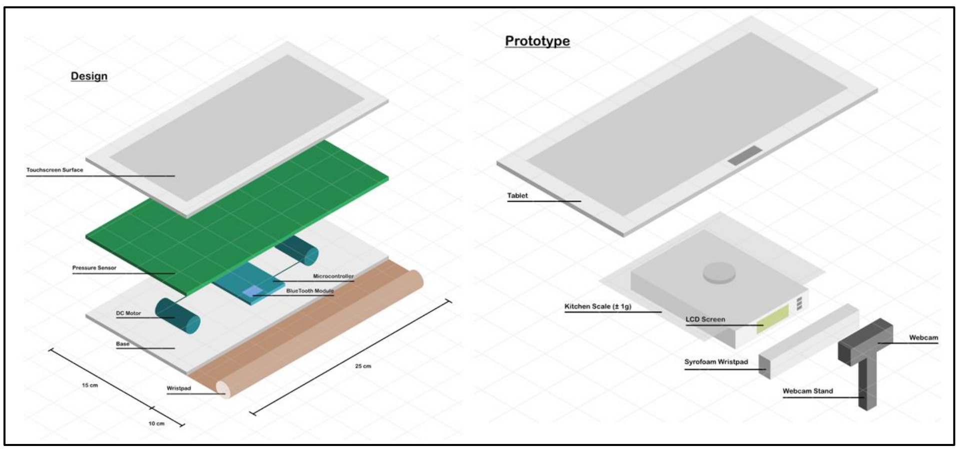


Figure 15. Technical drawings of the envisioned final design (left) and the prototype (right).

- The code for the computer vision model acts as a proxy for the keyboard's pressure sensor (also refer to Figure 2).

Figure 16. Automated notification system from the prototyped code.

- The physical prototype tests the most unbelievable part: human-machine interaction. After building and testing it, I immediately recognized that my fingers were not allowed to rest on the keyboard as that would trigger unwanted keypresses.

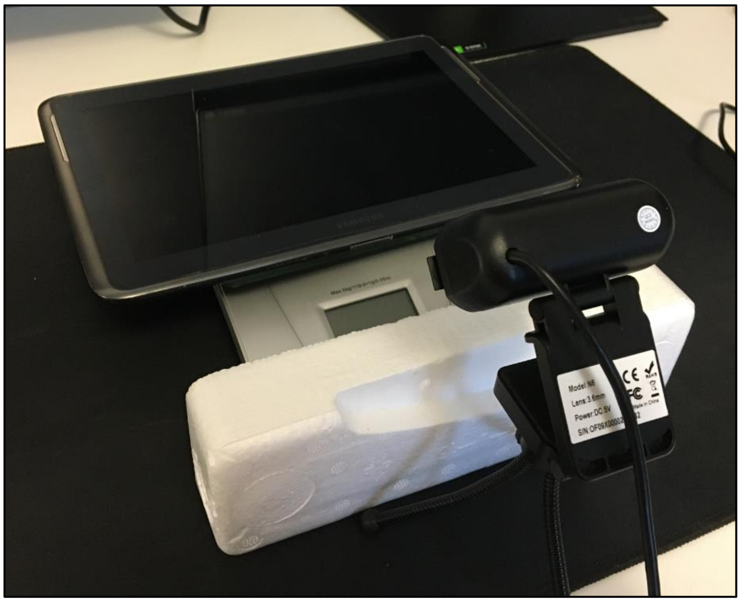


Figure 17. Physical prototype using a touchscreen tablet, kitchen scale, and webcam.

I would also like to remind myself of a candidate design from Sprint B of ESC101: a stress ball remote which can water plants to boost mental health. I prototyped it using a digital 3D model to learn how the components and user interact with each other in 3D-space.

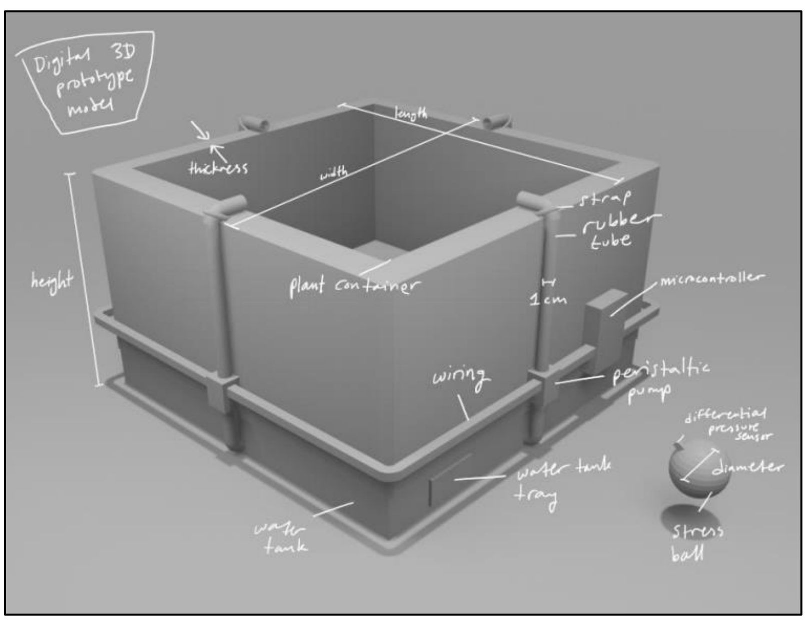


Figure 18. 3D model of the flowerpot planter design.

What I Learned

- Different forms of prototypes enhance understanding of the design in different ways.
- Prototyping is the most fun engineering activity!

What I Would do Next Time

- The code prototype became irrelevant after realizing that my fingers could not rest on the keyboard because this flaw immediately made the design a poor choice. If I were to create a physical model anyway, I would have started with that rather than the code because it is a more accurate representation of the design.

How this Project Influenced my Personal Engineering Process

- Prototypes are used to conduct testing protocols on.

2.3 Argument: Liquid Rocket Flight System Software (UTAT)

As a member of the rocketry avionics subsystem on the University of Toronto Aerospace Team, my responsibility is to design finite-state machine software to control the rocket's flight system. Since this was an R&D project (experimental), I had to research and evaluate numerous reference designs. My subsystem leads (Ammol Singh and Vedang Naik) also suggested I engage in selection-style design.

Constructing a digital circuit using an FSM logic grid: https://www.youtube.com/watch?v=Z4Zz7n-Lj0g

Evaluating External Libraries

Estate (https://github.com/jeanguyomarch/Estate)

- More complicated installation process.
- Uses a custom file extension (.est) to generate an appropriate C file which includes the header file. So, we also need to learn how to format the .est file, which seems very intuitive and simple.
- All we must do in the C file is initialize the library, specify the inputs and outputs, and simulate the state machine!

fsm-c (https://github.com/cloudedcat/fsm-c)

- Lacks documentation, which might make it tedious to understand and implement for our purposes.
- 81 lines of code seems like a relatively simple implementation. Once we understand it, it should be straightforward.

Conclusion:

- I could only find two FSM libraries in C...
- Need to try implementing both libraries for flight system to see which is easier.
- Suspecting Estate to be more flexible and comprehensive, but more complicated. Its documentation is helpful.
- fsm-c could be much easier to implement, but the header and example files should be analyzed beforehand to understand how exactly it works.
- fsm-c seems lighter than Estate.

Figure 19. Snippet of my evaluation of existing state machines.

However, after a couple of weeks, I felt too constrained and was not able to justify using any existing design. Thus, I used the Toulmin model to argue why reframing the opportunity for a custom solution is more effective.

Discussion

There exist external libraries for creating FSMs in C, however, they are either too heavy or have limited documentation (see evaluation). Since creating a custom FSM is relatively straightforward, simple, and light (according to the research above), it might be wiser to develop our own FSM. That way, we would also better understand how it works and tailor it for our specific application.

Figure 20. My initial argument for creating a custom solution.

I successfully convinced the leads and begun designing and developing the software (see Figure 3) with reference to the requirements which the subsystem leads wrote from before. During the team-wide design review, I presented my prototype and used the Toulmin model once again to justify my design choices.

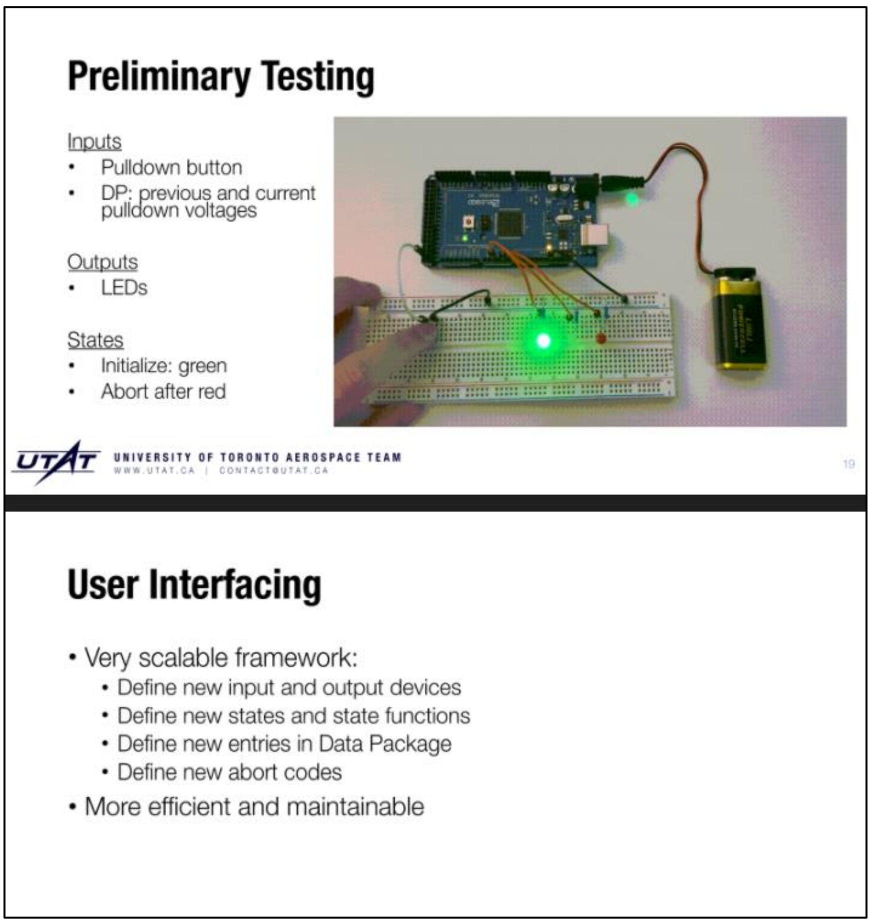


Figure 21. Two of my Design Review slides on testing and design justification.

What I Learned

- It is okay to reframe/rescope as long as you make a compelling, researched argument.
- Providing evidence and justification gives you more accountability and trust from teammates.

What I Would do Next Time

- I would have made my argument way sooner because the sunk cost fallacy is simply a fallacy. Team members want to see the best work from you.

How this Project Influenced my Personal Engineering Process

- Iteration is a crucial part of the engineering design process.
- Presenting your work and ideas is also a critical part since it can be a matter of whether your design gets approved or not by stakeholders and the rest of the team.

2.4 Testing: Designing a Box Girder Beam Bridge (CIV102)

My second engineering project in first year (first one being the PHY180 pendulum) is the beam bridge which I designed with 3 peers (Rory Gao, Victor Milne, and Eric Su). We were given a set of hard constraints regarding the load it can withstand and how much material it must use.

Using our intuition, we came up with several different cross-section designs. However, unlike the previous projects I discussed, there was no room for any initial convergence. This is because we had to calculate the specifications and match them with the constraints before recommending a design. In other words, each diverged idea had to be rigorously tested before being considered a candidate design. Since I value efficiency, I saved some time by writing simulation software where I can specify the dimensions of a specific cross-section shape and test multiple designs in a short time.

```
# one web glued at mid-width
# [force] = N and [length] = mm

# Cross-section:
# =====================
# |         |          |
# |         |          |
# |         |          |
# |         |          |
# |         |          |
# |         |          |

"""PARAMETERS"""
thickness = 1.27
flange_width = 95
web_height = 127
glue_interface = 10

diaphragm_width = flange_width
diaphragm_height = web_height

assert flange_width <= 100
assert flange_width + 2*web_height + (web_height + glue_interface) + min(c
assert 8*max(diaphragm_width, diaphragm_height) <= 1016

"""SECTION PROPERTIES"""
sum_A = flange_width*thickness + 3*(web_height*thickness)
y_bar = (flange_width*thickness)*web_height + 3*((web_height*thickness)*we
y_bar /= sum_A

I_flange = (flange_width*thickness**3)/12 + (flange_width*thickness)*(y_ba
I_web = 3 * (thickness*web_height**3)/12 + (thickness*web_height)*(y_bar -
I = I_flange + I_web
```

Figure 22. Simulating a triple-webbed cross-section for initial divergence.

For each failed design, we implicitly used SCAMPER to see how we can improve it by compromising its over-achieving specs to meet another constraint.

2020-12-06
@12:00-1:00 PM
Everyone:
- Discussed monosymmetric I-beam to maximize I and accommodate for column materials but found that longer flange buckles easily.

Hamza, Rory, Eric: Discussed column design: property section and failure loads/modes.
Victor: Optimized/designed design #2 based on theory, intuition, and the BMD/SFD.
Rory: Sketched matboard construction and laid out some guidelines for Concept II.

@1:00-2:00 PM
Hamza: suggested two different cross-sections for the beam depending on the sign of the moment (while maintaining *I* to maintain the support force).
Victor: Calculated section properties and loads. Discussed distributing the support reaction force onto the beam by folding the matboard.

Figure 23. Time logs for when we began optimizing the designs.

What I Learned

- Testing is always required to verify requirements.

What I Would do Next Time

- May have researched optimization techniques in load management and beam design.

How this Project Influenced my Personal Engineering Process

- In some design projects, iteration, reframing, and diverging may be restricted. Thus, my engineering process will have to take the context of the opportunity into account and only allow certain design activities under appropriate circumstances.

2.5 Research: Reducing Doctors' Burnout via a Smart Break-Scheduling System (BMEC)

The 2021 CUBE BioMedical Engineering Competition was a weekend-long design competition aimed at designing a solution to improve the efficiency in emergency rooms. My team (JinYoung Lee, Mehul Bhardwaj, and Aidan Dempster) and my project was about creating a scheduling system to give doctors regular breaks to improve their mental health.

I mainly focused on conducting research and presenting the background information for our pitch. I used a variety of sources with different levels of authority. I went to the university's Engineering & Computer Science Library to find credible peer-reviewed academic reports, read through curated CBC articles, and credibly browsed through community websites like Reddit [8]. Ultimately, I implicitly assessed the credibility via the CRAAP test and was only able to reliably discuss the peer-reviewed reports.

Source	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7604257/	https://www.cbc.ca/news/opinion/opinion-doctors-depression-anxiety-mental-health-1.5467404	https://www.reddit.com/r/medicine/comments/48vump/no_lunch_breaks_in_the_emergency_department/
Currency	2020 (last year)	2020 (last year)	5 years ago
Relevance	Based in USA but tests apply here too	Based in Canada and discusses ED	May not be based in Canada… But talks about the ED
Authority	Peer-reviewed academic report, NCBI	Author is a family doctor, opinion article (may be biased)	Reddit (community-based, not very professional)
Accuracy	Justified and conducted tests	Author is a doctor, comments support her	Disagrees with https://www.labour.gov.on.ca/english/es/faqs/general.php
Purpose	How to diagnose and address ER burnout	Raise awareness about mental health issues ER doctors face and calls to action	Partner worried about doctor working too much

Figure 24. CRAAP test on three sources of varying authority.

Figure 25. The references used in the background section of our BMEC pitch.

Additionally, the academic report was credible to the point that our testing protocol completely adopts the procedure that it outlined.

What I Learned

- Research can inform testing protocols.
- The CRAAP test can combat confirmation bias.

What I Would do Next Time

- Primary research (contacting doctors and hospitals) may have provided insight into the lived experiences of ER doctors (first-person experience).

How this Project Influenced my Personal Engineering Process

- Research is done constantly throughout the process.

3. Personal Engineering Design Processes

My personal design process is inspired by the Framing-Diverging-Converging-Representing model we used throughout Praxis I and II but has been refined to incorporate my values and philosophy of engineering [4]. This process serves as a checklist for what I believe constitutes as good design according to my past engineering activities. Since my philosophy of engineering is based on *Creative* Design and Northrop Frye's "The Educated Imagination" (Hoover Dam model), I named my process "The Engineered Imagination" as tribute to him [1].

3.1 Preparation: Team Analysis and Developing an Awareness

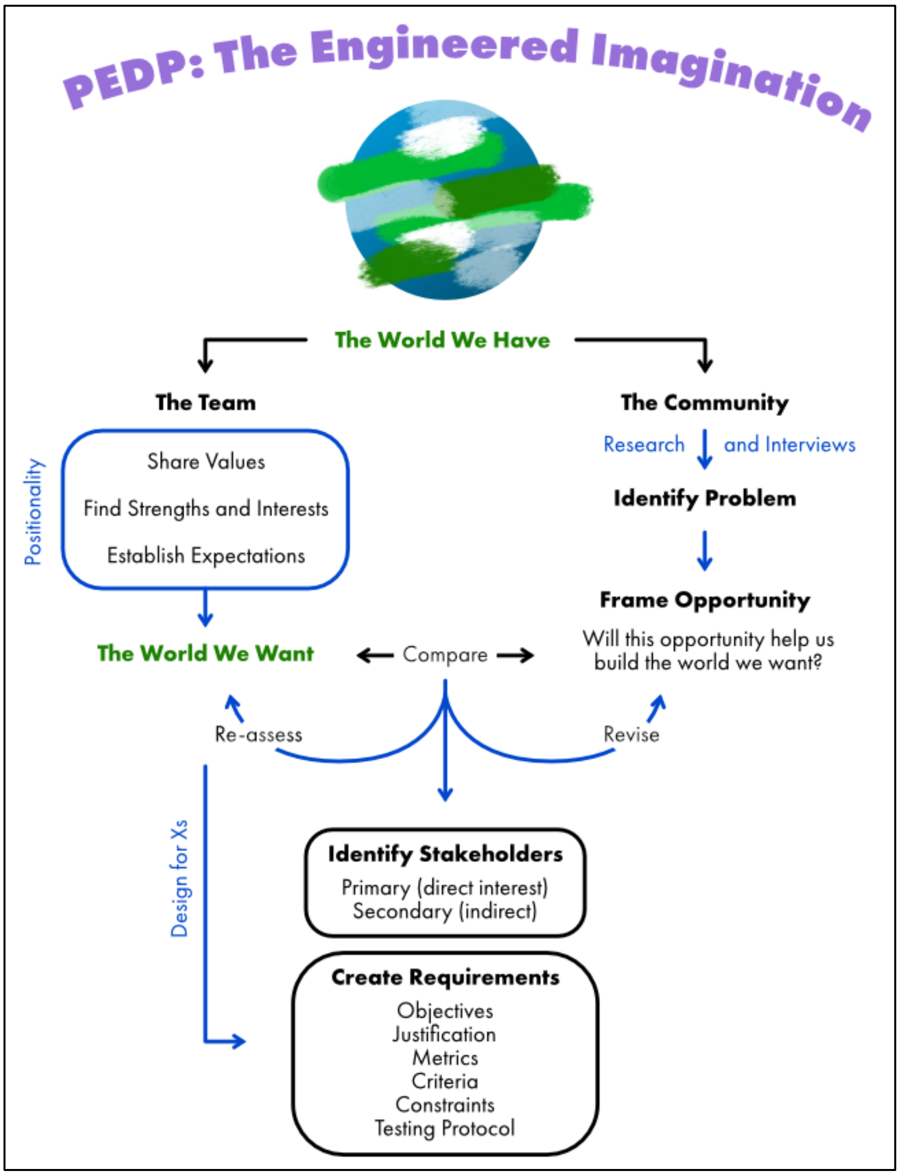


Figure 26. The preparation and framing phases of my PEDP for establishing a design mindset.

Since I believe our motivation for engineering and the results that come out of our design is shaped by the “world we currently have,” I believe we should pay special attention to reflecting on ourselves and developing self-awareness about our shared team values in the context of an opportunity. We refine this opportunity and re-assess our interests until we have what is known as a “good opportunity:” one in which we would feel satisfied with pursuing because it will help us build the “world we want.”

During ESC101 Sprint B, my team and I conducted a self-survey of our values and I took initiative to classify them into distinct categories and establish a common ground. After deducing that there were no conflicting values, I inferred that we all may share a similar mindset that could result in team-wide anchoring. This self-awareness informed my decision on which diverging tool to start with: Brainwriting because it serves to reveal our implicit biases.

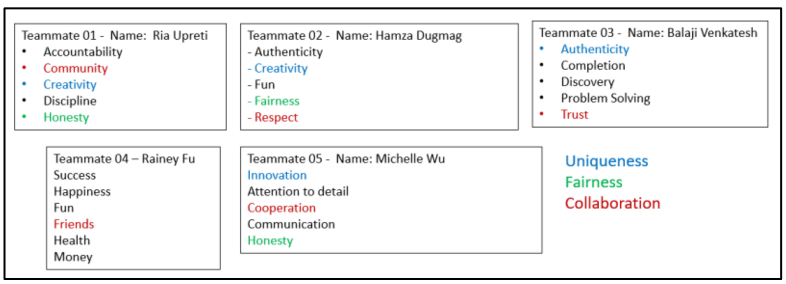


Figure 27. Student capture slides: sharing our values with the team.

This also allowed us to identify our Design for Xs (DfX). For example, I strived to Design for Effectiveness, while my teammate, Ria Upreti, refined my initial concept by Designing for Usability via a remote stress ball. We were then able to refine the given requirements after our initial divergence stage. After learning from this experience, I constructed my PEDP to maximize time efficiency by explicitly identifying our DfXs and using them to inform the requirements before any ideation.

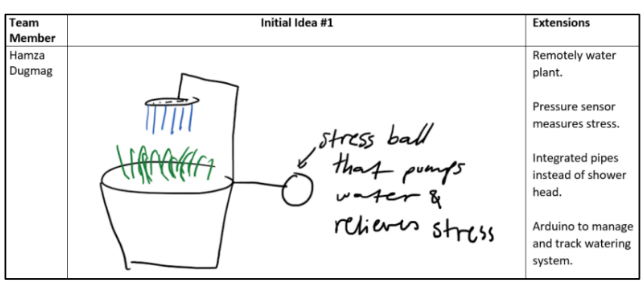


Figure 28. Initial brainwriting idea that was extended upon by Ria (see Figure 18 for prototype).

3.2 Framing: Grounding the Opportunity and Purpose of Design

The framing phase focuses on translating a problem into an opportunity by expanding on the requirements model we learned in lecture [9]. In addition to the justifying the Criteria and Constrains with research, I recommend explicitly justifying the Objectives and Metrics as well to minimize the risk of including an irrelevant design feature. For example, in our (Daniel Zhuang, Willis Guo, Alex Alexiev, Harry Chin, and I) ESC102 Request for Proposal (RFP) on cloth straightening, we had metrics derived from existing reference designs (e.g., water volume used for steaming). However, this anchored our design space, so we omitted the metric because it did not facilitate unique ideation as per my value for *Creative Design*.

6.4.4. Material Compatibility

Detailed Objective 4: Be usable on various types of clothing and clothing materials without damage.		
Justification: The store sells a wide variety of clothing material and shapes. Not every straightening method is compatible with every material. For example, the moisture of steam will ruin materials like wool and plastics like suede (https://www.fridja.com/2019/11/what-fabrics-can-be-steamed/)		
Metrics	**Criteria**	**Constraints**
Number of common materials in the Material Table (see below) that can be straightened without damage [number] *Justification:* HHB currently sells clothes from all categories in the Material Table, and the design should not restrict the variety of products the business sells. *Measurement process* Damage is defined as burns, holes, or permanent creases visible to the naked eye. A design is usable on a material if and only if it does not	More is better. Where there is a tie on the number of usable materials, the design damaging the less common material is preferred.	*Must* be able to be used on polyester and cotton, the two most common types of materials [22].

Figure 29. Sample detailed, approved requirement from our RFP written by Daniel Zhuang.

Moreover, conducting primary research into the stakeholders' lived experiences encourages participatory design and facilitates a unique and personalized problem-solving experience. Also, performing secondary research is critical for supporting our decisions for the creating the requirements. Standards, handbooks, and journal articles are credible sources which help define criteria, constraints, and testing protocols.

Ironing/steaming:

- Takes a lot of time. 1 – 2 hours per day, 3 min/clothing. No decrease in quality of clothing. Needs to straighten clothes after ironing.
- Tried on clothing – not ironed cannot sell.
- After ironing awhile: need to move hand up and down.
- Table not used: area consuming, not visually appealing.
- Using a table will cause damaging clothes, due to direct contact. Steam machine pauses when there is pain in hand. 15 minutes break; 1 hours before rest.
- Shoulder pain.

Figure 30. Snippet of our 4th interview with the RFP stakeholder to personalize the opportunity.

3.3 Diverging: Exploring and Evaluating Possible Solutions

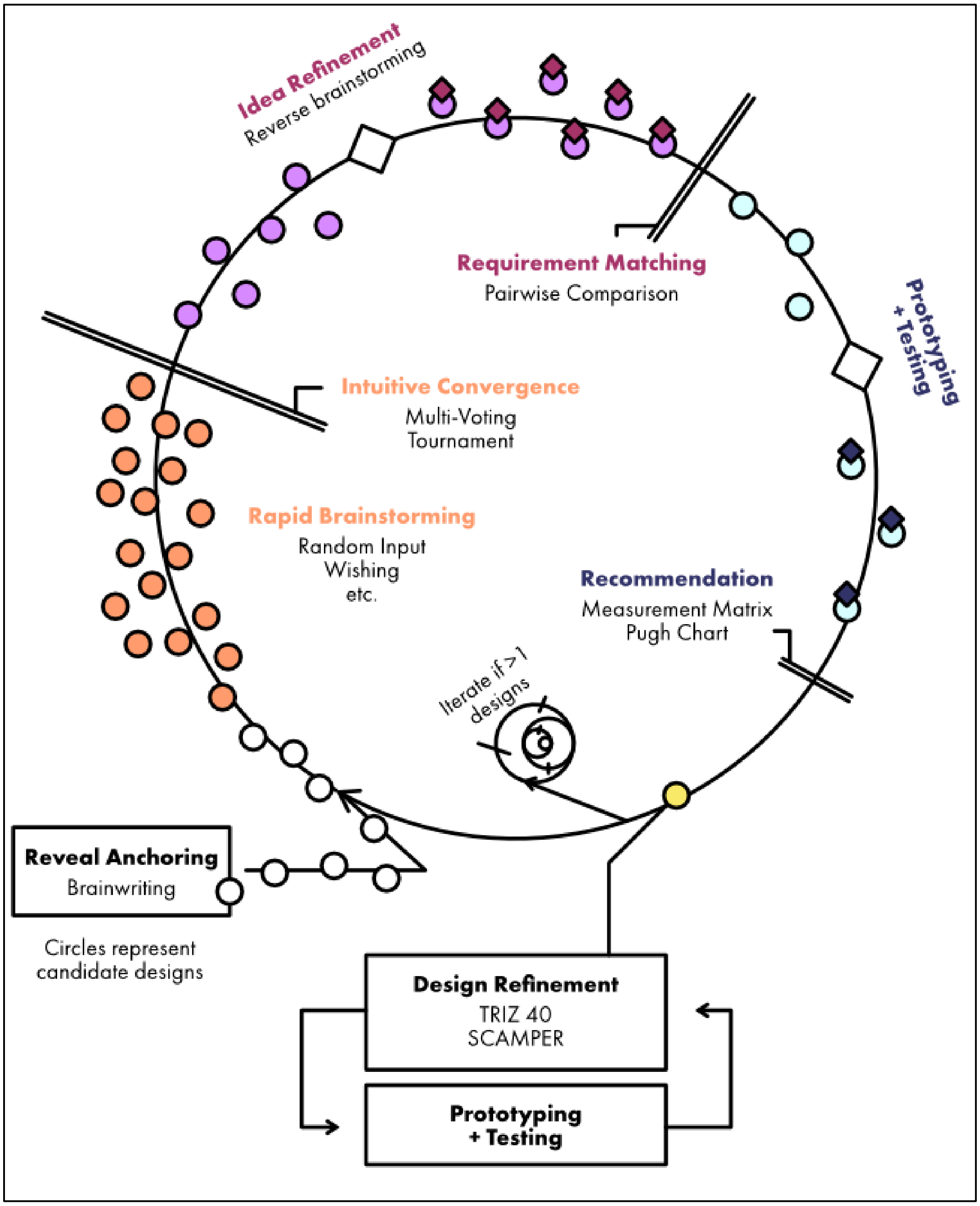
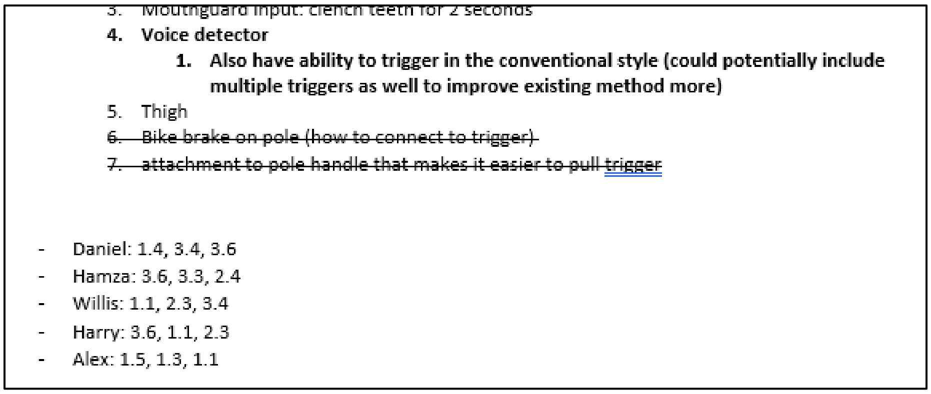


Figure 31. The iterative diverging and converging phases of my PEDP.

For diverging and converging, I took inspiration from the course's notion of a fractal process for design that occurs at different levels of detail at each iteration [10]. I paired this with the circular methodology of design as presented in "The Discipline of Design" to form a process that incorporates the team's interests into the process [11].

After a rapid brainstorming session to throw ideas into the pot, a loose converging activity allows teammates to reject any designs they would not be interested in moving forward with. After all, we are engineering a world we want. For example, Multi-Voting during the ESC102 project allowed my teammate, Alex Alexiev, to express his interest in machine learning and automated solutions.



3. Mouthguard input: clench teeth for 2 seconds
4. **Voice detector**
    1. **Also have ability to trigger in the conventional style (could potentially include multiple triggers as well to improve existing method more)**
5. Thigh
6. ~~Bike brake on pole (how to connect to trigger)~~
7. ~~attachment to pole handle that makes it easier to pull trigger~~

- Daniel: 1.4, 3.4, 3.6
- Hamza: 3.6, 3.3, 2.4
- Willis: 1.1, 2.3, 3.4
- Harry: 3.6, 1.1, 2.3
- Alex: 1.5, 1.3, 1.1

Figure 32. Snippet of multi-voting: Alex voted for category 1 designs which are all automated.

Each subsequent stage in the loop further refines the approved ideas, for example, Reverse Brainstorming may resolve flaws and remind us about the purpose for this design. We also introduce more prototypes which are subject to more rigorous convergence activities. The diverge-converge process is repeated until a single design survives. Ultimately, this phase in my PEDR shifts between *Conceptual Design* and *Embodiment Design* [12].

3.4 Converging: Selecting and Finalizing the Design

After a design has been prototyped, tested, and recommended, we further refine it through detailed specifications and introducing more features. These specifications are prototyped and tested to maximize opportunity for a feasible design that addresses the problem statement. For example, after selecting the voice-activated trigger system for our ESC102 project, we investigated the design contradiction between speed of deployment and reliability and used TRIZ 40 to introduce a manual override trigger. This polishing stage also allows for a more detailed physical prototype which ties all the components together. Next steps may also be outlined here. Ultimately, this phase in my PEDR shifts between *Embodiment Design* and *Detailed Design* [12].

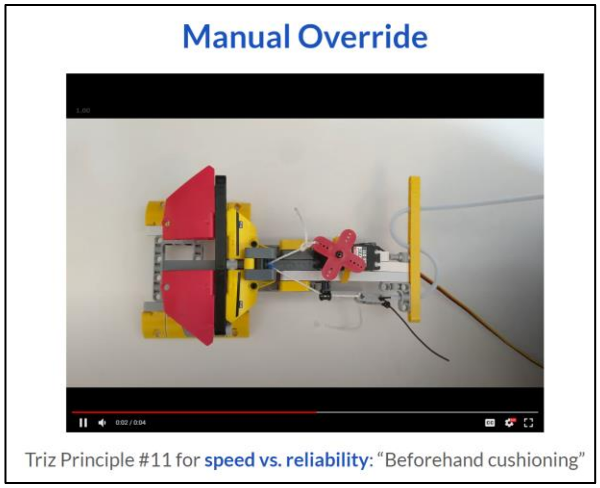


Figure 33. Alex designed a manual trigger and integrated it into a polished servo prototype.

3.5 Communicating: Branding the Design for Presentation

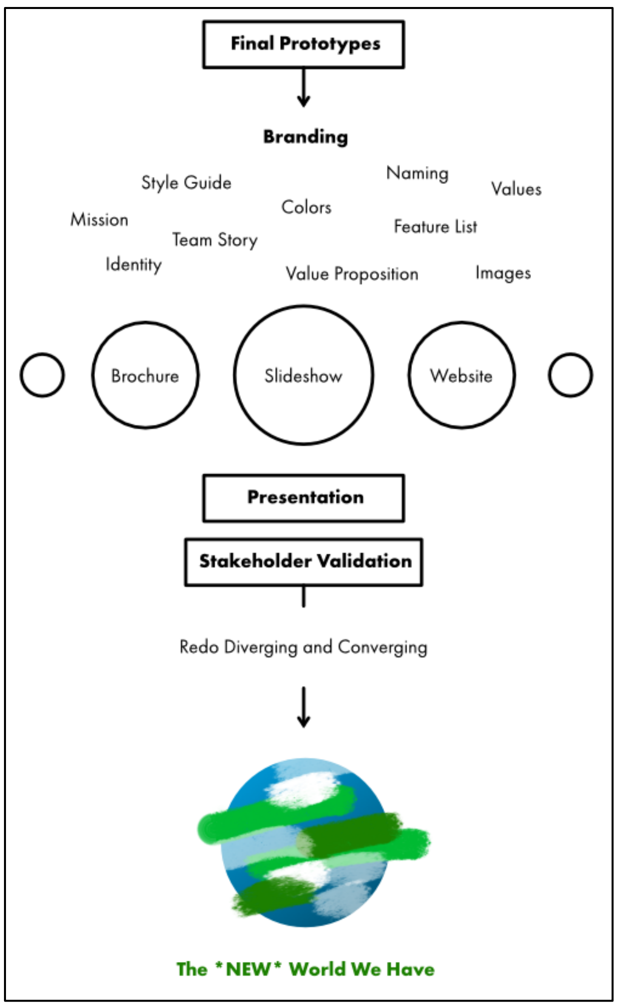


Figure 34. The representation stage of my PEDR.

The final stage focuses on presenting a Toulmin argument, justifying the chosen design as a solution to the opportunity. The purpose for branding the design is to create a memorable identity that the stakeholders can remember and appreciate. Rather than remaining experimental, branding provides the design team with an artistic avenue to represent their values, interests, and convey the design professionally.

For example, during the ESC102 Showcase, my team and I incorporated a consistent color scheme between the slideshow, front slide, and one-pager, came up with a name for our product ("VoiceEvo") (see Figure 4), and had relevant Zoom backgrounds (a snowy mountain). As we were presenting a demo of the product, Alex wore a ski suit and held ski poles to convey a sense of the skiers' lived experiences. However, we made sure to organize the information across all our mediums logically. I created a storyboard to focus on the design and its effectiveness as recommended by the ESC102 teaching team [13].

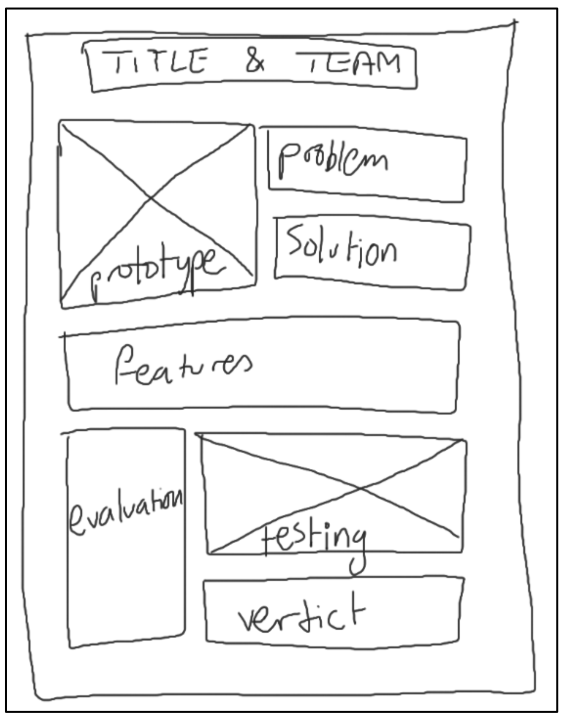
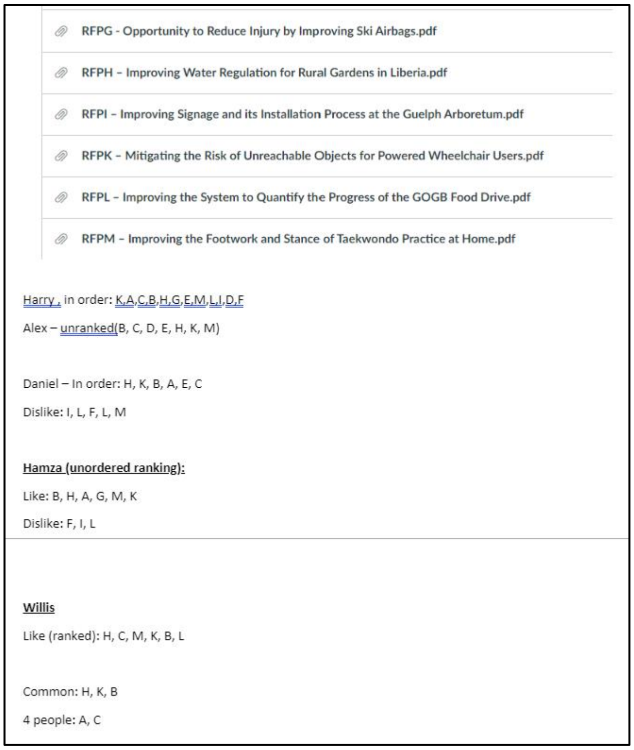


Figure 35. ESC102 Showcase one-pager initial storyboard.

4. Tools, Models, and Frameworks

The following discussion is an assessment of the tools and models used in my engineering design process and products.

4.1 Frame: Hoover Dam Model



RFPG - Opportunity to Reduce Injury by Improving Ski Airbags.pdf
RFPH – Improving Water Regulation for Rural Gardens in Liberia.pdf
RFPI – Improving Signage and its Installation Process at the Guelph Arboretum.pdf
RFPK – Mitigating the Risk of Unreachable Objects for Powered Wheelchair Users.pdf
RFPL – Improving the System to Quantify the Progress of the GOGB Food Drive.pdf
RFPM – Improving the Footwork and Stance of Taekwondo Practice at Home.pdf

Harry , in order: K,A,C,B,H,G,E,M,L,I,D,F
Alex – unranked(B, C, D, E, H, K, M)

Daniel – In order: H, K, B, A, E, C
Dislike: I, L, F, L, M

Hamza (unordered ranking):
Like: B, H, A, G, M, K
Dislike: F, I, L

Willis
Like (ranked): H, C, M, K, B, L

Common: H, K, B
4 people: A, C

Figure 36. Preliminary Multi-Voting of our top choices for a Request for Proposal to pursue (ESC102) We chose the ski airbag opportunity because we wanted to meet stakeholders outside Canada, enjoy skiing, and want to develop our mechanical/electrical engineering skills.

Description and How/When I Used it

This model is a representation of my philosophy of design. It describes how engineering is about using models to represent the world as it is, use science and math to envision a world we would like to live in, and use technology to build such a world [2]. See Sections 1.1 and 3.1 for the Hoover Dam model incorporated into my personal engineering design process. I use this model to remind myself about why I do and enjoy engineering, as well as to develop an open mind as I learn about the different values of my team to integrate into our work.

Purpose and Utility Evaluation

This model effectively develops my intentionality as an engineer and informs my actions. It embraces the human desire to innovate and create, and perfectly captures what engineering is to me. It motivates me to keep doing what I do and collaborate with others to solve real-world problems that we are passionate about.

4.2 Frame: Requirements Model

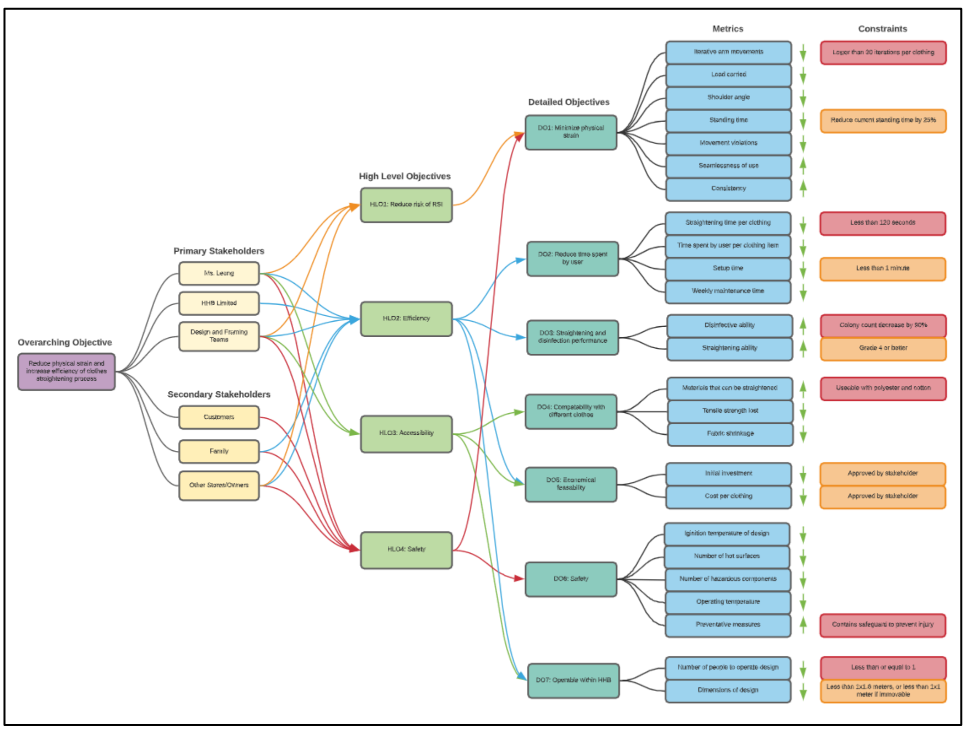
C. Design for Time Efficiency (DFT)

Objective: The recommended design maximizes the benefit gained from exercise within the duration of time needed to fully engage in the design.

Metric #1: The total energy expenditure (TEE) [kcal/day] is directly related to the health benefits perceived from the exercise as it decreased the relative risk of morbidity [14]. The energy is measured by administering doubly labeled water (DLW) to a test subject and measuring the elimination rate of the molecules in the DLW sample [15]. Thus, TEE is calculated by finding the ratio between energy released and time spent exercising converting the ratio to kcal per a whole day of exercising. Since the measurement process is tedious, the design team may explore other creative methods for measuring TEE.

Constraint and Criteria #1: More TEE correlates to a lower relative risk, however, since ~4780 kcal/day of exercise causes difficult ingestion and digestion, the utility curve is concave down parabolic [14]. The TEE must be lower than 4780 kcal/day. Thus, higher TEE is better until it reaches the peak at around half the constraint (~2390 kcal/day), at which more TEE becomes worse.

Metric #2: The time spent on the activity [minutes, min].



Figures 37-38. Sample requirement in ESC101 Sprint A (top) and the requirements flowchart in the ESC102 Request for Proposal by Alex Alexiev (bottom).

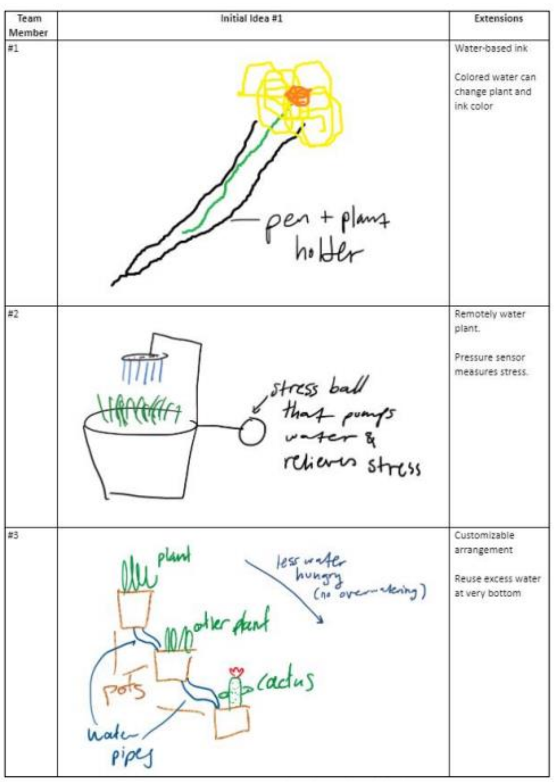
Description and How/When I Used it

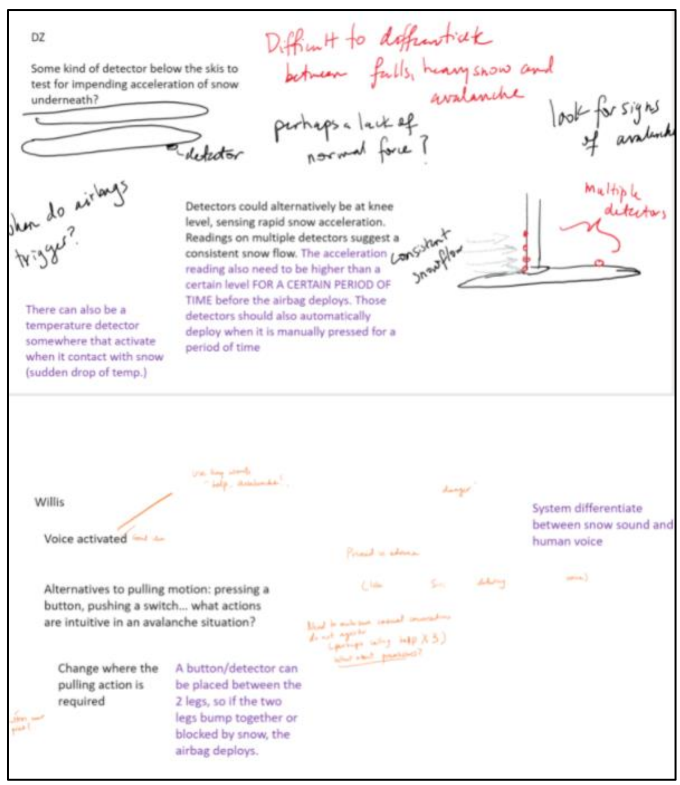
The requirements model defines how the features of the design should be according to Objectives, Metrics, Criteria, and Constraints [4]. It is the key model used in PEDR's framing phase. I have used this model with all my teams at the beginning of each project. When given a design brief, we reframed the requirements to match our team values.

Purpose and Utility Evaluation

This model is very rigorous as it requires research to justify the metrics, criteria, and constraints. It is also effective at promoting participatory design by incorporating the values of all stakeholders and the design team. The team's values dictate the Design for Xs while the stakeholders' lived experiences inform which ones should be prioritized.

4.3 Diverge 1: Brainwriting





Figures 39-40. Snippets of team Brainwriting during ESC101 Sprint B (left) and ESC102 (right).

Description and How/When I Used it

Brainwriting is a collaborative divergence tool I suggested to employ at the start of the divergence phase. Each team member individually comes up with a design idea, sketches it, and we rotate the designs to expand on each other's ideas [14].

Purpose and Utility Evaluation

Since we start brainstorming individually (without input from others), our unique biases and perspectives influenced our designs, which were then picked up by our teammates. This allowed us to identify our sensory limits and increase our-self-awareness about our creative mindset. It eliminated any inherent biases and established a standard for the other divergence tools. However, the activity is non-verbal, which limited our ability to understand each other's ideas and adapt our thinking to our teammates' perspectives.

4.4 Diverge 1: Random Input

Word	Input
University, Drizzle, Pith, Sari, Forest, Caramel	No Ideas
Shovel	- Rubber grips so you don't have to squeeze too hard (increase tension) - Brain wave input to robot so it can type automatically for you
Tomato	- Pomodoro thingy → take breaks
Closing	- Padded arm sleeve encloses arm to keep wrist straight (support) and heat
Electricity	- Robotic arm that types for you - Zaps you to keep your arm warm - Keyboard keys are at different height - Keyboard hangs from your fingers, no need to tense up when typing
Metal	- Magnets - A low energy heating element under a piece of metal to keep your hands warm while you type

Word	Ideas
Fishing	- Fishing wire strength transmits the energy - Drag a little wire behind your butt with the red fishing things that can get stuck in the avalanche and measure tension - Spinning reel system to trigger airbag - Fishing hook to secure onto bowden cable - Fishing bob offers warning that fish has been caught - a similar system for informing the user
Thought	- Mind reading trigger system - Measures brain waves - Mindflex: https://www.amazon.com/Mattel-P2639-Mindflex-Game/dp/B001UEUHCG
Emotion	- Feeling stressed - Whether that reflects an avalanche
Analysis	- Machine learning - Analyze snow conditions and slope and assign grades of risk to alert user so that they are more prepared (user-centered design) - offers user reminder
Tongue	- Similar to mouth guard idea

Figures 41-42. Snippets of team Random Input in ESC101 Sprint C (left) and ESC102 (right).

Description and How/When I Used it

A divergence process where random nouns are used as inspiration for design ideas [14]. My teams used https://randomwordgenerator.com/noun.php to generate the words [6]. This tool was used during the initial ideation process since it forcefully provides perspectives on the opportunity which we have not thought of before.

Purpose and Utility Evaluation

From my experience, this tool heavily depends on the context of the opportunity. During ESC102, most of the words were irrelevant and we were not able to come up with any design ideas efficiently. Fortunately, this activity is enjoyable because it is interactive and requires verbal communication. Since most of the words caught off us guard, it allowed us to de-anchor ourselves and explore other perspectives. Some words were also component-specific, encouraging us to engage in *Detailed Design* early in the process.

4.5 Converge 1: Multi-Voting

Touchscreen Keyboard	Arm Brace	Ergonomic Keyboard	Frame	Headset	Wrist Support Mouse-pad	Eye Tracing Software	Reminder App
III	III	III	II	III	II	I	

Figure 43. Team multi-voting in ESC101 Sprint C (see Figure 32 for ESC102).

Description and How/When I Used it

Each team member gets a few votes to select their favorite designs. They can cast multiple votes for the same design. The design with the most votes wins [15]. I used this tool after our rapid divergence activities to select which designs we would be happy with expanding.

Purpose and Utility Evaluation

Since this tool is casual, it effectively incorporates the team's values and interests by choosing the most fascinating designs. However, due to the lack of rigor, the best solution may not proceed to the next stage. Fortunately, I believe perfectionism is a waste of time and would prefer embracing my team's perspectives and interests in engineering design.

4.6 Converge 1: Tournament Style Selection

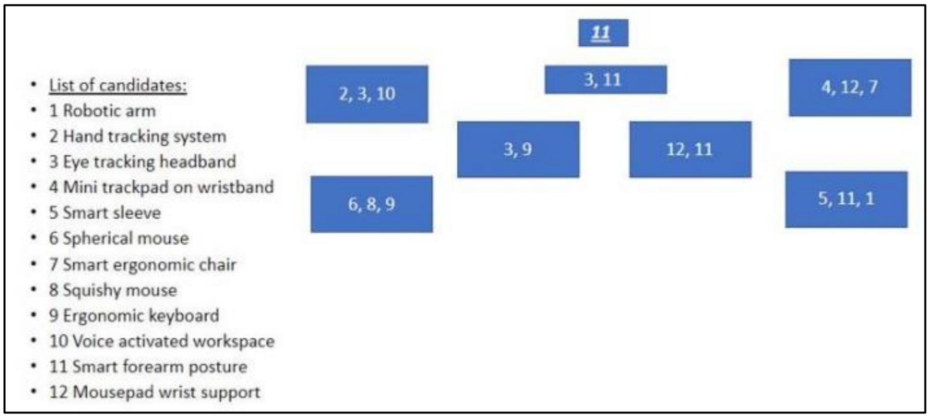


Figure 44. Team tournament-style selection in ESC101 Sprint C.

Description and How/When I Used it

This initial convergence tool is used to determine how different designs match up to each other [15]. The seeds were generated according to two criteria:

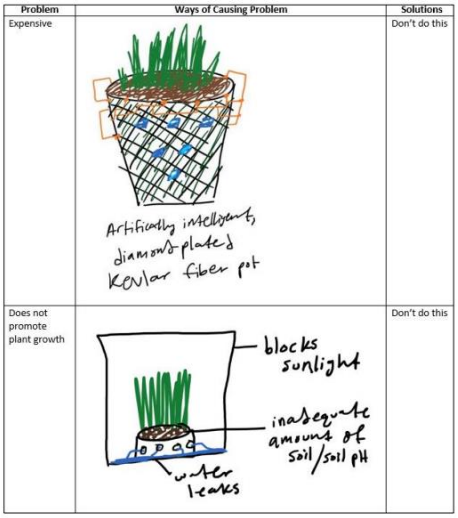
1. Similar designs matched early on since the winner can always be improved to include features from the weaker designs.
2. Promising designs are not matched early on to maximize the number of good designs at the end.

My team chose winners of each match based on unanimous decision.

Purpose and Utility Evaluation

I enjoyed this design activity because I am a fan of sports. However, the purpose of initial convergence is to select a set of equally promising designs. Having an absolute winner can anchor us to that design. Also, comparing the candidate designs in each match was not rigorous. It did involve a bit of bias based on our interests, which can be seen as a good thing since it incorporates team values and interests.

4.7 Diverge 2: Reverse Brainstorming



The Problem	Ways of Causing the Problem	Ways of solving the problem
The user forgets to activate the airbag	- The activation is too complicated - The user is under a lot of stress - The user is distracted - The user does not know there is an avalanche	- **Audio or light warning** - "Stay Calm and ___ whe a lot of snow is falling down" symbol - Mirror - **Motion detector along with camera**
The trigger activates the airbag 10 seconds after it is pulled	- The cable is too long - The cable is too stiff to be pulled - There is a signal delay - There is slack in cable	- put cable closer (reduce resistance) - Elastic cable material - Direct connection to bowden cable (no intermediary like a microcontroller)
Difficult for the user to use the trigger	- The trigger is in a hard-to-reach location - The trigger requires significant physical exertion/effort - The trigger process involves many steps - Cable is too difficult to pull - Requires two hands to use	- Use a button on ski pole on top - **Put the trigger on ski pole/snowboarders/on** their hands - **Make trigger use non-essential body parts** - **Make trigger automatic** - Requires only one body part to activate - Middle of chest? Thighs? Mouth? - Face mask?
The trigger automatically occurs, and cannot be reused	- False positives - System picks up signals from other sources (e.g. people, wind) - System perceiving falling/minor avalanche to be a major avalanche	- Multiple inputs required for activation - **Manual confirmation system**. Button or verbal override (2 second warning).Hold button for longer period of time (since user is safe).
The trigger requires multiple steps before activating airbag	- The activation is too complicated	- Using activation systems that only requires a single step input from users
The trigger does not connect with the cable properly The trigger disconnects from the bowden cable too often	- Some junction is loosened due to thermal contraction - Fastening system is too loose	
You lose the trigger when skiing	- Trigger is not well attached to the backpack, person, etc.	- Trigger should be focused on attaching to the person

The problem	Ways to cause the problem	Ways to solve the problem
Joints are cold	- Air cooling unit - Requires shorter sleeves	- Insulating layer (like cloth) - Heating unit
Repetition of same motion	- Performing same tasks every day	- Having breaks between repetition of tasks (and doing wrist stretching, etc) - Changing up tasks from day-to-day - Adjustable device
Uncomfortable surface	- Rigid/hard surfaces - Sharp angles at edges	- Cushion, pad - Non-contact solution (no need to wear anything)
Wrists an an awkward angle	- Keyboard at steep angle - Mouse at weird angle - Bad posture	- An adjustable keyboard which varies between large angles to fit the user - Keep keyboard at elbow height - Brace that helps to support wrist and

Figures 45-47. Snippets of team Reverse Brainstorming in ESC101 Sprint B (left), ESC101 Sprint C (bottom), and ESC102 (right).

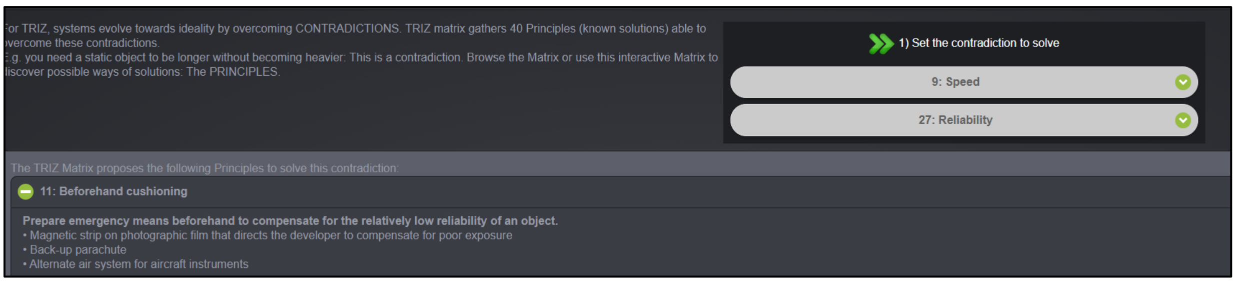
Description and How/When I Used it

Reverse Brainstorming changes the problem statement to identify ways in which the problem can be caused [14]. My teams and I used it to refine an existing set of candidate designs. We came up with a potential issue, looked for ways to cause those issues, and brainstormed ways to address them.

Purpose and Utility Evaluation

Unfortunately, many of the solutions we identified were trivial or obvious, thus, this tool was ineffective at directly synthesizing ideas. Rather, we used it to resolve potential issues of existing designs which we created using other divergence tools. Also, Reverse Brainstorming reminded us of the constraints and criteria, which allowed us to fit our designs to the requirements model more seamlessly.

4.8 Diverge 2: TRIZ 40



Contradiction:

1. Stabilize/secure the trigger system vs not inhibiting user motion
2. Quick activation and accidental triggering
3. False positives vs false negatives
    a. Accurate vs minimizing false positives
4. Durability vs weight
5. Temperature vs reliability
6. Ease of repair vs durability and stability, potentially
7. Extent of automation vs reliability

Figures 48-49. Using http://www.triz40.com/TRIZ_GB.php as a team to introduce a manual trigger in ESC102 (see Figure 33) (top) [16]. Other contradictions we found (bottom).

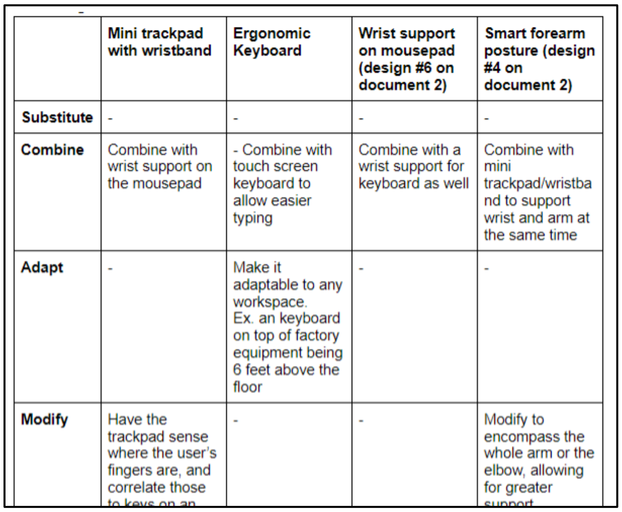
Description and How/When I Used it

TRIZ 40 is a matrix which leverages 40 design principles to solve a contradiction between two design features [16]. My ESC102 team and I used it to refine our chosen design. We simply used an online tool to determine which of the 40 TRIZ principles are most appropriate to employ [16].

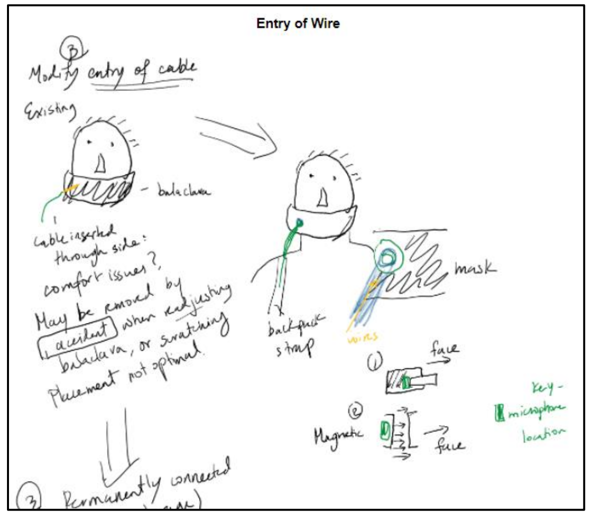
Purpose and Utility Evaluation

TRIZ 40 was very effective at managing risk. For example, it provided us with a means to increase redundancy and safety measures, especially since we were concerned about framing the opportunity to one that only required automated airbag activation systems. However, for some of the contradictions, we were unsure how to apply the TRIZ principles because most of them were contextualized to certain engineering design problems.

4.9 Diverge 2: SCAMPER



	Mini trackpad with wristband	Ergonomic Keyboard	Wrist support on mousepad (design #6 on document 2)	Smart forearm posture (design #4 on document 2)
Substitute	-	-	-	-
Combine	Combine with wrist support on the mousepad	- Combine with touch screen keyboard to allow easier typing	Combine with a wrist support for keyboard as well	Combine with mini trackpad/wristband to support wrist and arm at the same time
Adapt	-	Make it adaptable to any workspace. Ex. an keyboard on top of factory equipment being 6 feet above the floor	-	-
Modify	Have the trackpad sense where the user's fingers are, and correlate those to keys on an	-	-	Modify to encompass the whole arm or the elbow, allowing for greater support



Figures 50-51. Snippets of team SCAMPER in ESC101 Sprint C (left) and Daniel Zhuang's SCAMPER sketches in ESC102 (right).

Description and How/When I Used it

SCAMPER is a diverging activity used to *Substitute, Combine*, *Adjust*, *Modify*, *Put to other use*, *Eliminate*, and *Reverse* components of a design [17]. My teams and I used this tool to refine our top candidate designs, especially our chosen design. We identified the different aspects of the design and matched it to each letter in "SCAMPER" to identify any room for improvement.

Purpose and Utility Evaluation

Similar to TRIZ 40, this tool was effective in polishing minor flaws in our chosen design before presenting the recommendation. However, the adjustments we wrote down were usually vague because the tool focused more on *Embodiment Design* than *Detailed Design*. We had to spend time looking for specific components to change and achieve the specified design results.

4.10 Converge 2: Measurement and Comparison Matrices

Measurement Matrix	Touchscreen Keyboard	Wrist Brace	Ergonomic keyboard	Arm support (Frame)	Headset/Dictate
Effect on productivity (% increase/decrease wpm)	-70%... (touchscreen too sensitive, too many misclicks)	- (5%- 10%)	+ ~ 5% (to be tested)	- 1% (possibly a positive effect with an improved prototype)	+68 % May vary based on speaking speed vs typing speed (reference study to support)
Wrist angle (degrees)	0-5 +- 1	0-5 (adjustable)	0 (adjustable to user specifications, such as shoulder height, and wrist size)	0°	N/A
Range of size (boolean -- fit in a workplace)	Yes	Yes	Yes	Yes	Yes
Weight of device applied to user (grams)	Controlled by the software to try maximize it at 150+-1g (normal force)	<100	0 (no weight is applied to the user)	0 (no weight is applied to user)	< 100 (airpod is 0.14 ounce, mask material is cloth?)
Estimated Cost (dollars CAD)	~$250	$25 (estimated)	~$30 (estimated)	~$20 (estimated)	~ $100 + (mass-loaded vinyl + microphone)
Comfort (Rubric on scale of 1-4)	3	2	3	4	2
Additional Considerations		Helps to keep wrists warm			Noise pollution (decibels)

Comparison Matrix (in order of priority)	Touchscreen Keyboard	Wrist Brace (reference)	Ergonomic keyboard	Arm support (Frame)	Headset/Dictate
Wrist angle (degrees)	Same	Reference	Same	Same	Better
Effect on productivity (words per minute)	Worse	Reference	Better	Better	Better
Weight of device applied to user (grams)	Same	Reference	Better	Better	Worse
Comfort of Device (rubric)	Better	Reference	Better	Better	Worse
Range of size (boolean -- fits on desktop)	Same	Reference	Same	Same	Same
Cost (CAD)	Worse	Reference	Same	Same	Worse
Additional Features / Considerations	Worse	Reference	Worse	Worse	Worse

Metrics	Camera	VoiceEvo	Mouthguard
Body movement restriction level [rubric]	1	1	2
Detection accuracy [%]	75-85	95	99
Time to deployment upon input [s]	5	2	1.5
User activation steps [number]	0	1	1
Power consumption (± 0.1 W)	5	1.8	1.5
Number of single points of failure (SPOF) and dependencies [number]	3	3	4
Maintenance/setup time before use) [± 2 s]	15	30	30
Design Cost Estimate [CAD]	~180	~80	~130

Metrics ordered in *decreasing* priority.

Figures 52-54. Team measurement (left) and comparison (right) matrices in ESC101 Sprint C. Fused measurement and comparison matrix in ESC102 (bottom).

Description and How/When I Used it

A measurement matrix is a table containing results of testing procedures while a comparison matrix compares how the results match relative to a benchmark with reference to the requirements model [4]. I used them *as intended* at first (ESC101) by having two separate tables. However, I recognized how much space they take up and the difficulty associated with navigating between the two tables. Thus, I used them *as desired* in ESC102 and fused them together to create a single table where the entries are measurements, and the cells are color coded by comparison. My team used these tables after prototyping and testing our top choices to finally recommend a solution.

Purpose and Utility Evaluation

This representation allows us to order the metrics by priority and make an accurate, holistic judgement about the recommended design using the Toulmin model. However, selecting a benchmark is tedious since it is a matter of trial and error and making an approximate guess as to whether the comparisons are as equal as possible (i.e., a design is not too obviously good or bad).

4.11 Converge 2: Pairwise Comparison

	1.1 (camera)	2.1 (risk)	2.2 (mirror)	3.1 (voice)	3.2 (thigh)	Mouthguard
1.1 (camera)	/	---	+++	---	+++	+++
2.1 (risk)	2.1 has fewer false +/- than 1.1 due to manual trigger. 1.1 has fewer steps 2.1 inhibits user motion more than 1.1 because user needs to look at device +++	/	+++	---	+++	000
2.2 (mirror)	2.2 inhibits user motion: display distracts user 2.2 has fewer false positives 2.2 more water protected 2.2 requires more steps due to manual trigger ---	2.2 inhibits user motion since views of display are more frequent 2.2 has fewer components Lower detection rate since one will not always view mirror ---	/	---	---	+++
3.1 (voice)	3.1 has more steps than 1.1 3.1 is more reliable Fewer components +++	2.1 has no false positives since user pulls trigger 3.1 does not cause user to look at accessory device (inhibition) 3.1 is relatively lower maintenance, does not need to extract real time data	3.1 fewer false positives from accurate detection 3.1 does not cause user to look at screen (inhibition) 3.1 More reliable from lack of need to communicate through GPS, or	/	+++	+++

Figure 55. Team pairwise comparison table in ESC102.

Description and How/When I Used it

Each candidate design is compared to all the other designs and wins if it matches the requirements model the most based on holistic judgement [15]. I used it with my team in ESC102 to narrow down our top 6 designs to the three most promising ones before conducting any tests.

Purpose and Utility Evaluation

Although this activity is tedious since there are $(n-1)!$ comparisons (n designs), this activity is effective at understanding why a design is better than the other in terms of components. This also helps refine the weaker designs to adopt components of stronger designs and maximize its potential.

4.12 Communicate: Toulmin Model of Argument

- Although the mouthguard sensor has a high true positive detection accuracy, we anticipate a high false positive rate also since the user may clench down in teeth unintentionally. It is also more restrictive and relies on Bluetooth, another point of failure.
- For these reasons, we decided to eliminate the mouthguard
- The lower power consumption and time to deployment are critical efficiency and safety metrics, since they relate directly to the framing of the opportunity. While the camera requires no user involvement, it has a lower accuracy and a longer time delay that contradicts our two most important metrics. As a result, VoiceEvo is our recommended design.

Figure 56. Toulmin argument for selecting the voice-activated design in ESC102. See Figure 20 for my arguments at UTAT.

Description and How/When I Used it

The Toulmin model is a structure of argument for making a claim and supporting it with justification and evidence relative to a qualifier [18]. I used mainly used it to justify my reframing at the beginning of the design process as well as to recommend a final design at the end of the design process.

Purpose and Utility Evaluation

It is a very rigorous model for presenting and defending one’s design ideas and actions. Although dealing with counterarguments may be tedious, doing so only makes your argument stronger.

4.13 Communicate: Team Effectiveness Inventory

6. Openly express ideas and opinions

	Did not express ideas or opinions	Expressed ideas and opinions in a manner which detracted from the team's productivity	Expressed ideas and opinions in an open and constructive manner	Expressed ideas and opinions in an open and unbiased manner that welcomed input from others
Willis Guo	○	○	○	●
Alexander Alexiev	○	○	●	○
Hamza Dugmag	○	○	●	○
Daniel Zhuang	○	○	○	●
Harry Chin	○	●	○	○

commitment to the team improved everyone's confidence in our work. This behavior also improved my trust in you. I encourage you to keep up this responsibility but also try to reach out to teammates and lend a hand to explore aspects of engineering design other than prototyping. I look forward to working with you in future group projects.

Hamza Dugmag

I believe that you are great at raising contentious issues in a constructive way. This behaviour challenges everyone's biases and can get rid of anchoring to improve productivity. For example, after our discussion with the TAs after BETA, we realized that we needed more than 2 candidate designs. You suggested to include the mouthguard sensor for showcase, however, most of the team members believed that it would be a waste of time to conduct testing on this candidate design. Luckily, this introduced a new strategy for success that challenged everyone's biases. Ultimately, you were able to convince the team to include it, which brought more depth to our engineering arguments at showcase. I suggest you to constantly reveal the team's implicit biases to better reflect on our perspectives and explore more unique solutions.

On the other hand, I believe you need to listen more actively and allow others to express their ideas. I noticed that throughout the entire semester, you had a lot to say on everything (maybe due to your perfectionism). Whenever someone initiated a discussion, you were always the first one to jump in, sometimes at the cost of cutting another teammate off or preventing them from sharing their ideas and contribute to a more diverse discussion. I suggest you take a couple moments to reflect on whatever prompt your teammate poses, as well as encourage your team to share what they think before you jump in. This can improve trust between you and your everyone else.

[redacted]

I do think you should be more confident in your teammates as that can improve team chemistry. I believe that at some points in the process you were in a sunk cost fallacy and tried to suggest fighting through any problems we were facing. For example, after BETA, our discussion with the TAs revealed

Figures 57-58. ESC102 Phase II TELS feedback using the team effectiveness inventory. Note that the same feedback process was conducted for Phase I TELS as well.

Description and How/When I Used it

The Team Effectiveness Inventory is a set of interpersonal behaviors which constitute for an effective team [19]. I used it during TELS I and TELS II to provide feedback on how my teammates were interacting with me and contributing to the team's productivity. I submitted these feedbacks after the Request for Proposal and Showcase respectively (the two largest ESC102 projects of the semester). When providing feedback, I explicitly stated two actions that my teammates took (with reference to the inventory) and how they impacted the team (one positive and the other negative). I then proceeded to give advice on how to improve their interpersonal collaboration skills.

Purpose and Utility Evaluation

The inventory helps structure my feedback and effectively communicate what I perceived from my teammates for them to grow and improve. I believe it was mostly an exhaustive list of good attributes that each teammate should exhibit.

4.14 Research: University of Toronto Engineering & Computer Science Library

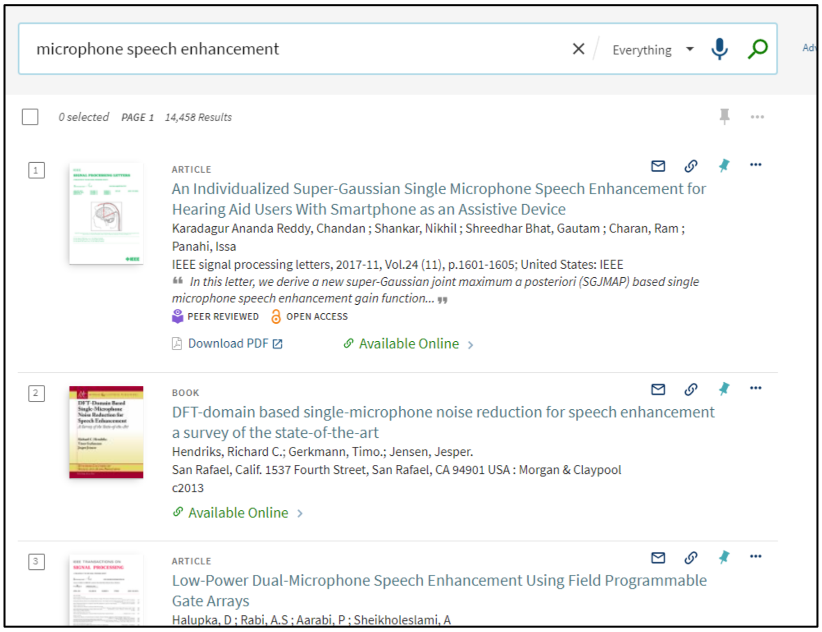


Figure 59. Searching for reputable secondary sources on the U of T Engineering & Computer Science Library for ESC102 testing protocols.

Description and How/When I Used it

This online tool available to University of Toronto students provides us with access to scholarly articles, academic reports, engineering standards, handbooks, and many more credible sources [8] [20]. I use it as the first place I visit to frame my opportunity, justify my constraints and criteria, and establish testing protocols.

Purpose and Utility Evaluation

Although this is the most accessible source for credible resources, I find it tedious to use the search bar when looking for articles about a specific engineering topic. The search results are very sensitive to the exact phrase used, and a niche search term may yield outdated or irrelevant results.

4.15 Research: CRAAP Test

Description and How/When I Used it

See section 2.5 for my employment of the CRAAP test. This test is used to evaluate sources by their *Currency*, *Relevance*, Authority, *Accuracy*, and *Purpose* [21]. I implicitly use the test when conducting research, however, during BMEC, I explicitly relied on it to evaluate which sources to include in the background section of our presentation, especially since we had a limited time to prepare it.

Purpose and Utility Evaluation

The test is flexible, and its metrics are appropriate. When I used it during BMEC, it improved my intentionality and self-awareness about what information I was searching for. Also, it mitigated confirmation bias by questioning the source's authority.

Appendix A: References

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[8] R. Irish, P. Sheridan, P. Kinnear and P. Asare, "Lecture 05: Communities, Credible Sources, and Framing Perspectives," Toronto, 2021.

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[18] R. Irish, "Building a Solid Argument," Toronto, 2020.

[19] R. Irish, P. Sheridan, P. Kinnear and P. Asare, "Lecture 19: Moving to Phase II and Team Feedback - TELS," Toronto, 2021.

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[21] "Evaluating Sources: The CRAAP Test," Benedictine University, 19 January 2021. [Online]. Available: https://researchguides.ben.edu/source-evaluation. [Accessed 30 April 2021].

Appendix B: Source Extracts

[1]

I

THE MOTIVE FOR METAPHOR

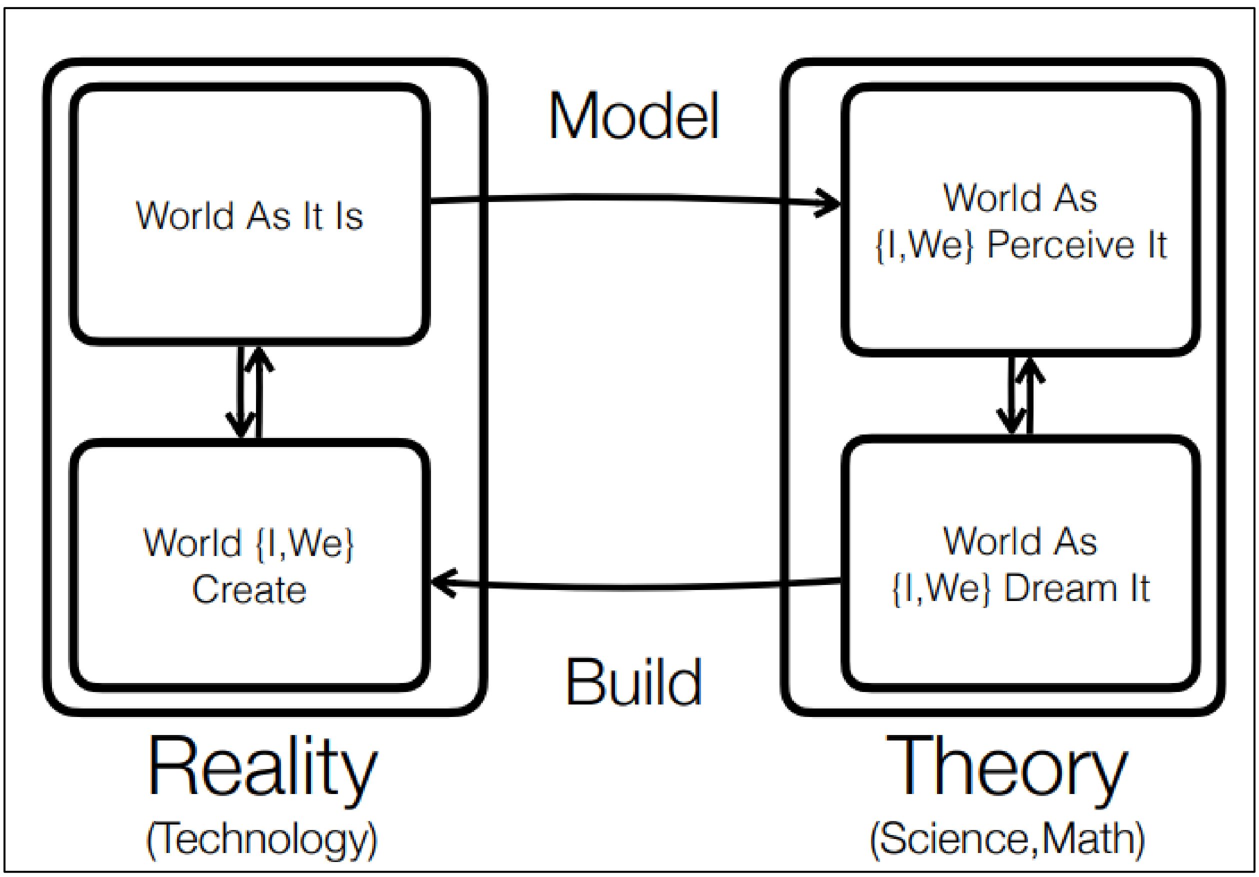
FOR THE PAST TWENTY-FIVE years I have been teaching and studying English literature in a university. As in any other job, certain questions stick in one's mind, not because people keep asking them, but because they're the questions inspired by the very fact of being in such a place. What good is the study of literature? Does it help us to think more clearly, or feel more sensitively, or live a better life than we could without it? What is the function of the teacher and scholar, or of the person who calls himself, as I do, a literary critic? What difference does the study of literature make in our social or political or religious attitude? In my early days I thought very little about such questions, not because I had any of the answers, but because I assumed that anybody who asked them was naïve. I think now that the simplest questions are not only the hardest to answer, but the most important to ask, so I'm going to raise them and try to suggest

8 THE EDUCATED IMAGINATION

scheme of human affairs. It's the power of constructing possible models of human experience. In the world of the imagination, anything goes that's imaginatively possible, but nothing really happens. If it did happen, it would move out of the world of imagination into the world of action.

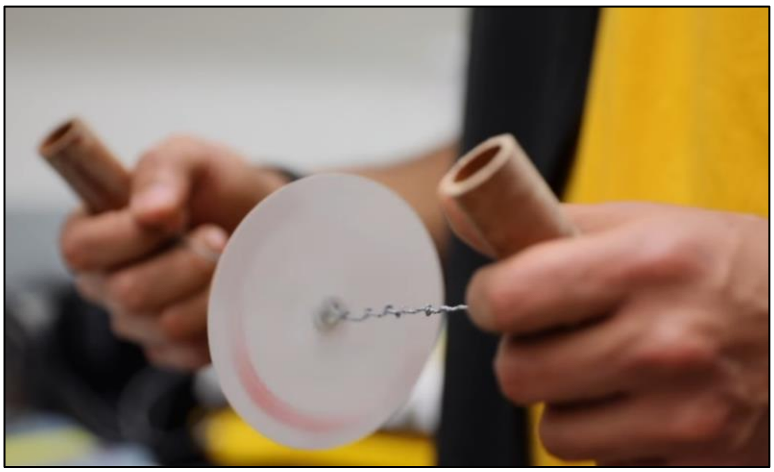
> The simple point is that literature belongs to the world man constructs, not to the world he sees; to his home, not his environment. Literature's world is a concrete human world of immediate experience. The poet uses images and objects and sensations much more than he uses abstract ideas; the novelist is concerned with telling stories, not with working out arguments. The world of literature is human in shape, a world where the sun rises in the east and sets in the west over the edge of a flat earth in three dimensions, where the primary realities are not atoms or electrons but bodies, and the primary forces not energy or gravitation but love and death and passion and joy. It's not surprising if writers are often rather simple people, not always what we think of as intellectuals, and certainly not always any freer of silliness or perversity than anyone else. What concerns us is what they produce, not what they are, and poetry, according to Milton, who ought to have known, is "more simple, sensuous and passionate" than philosophy or science.

[2]



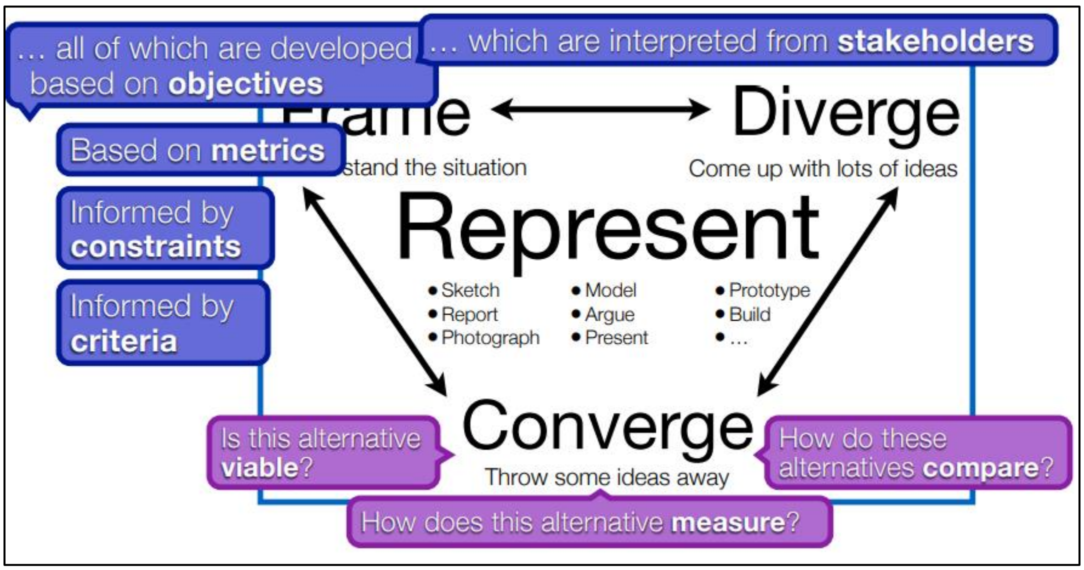
[3]

> Now, using the same mechanical principles, Stanford bioengineers have created an ultra-low-cost, human-powered centrifuge that separates blood into its individual components in only 1.5 minutes. Built from 20 cents of paper, twine and plastic, a “paperfuge” can spin at speeds of 125,000 rpm and exert centrifugal forces of 30,000 Gs.



[4]

- (A) **Invention** ≈ "I didn't even think that was possible?"
- (B) **Creative Design** ≈ "I never thought of designing it like that!"
- (C) **Algorithmic Design** ≈ "You and the software figured things out. Sometimes in unexpected ways."
- (D) **Routine Design** ≈ "You followed standard procedure to do what was expected (with some contextualising)"
- (E) **Handbook engineering** ≈ "You have applied the correct model to the situation!"
- (F) **Sizing** ≈ "You picked parameters by reading values off of { graphs, tables } and integrating calculations"
- (G) **Selection** ≈ "You decided from 'off the shelf' options"



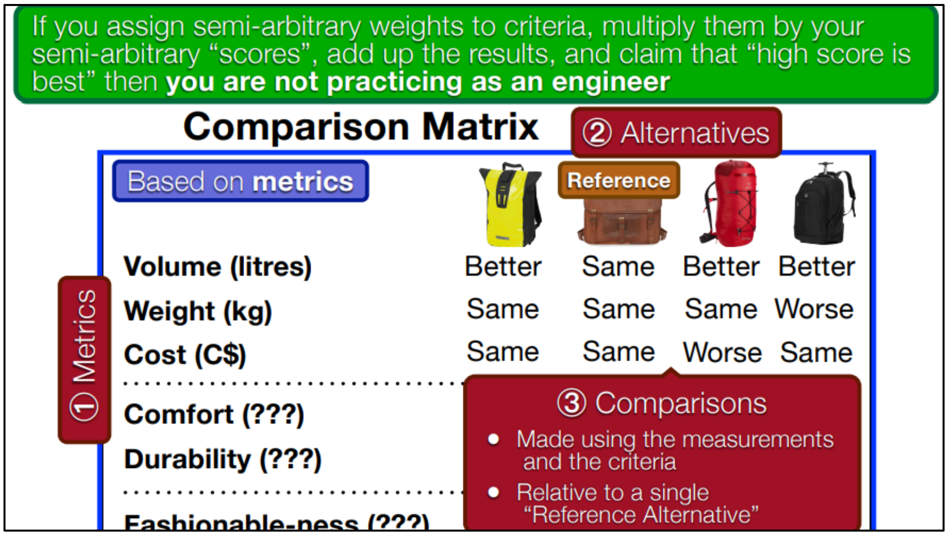
Based on **metrics**

Measurements Matrix

Volume (litres)	6.4	2.3712	16	10.5
Weight (kg)	2.1	3	2.2	5.1
Cost (C$)	49.99	56.49	88.72	69.99

Based **only** on the numbers in the table, what concerns do you have about **the metrics** or **how the measurements were obtained**?

Significant Figures are Real!
If you can measure 2.3712 L, you either are imagining it, have spent time acquiring meaningless data, or have an incredibly (expensive) precise tool.



[5]

ABSTRACT

This RFP aims to inform design teams about an opportunity to improve avalanche airbags for the use by an Italian group of backcountry skiers and ski guides, SUCAI. This group, as well as many skiers around the world, wear avalanche airbags when skiing off resort grounds in order to lower the risk of being fatally buried in an avalanche. This RFP aims to solicit proposals to improve the mechanism that triggers the airbag. Specifically, the design team is to propose a new device that can produce a pulling effect through a Bowden cable in the event of an avalanche, triggering the avalanche airbag to inflate.

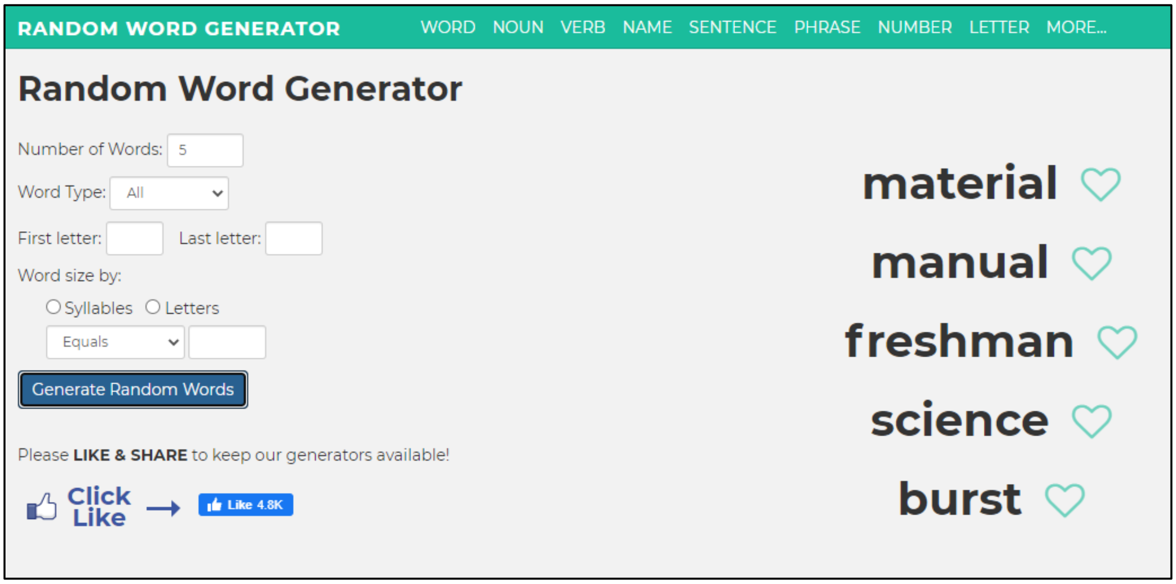
From our first interactions with Luca, our contact with the Italian backcountry skiing community, we were struck by the danger avalanches posed to skiers. When an avalanche is triggered there is a substantial risk of being buried under it, as the raffling snow tends to run over anything in its path. This safety concern is mitigated by backpacks with integrated airbag systems, which allow the user to rise on top of the snow particles by increasing its size, a principle also known as the Brazil Nut Effect. Currently, these systems rely on a handle trigger for manual activation that, in high stress moments like avalanches, can be forgotten about or impracticable. Moreover these backcountry backpacks are infeasible for skiers, as the trigger system is incompatible with the use of ski poles.

The opportunity being presented through this RFP is to improve the current design for trigger systems intended to deploy ski airbags. One of the main concerns with current designs is that the motion required to trigger inflation is exaggerated, and not always possible to perform when caught in an avalanche. Thus, this opportunity seeks to promote designs that maximize speed of deployment, safety, and reliability.

The reason behind scoping down directly to trigger systems specifically was that the airbag was a proven and effective safety measure for backcountry skiers (a statement which Luca agreed with). In fact, our research showed that *properly deployed* airbags tended to halve avalanche fatalities (Temper). Given this research, we felt it appropriate to focus our opportunity on the trigger mechanism in order to maximize the number of successful airbag deployments.

Based on our interactions with Luca and other SUCAI members, as well as our own research on the backcountry snowsport community, it is clear that a design space for a new airbag trigger mechanism exists, and improving their design would increase the safety of those who take part in backcountry skiing and snowboarding. Moreover, the scoping and requirements model offers first-year engineering design teams the resources and fundamental understanding required to best aid them in diverging and converging on a broad set of candidate designs.

[6]



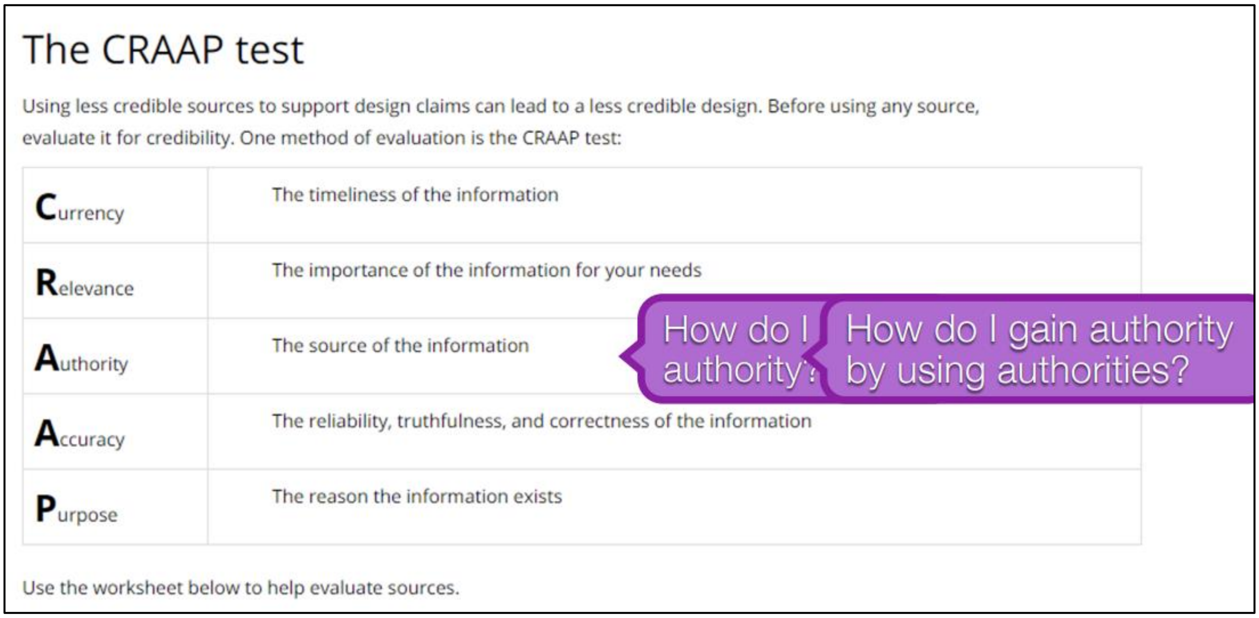
[7]

3.3. Non-inflation rates and underlying causes

The overall non-inflation rate in the sample of airbag users was 20% (61/307). Information on suspected causes of non-inflations was available for 52 cases: 60% (31/52) were attributed to deployment failure by users, 12% (6/52) to maintenance errors (e.g., canister not attached properly), 17% (9/52) to device failures (i.e., performance issues that resulted in design and/or production revisions) and 12% (6/52) to destruction of the airbag during involvements. Relative to the total number of users, the rate of airbags destroyed in involvements was 2% (6/307) and the rate of device failures was 3% (9/307).

The observed overall non-inflation rate of 20% (61/307) clearly highlights that non-inflations still pose a considerable threat to the performance of avalanche airbags. Deployment failure by the user was identified as the main cause of non-inflations. Whereas

[8]



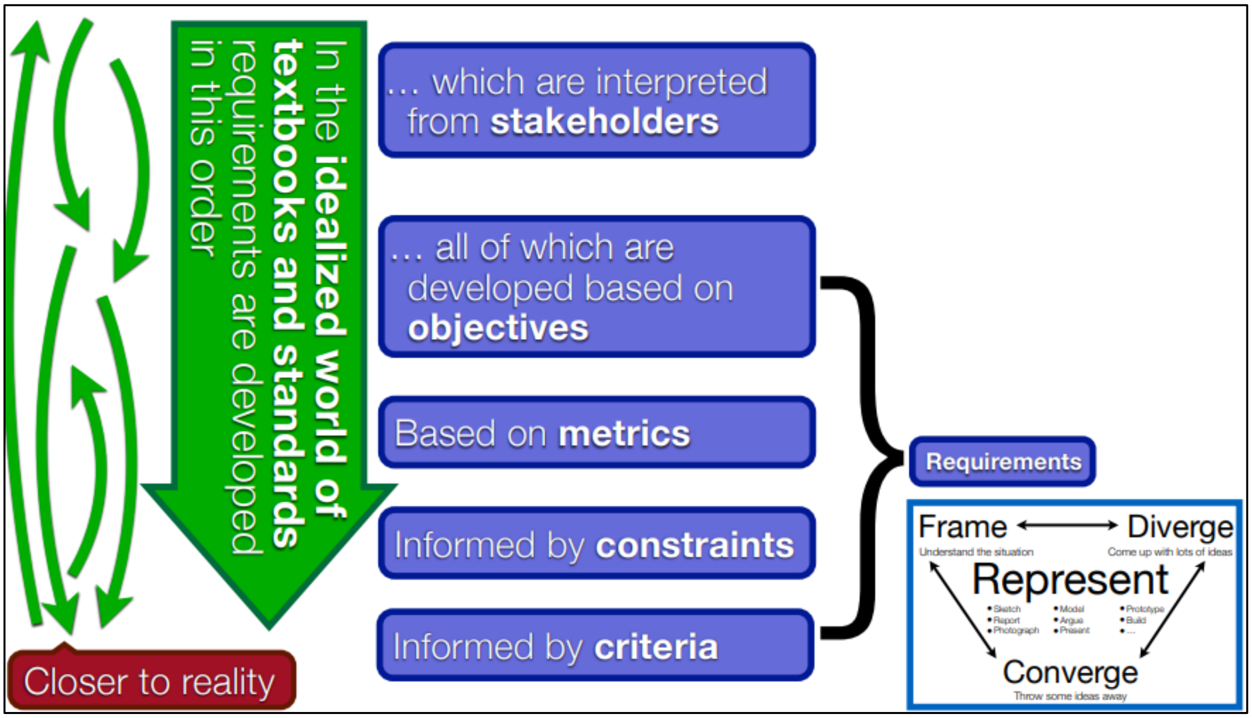
The CRAAP test

Using less credible sources to support design claims can lead to a less credible design. Before using any source, evaluate it for credibility. One method of evaluation is the CRAAP test:

Currency	The timeliness of the information
Relevance	The importance of the information for your needs
Authority	The source of the information
Accuracy	The reliability, truthfulness, and correctness of the information
Purpose	The reason the information exists

Use the worksheet below to help evaluate sources.

[9]


In the idealized world of textbooks and standards requirements are developed in this order
… which are interpreted from stakeholders
… all of which are developed based on objectives
Based on metrics
Informed by constraints
Informed by criteria
Requirements
Frame
Understand the situation
Diverge
Come up with lots of ideas
Represent
Converge
Throw some ideas away
Closer to reality

[10]

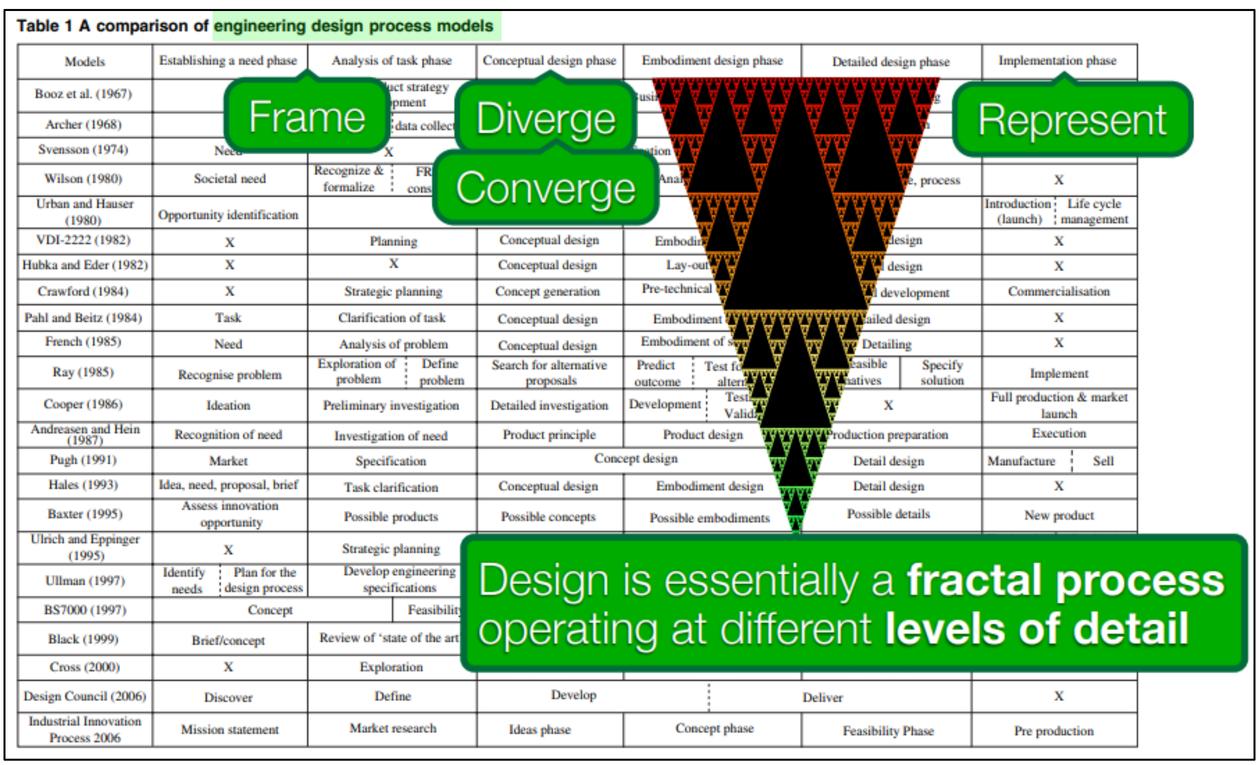
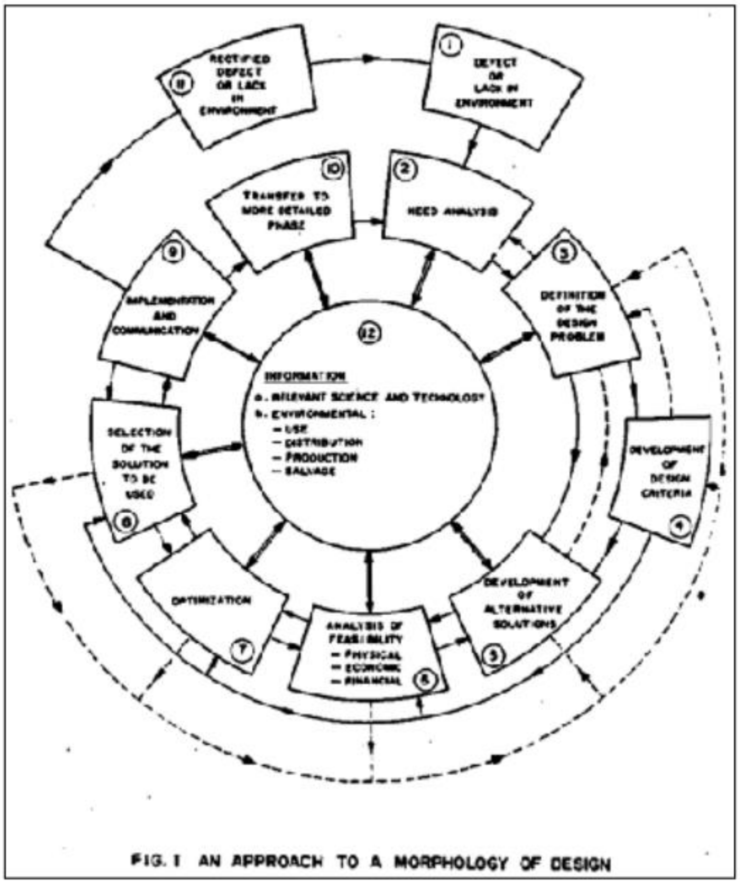
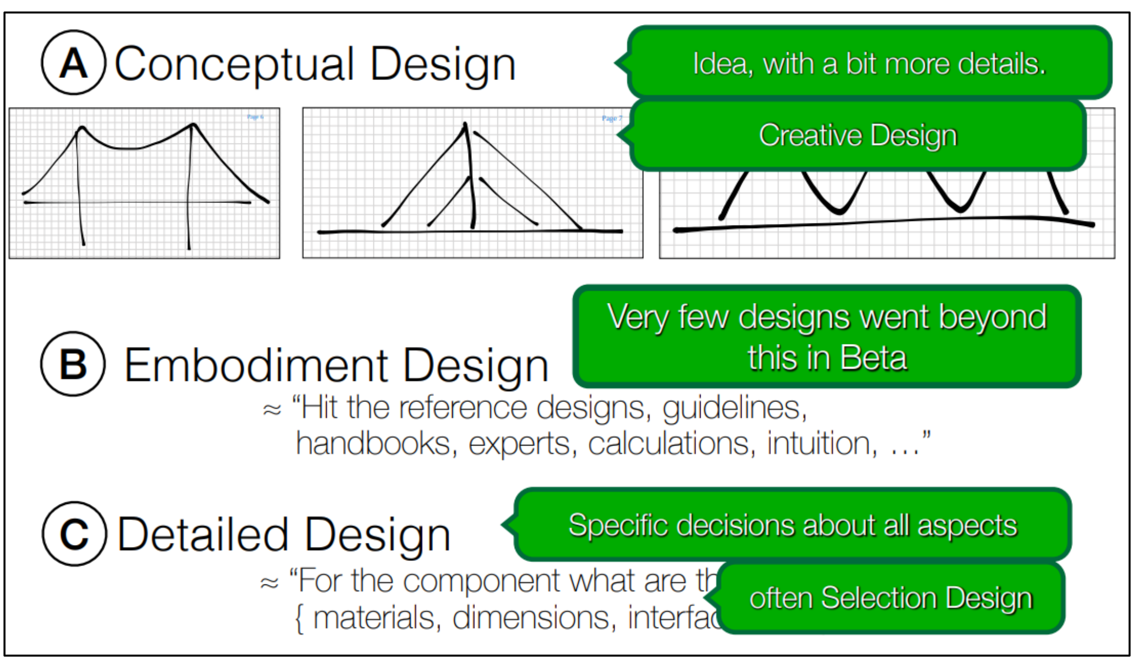


Table 1 A comparison of engineering design process models
Models
Establishing a need phase
Analysis of task phase
Conceptual design phase
Embodiment design phase
Detailed design phase
Implementation phase
Frame
Diverge
Converge
Represent
Design is essentially a fractal process operating at different levels of detail

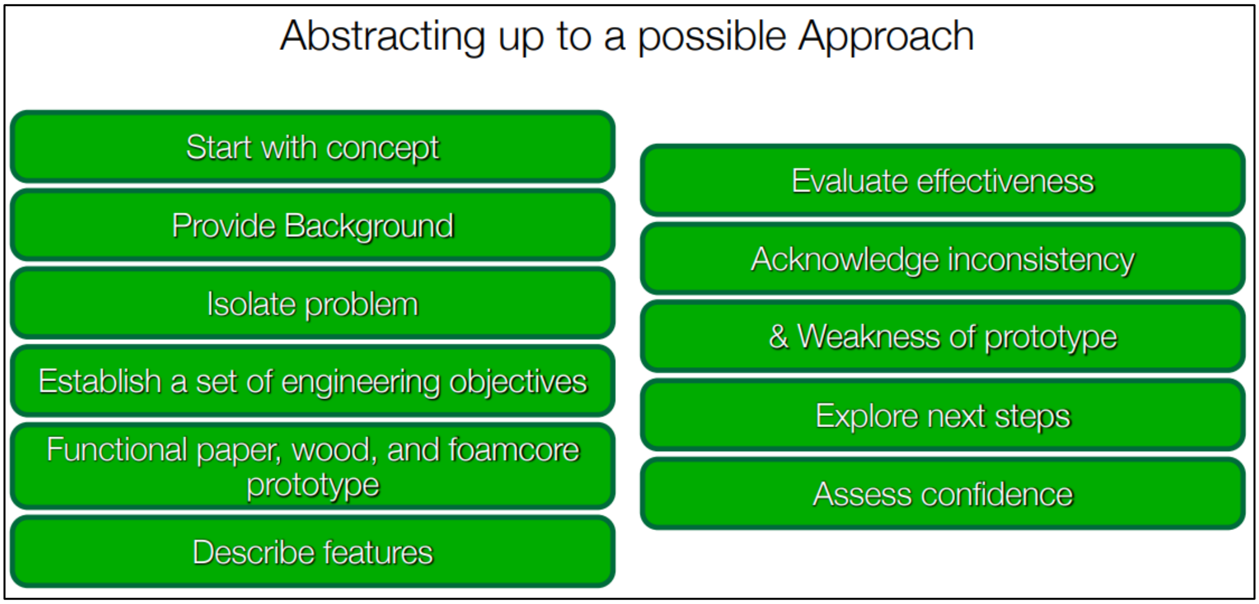
[11]

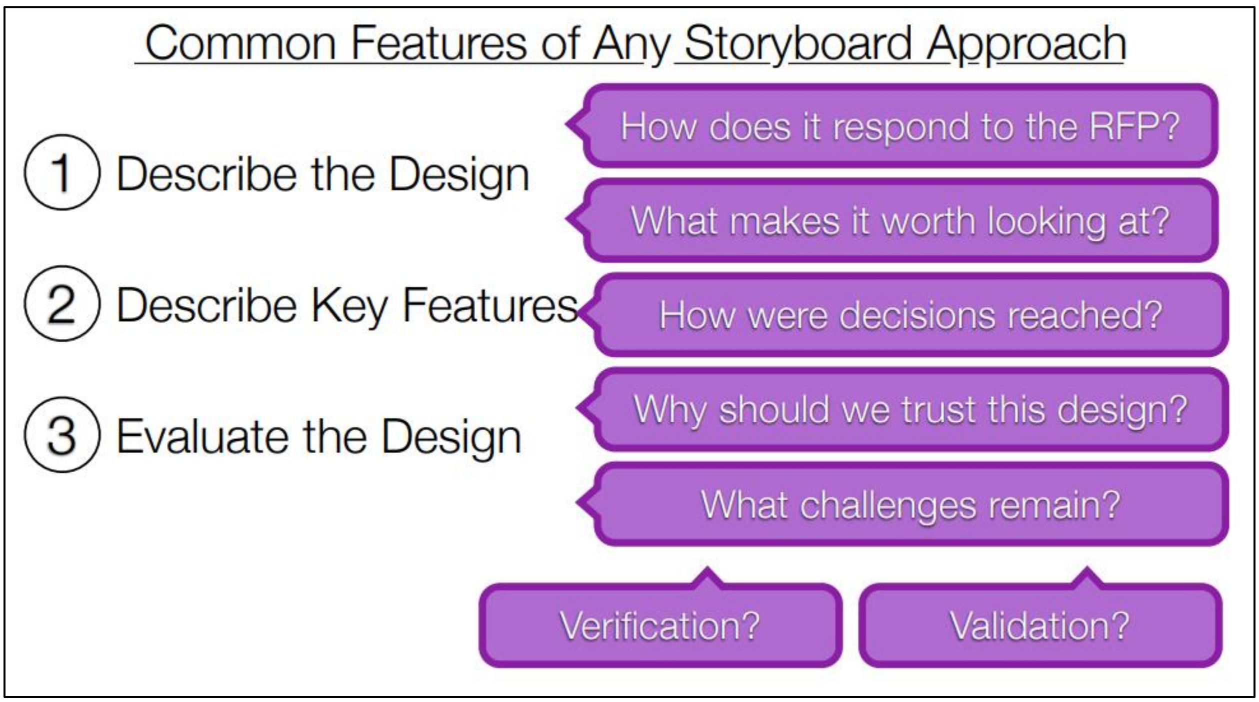

DEFECT OR LACK IN ENVIRONMENT
NEED ANALYSIS
DEFINITION OF THE DESIGN PROBLEM
DEVELOPMENT OF DESIGN CRITERIA
DEVELOPMENT OF ALTERNATIVE SOLUTIONS
ANALYSIS OF FEASIBILITY
– PHYSICAL
– ECONOMIC
– FINANCIAL
OPTIMIZATION
SELECTION OF THE SOLUTION TO BE USED
IMPLEMENTATION AND COMMUNICATION
TRANSFERED TO MORE DETAILED PHASE
RECTIFIED DEFECT OR LACK IN ENVIRONMENT
INFORMATION
a. RELEVANT SCIENCE AND TECHNOLOGY
b. ENVIRONMENTAL:
– USE
– DISTRIBUTION
– PRODUCTION
– SALVAGE
FIG. 1 AN APPROACH TO A MORPHOLOGY OF DESIGN

[12]


A Conceptual Design
Idea, with a bit more details.
Creative Design
B Embodiment Design
Very few designs went beyond this in Beta
≈ "Hit the reference designs, guidelines, handbooks, experts, calculations, intuition, …"
C Detailed Design
Specific decisions about all aspects
≈ "For the component what are th
{ materials, dimensions, interfac
often Selection Design

[13]


Abstracting up to a possible Approach
Start with concept
Provide Background
Isolate problem
Establish a set of engineering objectives
Functional paper, wood, and foamcore prototype
Describe features
Evaluate effectiveness
Acknowledge inconsistency
& Weakness of prototype
Explore next steps
Assess confidence


Common Features of Any Storyboard Approach
1 Describe the Design
2 Describe Key Features
3 Evaluate the Design
How does it respond to the RFP?
What makes it worth looking at?
How were decisions reached?
Why should we trust this design?
What challenges remain?
Verification?
Validation?

[14]

Divergence

BRAINWRITING 6-3-5

How to use: individual / group | open / closed problems | products / services

Description:

A creativity tool aimed to address the potential deficiencies of brainstorming (uneven participation and verbally led) by encouraging participation from all, with an emphasis on sketching of ideas.

Steps:

1. Establish team & Define scope and purpose

A good size team for brainwriting is between 3 to 8 people - 6 is about right, hence the '6' in the name of the tool. As with brainstorming, the process will be more effective with a clear focus.

2. Each team member captures 3 ideas each

Each team members writes, describes or sketches 3 ideas each on a piece of paper. It is highly recommended that at this stage, the participants should be encouraged to sketch their ideas, an annotate the sketches with writing where appropriate. It may help the team members to focus on the top 5 elements of product functionality, as viewed as important by customers. This stage should last around 30 minutes (longer if people are still going strong, shorter if ideas have dried up) and in that time, a team of 6 people should have produced between 15 to 30 unique concepts.

3. Pass the concepts around the table - 1 round

Following the initial session, the concepts are passed to the right, to the next person around the table. Allow 10-15 minutes for each person to add to, modify and extend each of the ideas passed to them. Once they have done this, the sheets are passed on until all ideas have been seen and modified by all team members. This can take in total about 60 minutes. The focus of any modifications to ideas should be on advancing the idea, not criticising.

4. Repeat 5 times

It is recommended that they are passed around the table in total 5 times, to encourage combination of ideas, refinement and development of concepts. This can be laborious, and the rounds should be spaced out in time to prevent the team becoming stale. After a few rounds, it can be beneficial to use traditional brainstorming rules, to encourage some debate and discussion about the ideas, with a view to advancing the concepts more quickly and potentially eliminating the weakest ones.

More information:

http://www.mycoted.com/Brainwriting

8 CreativityToday.net

Divergence

RANDOM INPUT

How to use: individual / group | open / closed problems | products / services

Description:

Random Input is a lateral thinking tool. It is very useful when you need fresh ideas or new perspectives during problem solving. Random input is a technique for linking another thinking pattern into the one we are using. Along with this new pattern comes all the experience you have connected to it.

Steps:

To use Random Input, select a random noun from either a dictionary or a pre-prepared word list. It often helps if the noun is something that can be seen or touched (e.g. 'helicopter', 'dog') rather than a concept (e.g. 'fairness'). Use this noun as the starting point for brainstorming your problem.

You may find that you get good insights if you select a word from a separate field in which you have some expertise.

If you choose a good word, you will add a range of new ideas and concepts to your brainstorming. While some will be useless, hopefully you will gain some good new insights into your problem. If you persist, then at least one of these is likely to be a startling creative leap.

More information:

http://www.sociology.org.uk/as4i3ri.pdf

http://www.randomwordgenerator.com

18 CreativityToday.net

Divergence

Reverse Brainstorming

How to use: individual / group | open / closed problems | products / services

Description:

Reverse the problem to: '*How to cause it*'

Change the wording of the problem on which you are working from how to solve it to how to cause it.

Steps:

1. *Identify ways of **causing** the problem*
2. Identify different ways of causing the problem. You can use creative approaches or analytic methods
3. *Find ways of **preventing** the problem being caused*
4. Now identify ways of preventing the problem causes identified in the previous step from being caused.

Example:

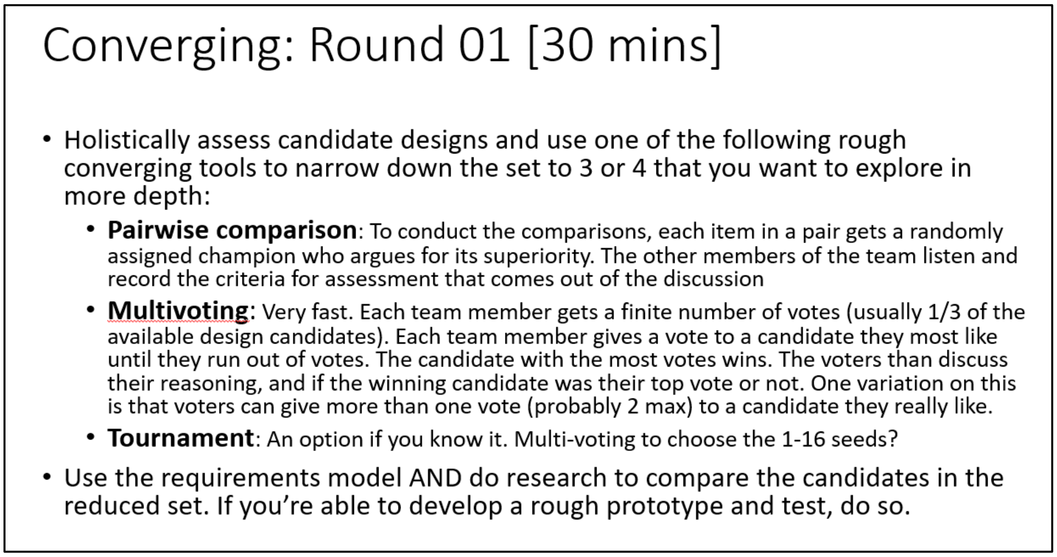
I am seeking to to keep a folding chair open. I reword it as 'how to make a folding chair fold up'. I use a spring, an elastic band, a lever. I reverse the lever so the spring or elastic keeps the chair open.

More information:

http://www.team-creations.com/Services/Library/Articles/Creativity/reverse%20brainstorming.htm

20 CreativityToday.net

[15]



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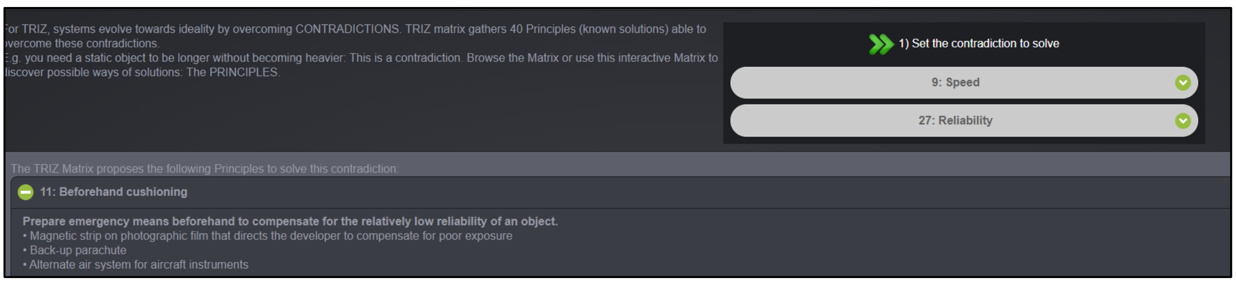

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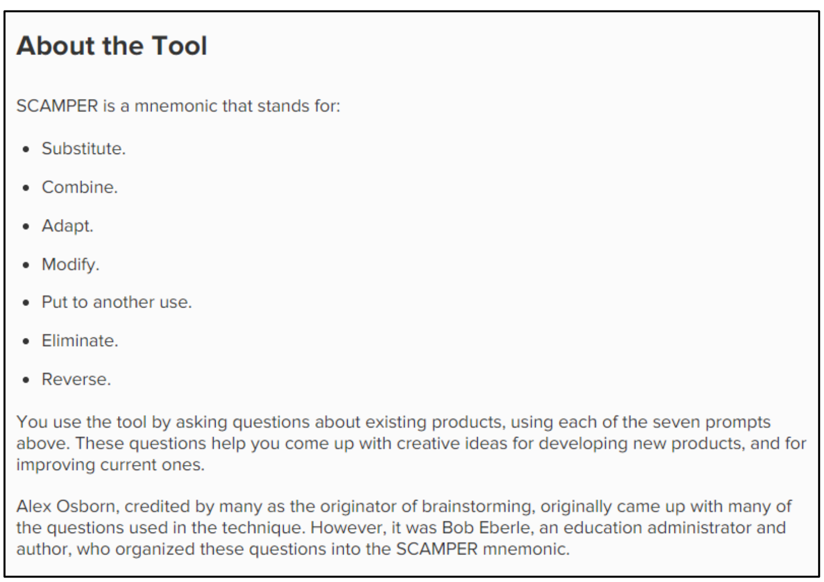


About the Tool

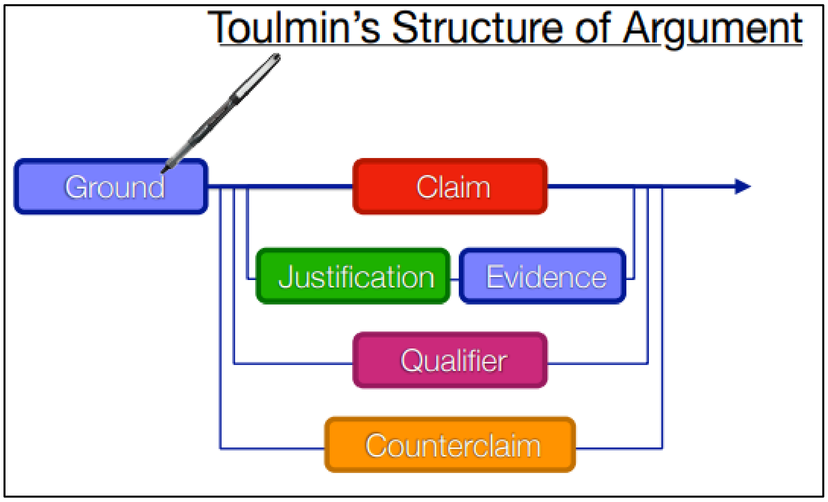
SCAMPER is a mnemonic that stands for:

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

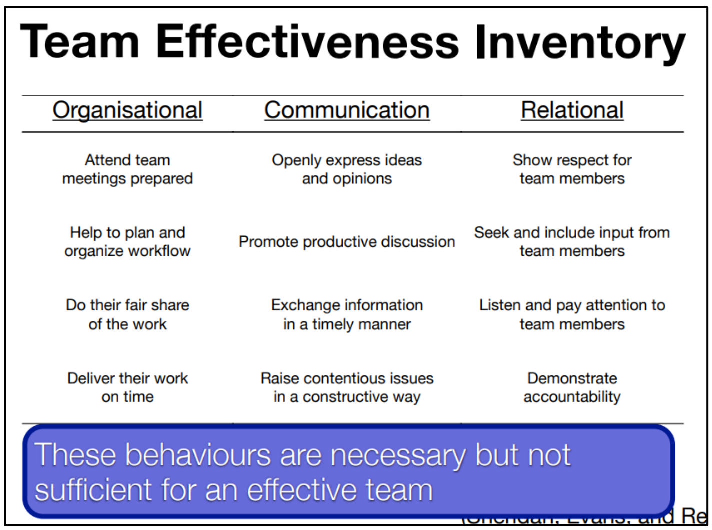
You use the tool by asking questions about existing products, using each of the seven prompts above. These questions help you come up with creative ideas for developing new products, and for improving current ones.

Alex Osborn, credited by many as the originator of brainstorming, originally came up with many of the questions used in the technique. However, it was Bob Eberle, an education administrator and author, who organized these questions into the SCAMPER mnemonic.

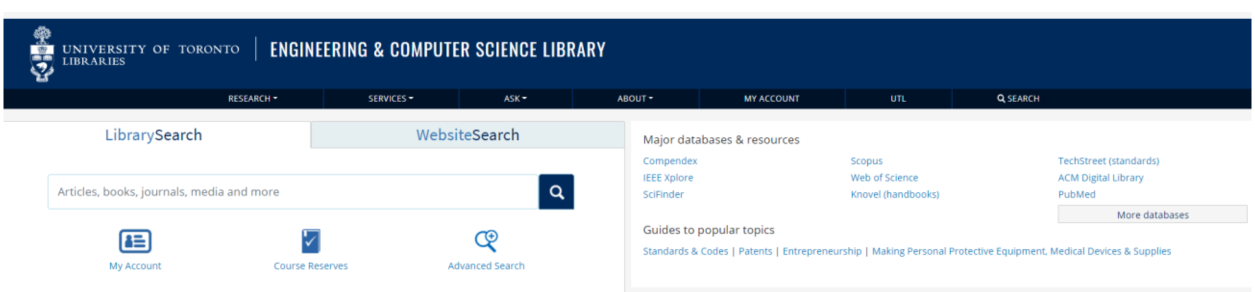
[18]


Toulmin's Structure of Argument
Ground
Claim
Justification
Evidence
Qualifier
Counterclaim

[19]


Team Effectiveness Inventory
Organisational
Communication
Relational
Attend team meetings prepared
Openly express ideas and opinions
Show respect for team members
Help to plan and organize workflow
Promote productive discussion
Seek and include input from team members
Do their fair share of the work
Exchange information in a timely manner
Listen and pay attention to team members
Deliver their work on time
Raise contentious issues in a constructive way
Demonstrate accountability
These behaviours are necessary but not sufficient for an effective team

[20]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SERVICES
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SEARCH
LibrarySearch
WebsiteSearch
Articles, books, journals, media and more
My Account
Course Reserves
Advanced Search
Major databases & resources
Compendex
IEEE Xplore
SciFinder
Scopus
Web of Science
Knovel (handbooks)
TechStreet (standards)
ACM Digital Library
PubMed
More databases
Guides to popular topics
Standards & Codes | Patents | Entrepreneurship | Making Personal Protective Equipment, Medical Devices & Supplies

[21]

Currency: the timeliness of the information

- When was the information published or posted?
- Has the information been revised or updated?
- Is the information current or out-of date for your topic?
- Are the links functional?

Relevance: the importance of the information for your needs

- Does the information relate to your topic or answer your question?
- Who is the intended audience?
- Is the information at an appropriate level (i.e. not too elementary or advanced for your needs)?
- Have you looked at a variety of sources before determining this is one you will use?
- Would you be comfortable using this source for a research paper?

Authority: the source of the information

- Who is the author/publisher/source/sponsor?
- Are the author's credentials or organizational affiliations given?
- What are the author's credentials or organizational affiliations given?
- What are the author's qualifications to write on the topic?
- Is there contact information, such as a publisher or e-mail address?
- Does the URL reveal anything about the author or source?
    - examples:
        - .com (commercial), .edu (educational), .gov (U.S. government)
        - .org (nonprofit organization), or
        - .net (network)

Accuracy: the reliability, truthfulness, and correctness of the content

- Where does the information come from?
- Is the information supported by evidence?
- Has the information been reviewed or refereed?
- Can you verify any of the information in another source or from personal knowledge?
- Does the language or tone seem biased and free of emotion?
- Are there spelling, grammar, or other typographical errors?

Purpose: the reason the information exists

- What is the purpose of the information? to inform? teach? sell? entertain? persuade?
- Do the authors/sponsors make their intentions or purpose clear?
- Is the information fact? opinion? propaganda?
- Does the point of view appear objective and impartial?
- Are there political, ideological, cultural, religious, institutional, or personal biases?