Summing it Up

An Engineering Handbook for Undergraduate Students

Victoria Rose Spada
2019

An Engineering Handbook for Undergraduate Students

By Victoria Spada

Acknowledgements

This page is dedicated to thanking and accrediting my Praxis I and II teammates for their ideas, collaboration, and contributions that support this handbook.

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1. Identity

1.1 Introduction and Values


My twin sister and I graduating from our high school art program.

I, Victoria Rose Spada, am a first year undergraduate student at the University of Toronto studying Engineering Science. I have Italian heritage and live in Toronto, Ontario with my parents, my brother, and my sister. I am a fundamentally curious, empathetic, and imaginative student. I was a visual arts student through high school and hope to carry my artistic past into my vision of bettering to society as an engineering student. In my work I value personal growth, simplicity, clarity, and imagination.

I hope to major in Energy Systems Engineering and have a career centered on environmental sustainability. Through my school experiences I have developed a strong interest in environmental science and am eager to act on my interests in a fashion that is not possible through school alone. Designing and prototyping an exhibit about compost at the Ontario Science Centre was one of my personal experiences that pushed me to see my passion for sustainability. I want to see a world where environmental sustainability is always at the forefront of our thoughts.

1.2 Skills

1.2.1 Visual Arts

I was a visual arts student in the Regional Arts Program at St. Elizabeth Catholic High School through my high school career. I have had a strong passion for visual arts since I was a toddler and continue to carry this passion today. I have extensive experience in the following traditional art forms:

- Painting (Oil, Acrylic, Gouache)
- Life Drawing
- Watercolors
- Lino/Printmaking
- Sculpture

I also have some experience in graphic design through Photoshop and Illustrator.

1.2.2 Written Communication

My written communication skills have been refined through my job as a tutor and my involvement in the St. Elizabeth High School Writer's Club as President. I can write anything from a riveting story to a persuasive essay on most unbelievable ideas, which becomes evident in the writing of design briefs and reviews. Academic writing aside, I also enjoy writing personal journals, short stories, and poetry, which is what prompted me to become involved in my high school's writing community.

1.2.3 Computer Skills

I am a novice programmer in the languages of C, Python, and MatLab, as taught in ESC180, ESC103, and ESC190. I can apply my programming knowledge to model and solve computational and optimization problems.

1.3 Biases

It is highly important that I recognize my biases so that they do not control my work or cloud my vision. One of my most prominent biases is my tendency to try to visualize things. As a student, when I am assigned a project I often lean towards tangible solutions when intangible solutions are also possible. I also tend towards simple solutions in engineering design because in my opinion, the simplest designs can accomplish the same functions as more complex designs, and they are less error prone if they are simple.

When viewing an opportunity I may also be inclined to view stakeholders as being similar to me (ie, assuming that we share values, beliefs) and I may assume they share my problems or do not have any problems that I do not see immediately. In my work as an engineering student I do my best to force my mindset to be as outward and unbiased as possible so that I interpret (as opposed to assume) information.

1.4 Interests

My main interests include painting, music, watching classic movies, and environmental science.

As mentioned above, I have always had a passion for visual art and was a visual arts student through high school. My favorite subjects include portraiture (particularly my close friends and family) and classic paintings. For several years I have used visual arts as an outlet for my emotions and values. When painting a close friend of mine I always feel that I gain a closer connection to them and feel a greater empathy for their true selves. One of my personal goals is to compile my works into a small gallery for my home to which I will dedicate a wall.

My interest in the arts extends to music and film as well. Though I am in no way a musician or an actor, in my spare time I love to listen to jazz and opera or rewatch my favorite classics and musicals.

Another one of my interests is my interest in environmental science. I hope to pursue a degree in Energy Systems Engineering and from there have a career focused on sustainable energy. I like to think that I help the world in small ways on a daily basis by using reusable cutlery and cups and being as paper-free as possible. Whenever I have a spare moment I also love to dig up articles on new advances in the environmental engineering industry; I find solar energy really fascinating!

2. Product-Focused Index

The following section is an introduction to design projects I have been a part of this year. These projects will serve as a reference and inspiration for the Personal Engineering Design Process developed later.

2.1 Build/Test Launcher

The build/test projectile launcher was a design project wherein my Praxis II team and I designed and built a projectile launcher to launch small projectiles a distance of 16 ft. This project was more of a team-building project than a task-oriented project; from this project our team discovered the ways we work best together and how our skills come together.

2.1.1 Diverging

In the diverging process for this product our team relied heavily on brainstorming. By brainstorming we were able to come up with several pre-existing launchers that we could build. From there we brainstormed how we could tailor these ideas to be feasible to our building skill sets.

2.1.2 Converging

Converging to a final idea was as simple as a system 1 pairwise comparison. We did not have a lot of time and wanted to quickly agree on a reasonable idea that we all liked and then use all the time we had to build. We decided to build a launcher that was essentially a pendulum with a swinging mallet; we used classical mechanics to model our projectile and find the required angles for all target distances before building.

2.1.3 The Final Iteration

After building our launcher and testing it we found that the launching was not as accurate as we had hoped. The accuracy of the launcher was highly dependent on how accurately the launching person estimated the launch angles (not to mention that the launcher also wobbled!). We decided that another iteration would probably be best and quickly put our heads together to come up with the system pictured below:

Figure 1. *My Praxis II team and I on testing day.*

This system launched the projectile just a few inches as opposed to 16 ft and relied on our teamwork, as we each had a string to pull that essentially pulled our launcher close to the target. To launch the projectile one teammate pulled on their string and the projectile would land a few inches ahead of the launcher and onto the target. This concept appeared very late in the design process but was also very successful and taught us the value of trusting each other to start over when necessary.

2.2 A Solution to Wet Socks on a Rainy Day

This project was a rollercoaster just from the sheer number of times my Praxis I team and I reframed and rescoped the issue. Given a design brief about protecting student knapsacks on a rainy day we wanted to reframe it to a narrower topic that we were driven to solve.

2.2.1 Framing

The framing of this problem was highly discussion-based. We put ourselves in the shoes of the original authors of the design brief and tried to envision the steps they took to frame the problem. My team and I agreed on the fact that their main objective/motive was to help commuting students on rainy days. We came up with questions such as:

- What bothers you most while commuting on a rainy day?
- What things do we carry/wear that get soiled on rainy days?
- Do we want to stop the things we carry from being wet or do we want to help mend the situation once it is already wet?

From there we used wishing to pinpoint the worst things that happen to us on rainy days. Wishing was very useful and we tried formulating design requirements for different possible frames:

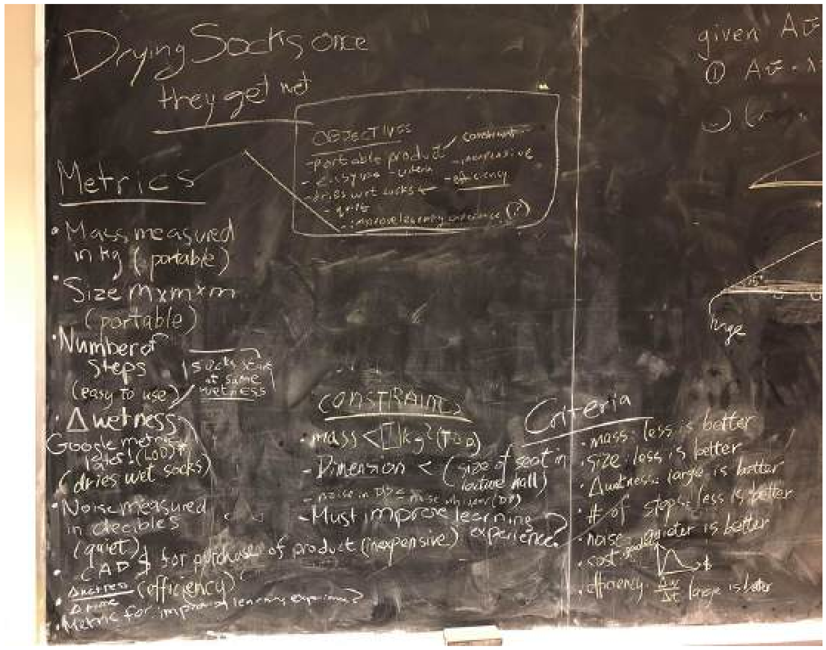


Figure 2. *An example of our "low-fidelity requirements model".*

We decided that the model shown in Figure 2 explained the problem we wanted to solve: quickly and thoroughly drying wet socks on rainy days.

2.2.2 Diverging

My Praxis I team and I had one diverging tool that we preferred over the others: brainstorming. We had two approaches to brainstorming: individual and group. In individual brainstorming we took a few minutes to jot down broad ideas for solutions to our problem (Figure 3).

Figure 3. *An example of individual brainstorming.*

In group brainstorming (which generally occurred after individual brainstorming) we explained ideas as they came to us and built on each other's ideas. This generally brought extremely broad ideas to slightly more refined alternatives that were more drawn out.

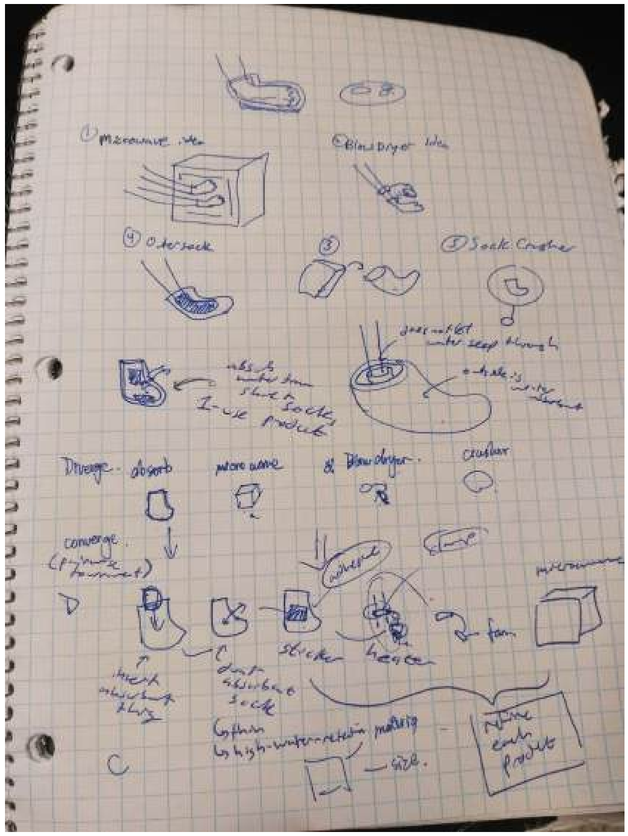


Figure 4. *An example of notes from group brainstorming.*

As shown in Figure 4, group brainstorming takes broad ideas down several routes. Collaborating to generate ideas creates a more diverse set of alternatives.

2.2.3 Converging

My Praxis I team and I used several converging tools, including pairwise comparisons, multi-voting, ratings matrices, and Pugh charts.

Due to the large number of alternatives my team and I had generated, we had to take a system 1 approach to converging some of them out, as testing all of the ideas was not feasible. In our first round of converging we used pairwise comparisons (Figure 5) to weed out ideas that were least preferred and/or unfeasible.

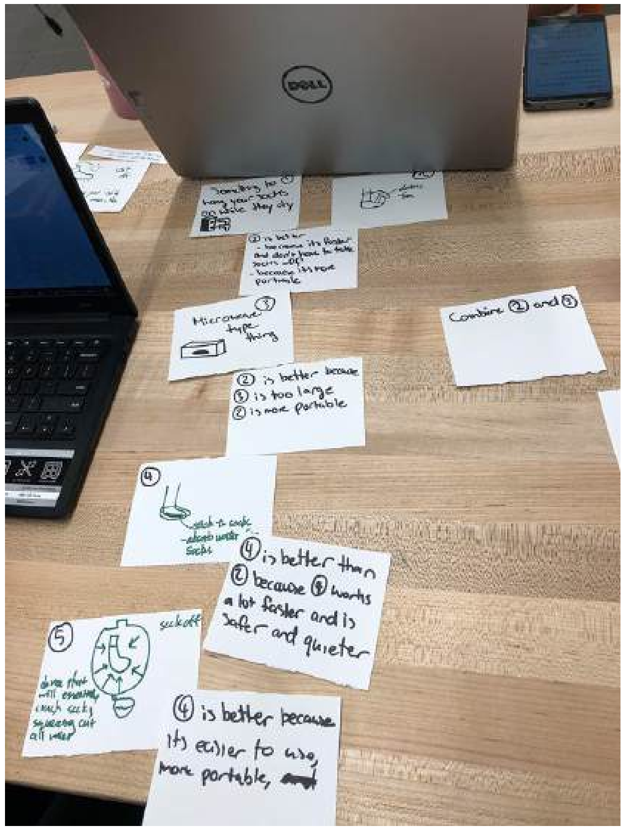


Figure 5. *Pairwise comparisons of broad ideas.*

After converging to a smaller set of broad ideas my team and I decided that we would use multivoting to choose which ideas we would take a lot of time to flesh out. When multivoting we explained why we had preference for the ideas we voted for; this was especially important because two of our ideas had a tie and we had to decide which of the two ideas to work on moving forward (Figure 6).

- **2nd round converging (multi-voting)**

	1.1	1.2	1.3	2.0	3.1	3.2
Sheri		✓			✓	✓
Victoria		✓	✓		✓	
Mulan		✓	✓		✓	
Daniel		✓		✓		✓

Figure 6. *Multivoting to converge to three key concepts (1.2, 3.1, 3.2). Note that the alternatives are represented as indices.*

Not knowing what results we would produce, my team and I produced a ratings matrix (Figure 7) for relatively rigorous designs based on research and with a reference design as our neutral item. My team and I converted the ratings matrix into a Pugh chart to holistically evaluate our ideas.

Ratings Matrix

	1.2	3.1	3.2	Reference Design
Δwetness/Δtime	≈ 1 minute	≈ 5.86g/min	≈ 0.7g/min	(takes 2-3 hours)
Number of steps	1. put your shoes off 2. put the product on 3. put your shoes on 3 STEPS	1. Fasten the device on the leg 2. Adjust the direction to the shoes 3. Press "on" 3 STEPS	1. Insert feet in machine 2. Turn machine setting to sock 3. Press "on" 3 STEPS	1. Take shoes off (with socks) 2. Put the dryer in the shoe 3. Set the heat settings 4. Turn the dryer on 4 STEPS
noise	0 dB	65 dB	20 dB	
size	27cm tube with 10 cm diameter	Fasten: 7.9 x 9.4 x 5.6 cm, motor: 13.517x14.472x 11.700 cm	45x38x38 cm	7.2 x 2 x 2.1 inches
mass	0.1	≈95.27 g	≈ 10 lbs	10.1 ounces
Number of electric parts	0	1 heater	5 rectangular heaters	2 shoe heaters that contain several parts
Cost $CAD	≈ 4.68 / pair (w/ 3g of sodium polyacrylate, approx .3 yard of Zorb/pair)	$101.17+14.39= $115.56	$65.03x5 + $120.96 = $446.11	$58.04
Number of materials	2 (outer fabric, absorbent material)	3 (heating motor, plastic shell, fasten part)	3 (plastic shell, outer layer, heaters inside)	

	1.2 (absorbent sock)	**3.1 (air dryer)**	**3.2 (box heater)**	**Reference Design**
Δwetness/Δtime	+	+	+	N
Number of steps	+	+	+	N
noise	+	-	-	N
size	+	-	-	N
mass	+	+	-	N
Number of electric parts	+	+	-	N
Cost $CAD	+	-	+	N
Number of materials	+	+	+	N

Figure 7. *A Ratings Matrix converted to a Pugh Chart used to converge to one broad idea.*

The Pugh chart showed very promising results for one particular alternative (1.2, or the "absorbent sock") so we made the decision to approach that sole product and make each design decision highly rigorous to ensure that our product was truly optimized. This Pugh chart stood as a turning point in our design process.

For final converging procedures, my team and I developed a ratings matrix for each detailed design decision (Figure 8). We came up with multiple ideas for each detail through research and used physical testing and research to develop ratings matrices. Ratings matrices were evaluated with reference to our Requirements Model for the project, as success in one rating may not be as relevant as success in another rating.

How did you choose the outer layer?: Final choice: Zorb
Ratings Matrix

	Polyester with Cellulose surface finish	Rayon	Spandex	Zorb
Density	1.37 g/cm^3 [1a]	1.54-1.64g/cm^3 [2a]	[3a] 0.98 g/cm^3	[4a] 235 GSM
Percentage Stretch before break	22.9% [1b]	13% [2a]	>100% [3b]	N/A ("non-stretchy") [4a]
Safety	Compatible with skin… May cause irritation after long-term exposure [1c]	Compatible with skin… May cause irritation after long-term exposure [2c]	Causes mild skin irritation [3a]	Non-irritating, hypoallergenic [4a]
Absorbing Properties (yes/no)	[1d] no	[2d] yes	[3d] no	[4a] yes

How did you choose the absorbent material? Final choice: ***Sodium polyacrylate***

	Pure Sodium Polyacrylate	**Absorbent Pellets (by Recycphp)**	**Anhydrous Calcium Chloride**
Absorbing ability (how many times of its weight does it absorb?)	300 x [1a]	10 - 25 x [2a]	1.0 x [2a]
Density	1.22 g/cm³ [1b]	0.3 g/cm^3 [2a]	2.15 g/cm^3 [3a]
Toxicity	Eye Irritant [1c]	Non-toxic [2a]	Non-toxic, desiccant [3b]
Price/g	$0.26/g [1d]	NA	$0.02/g [3c]

Figure 8. *Ratings Matrix for two of our design decisions.*

Our final product, dubbed as "the absorbent sock", was made out of Zorb (a diaper fabric) and contained 0.6g of sodium polyacrylate between the inner and outer layers of Zorb. It would be made in several sizes up to 33 cm long tube with 13cm diameter.

2.2.4 Representations

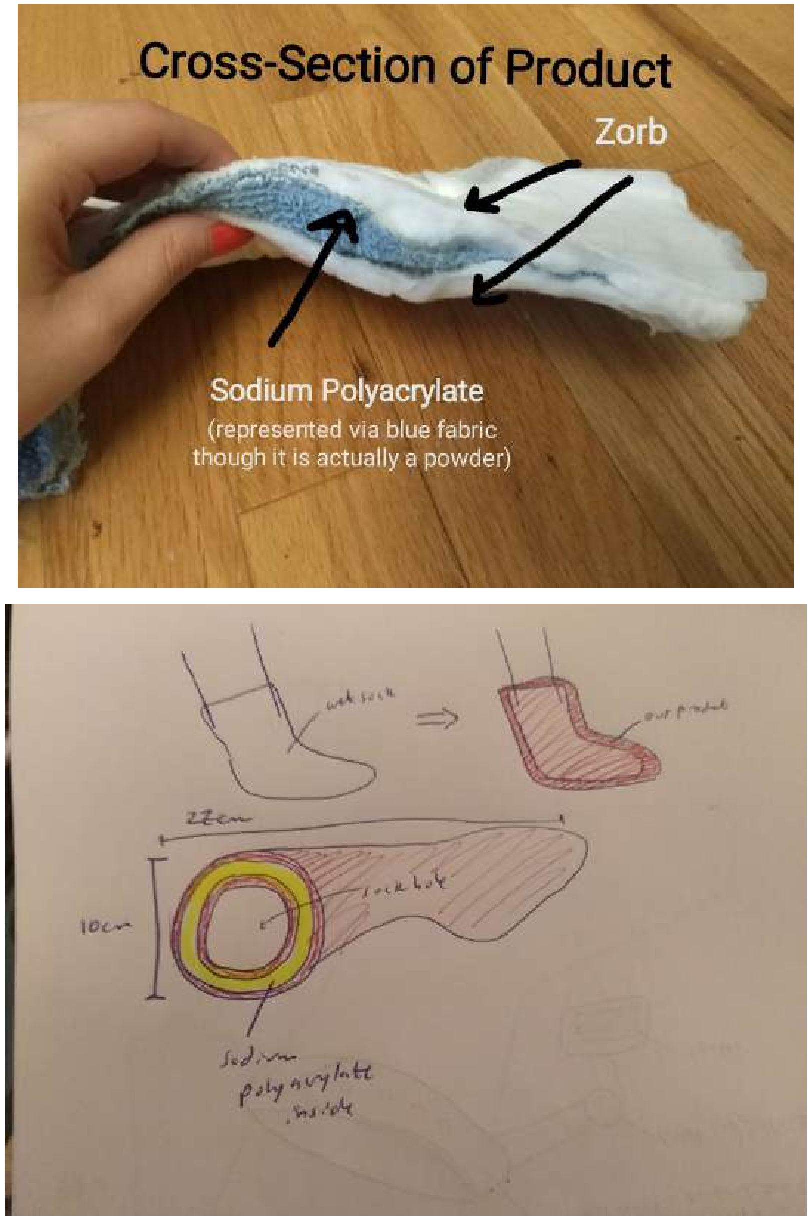
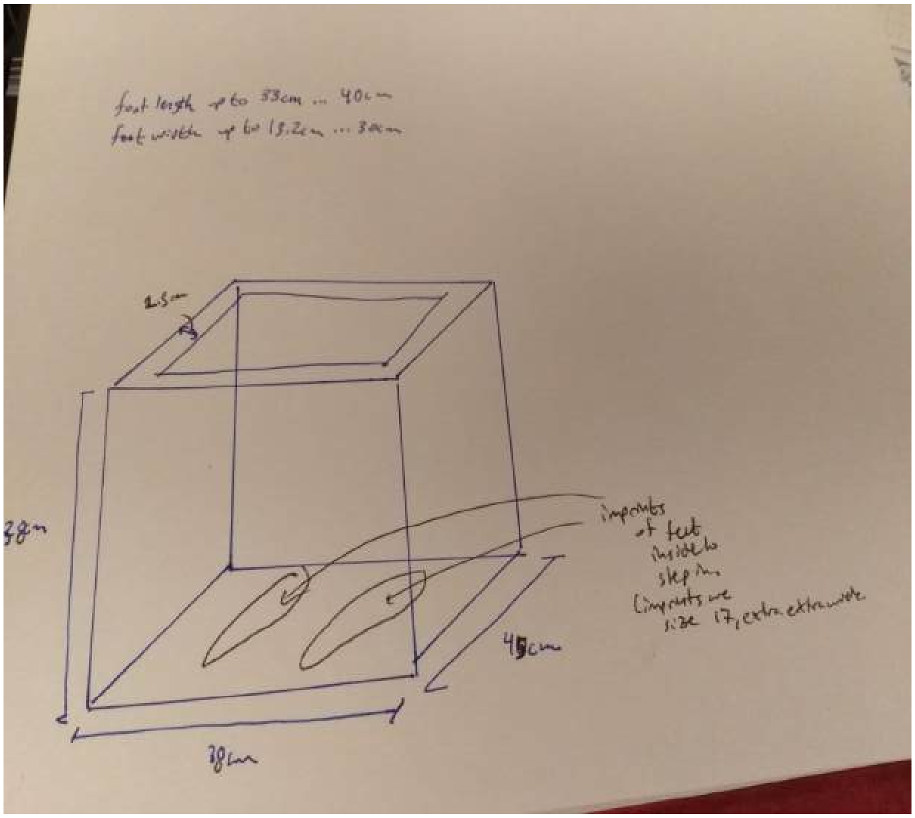


Figure 9. *Representations of our final product.*



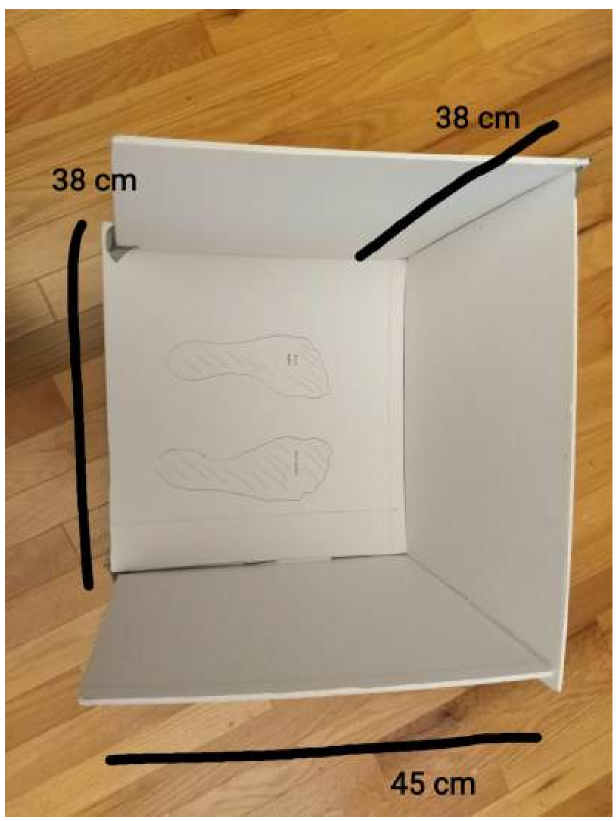


Figure 10. *Representations of one of our initial ideas in the Pugh chart, "the box heater".*

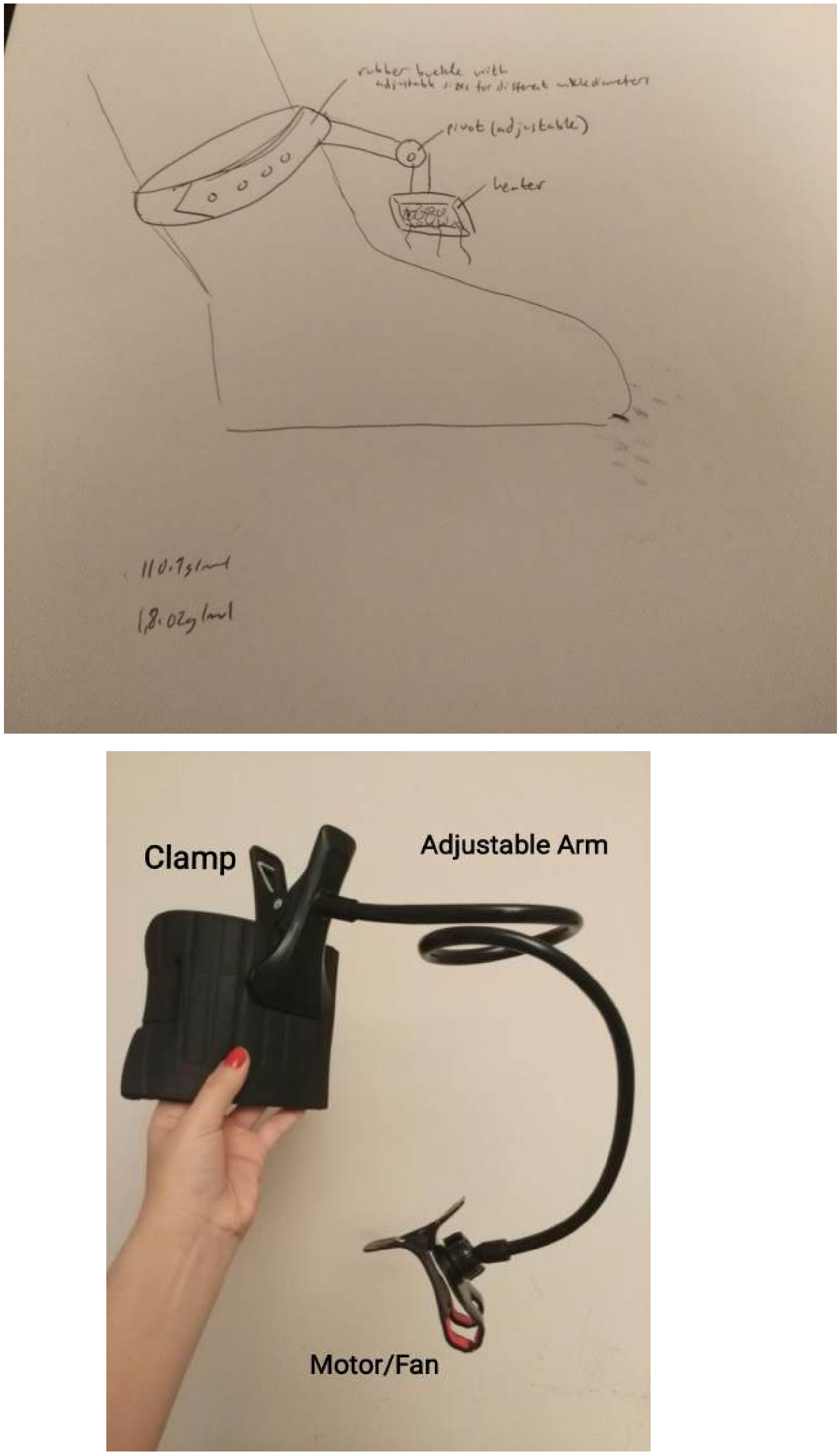


Figure 11. *Representations of one of our initial ideas in the Pugh chart, "the ankle clamp".*

2.3 Paint Scraping Tool for Sgt. Splatter PaintBall

The following project was completed by my Praxis II team and myself. We were given an RFP that sought a solution to increase the efficiency of the staff at Sgt. Splatters Paintball while scraping paint off of the facility walls.

2.3.1 Framing

We framed the situation based on our team values and the outcome desired by the staff at Sgt. Splatters. We also used tools such as wishing, brainstorming (Figure 12), and concrete/abstract (Figure 13). We decided to scope our project to the design of a custom scraper for the staff at Sgt. Splatters. There were two major reasons why we chose to do this:

1. The staff at Sgt. Splatters clearly stated they were not interested in anything involving destructive renovation or anything that would take a long time to set up. They wanted an easy solution.
2. My team and I had a common value of simplicity and saw the scraper as a simple solution capable of doing great things if designed appropriately.

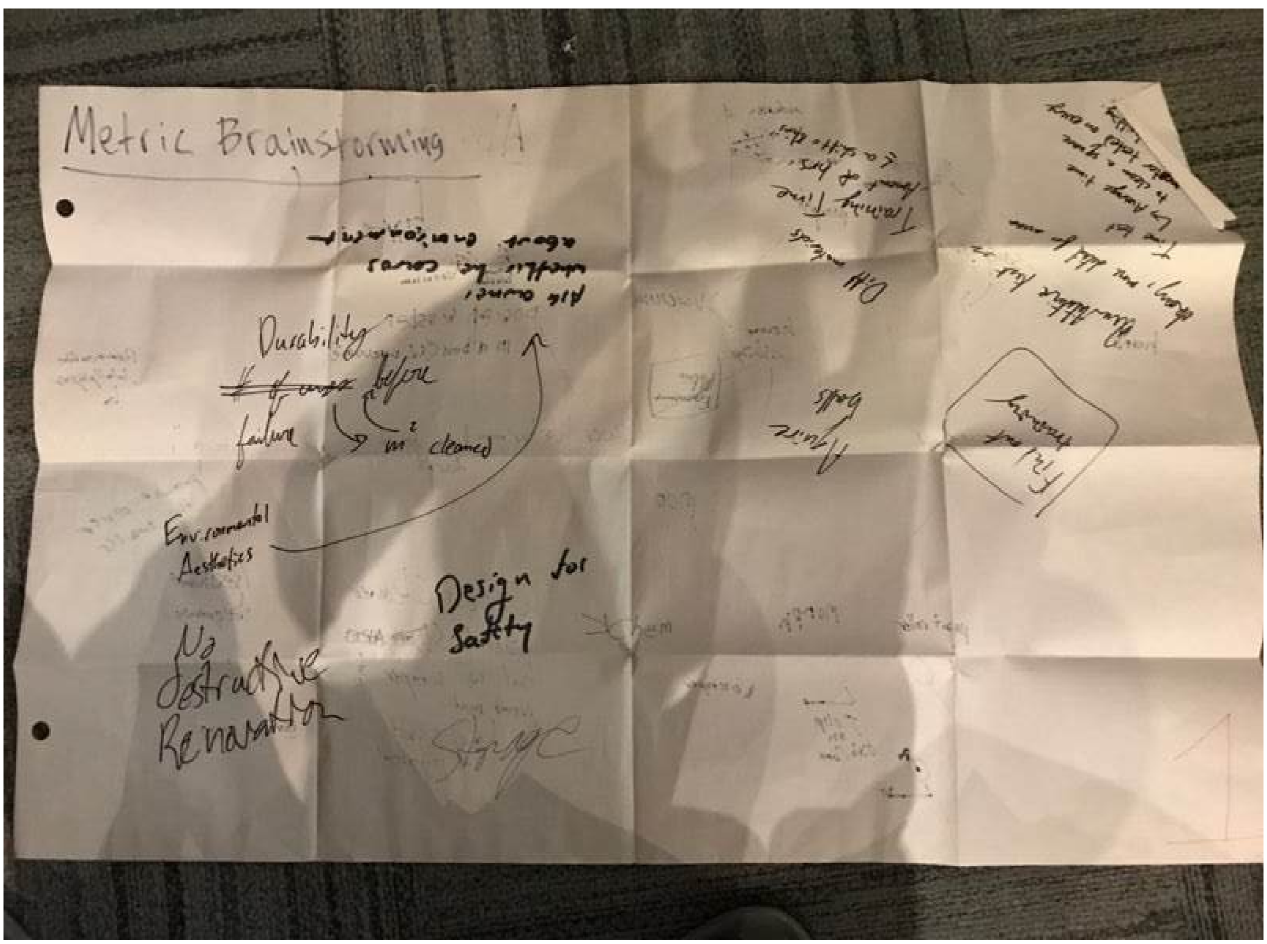


Figure 12. *Metric brainstorming from reframing the RFP.*

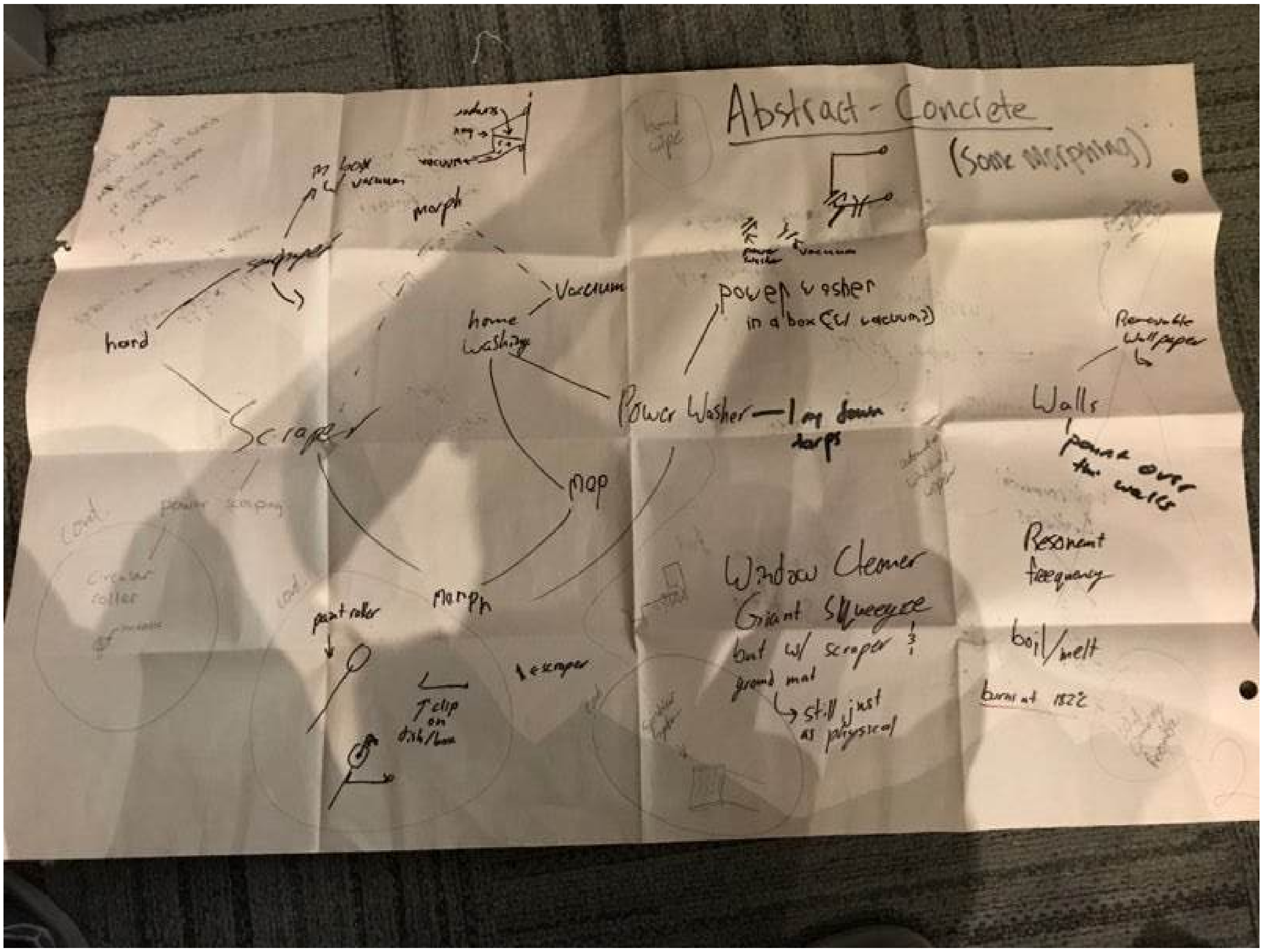
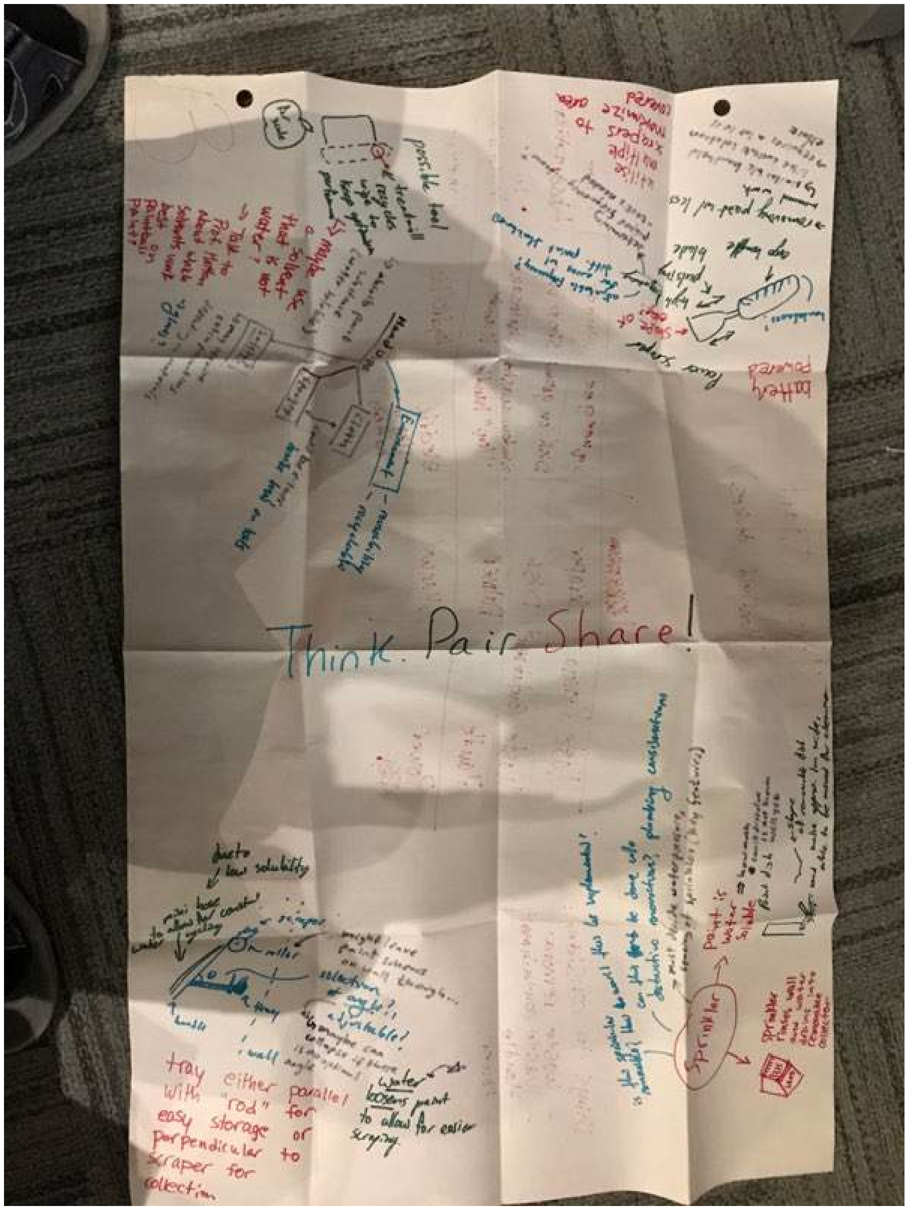


Figure 13. *An abstract/concrete model of our project.*

2.3.2 Diverging

To diverge on ideas we initially used wishing, think/pair/share, and brainstorming. Think/pair/share (Figure 14) and brainstorming (Figure 15) were the most relied on tools for diverging and produced lots of results in a short period of time. We found that think/pair/share was a very fruitful tool. Think/pair/share put all of our ideas on the table, and the time we took to build on each other's ideas produced very unique results.


Think. Pair. Share!
tray either parallel with "rod" for easy storage or perpendicular to scraper for collection
water loosens paint to allow for easier scraping
sprinkler
battery powered

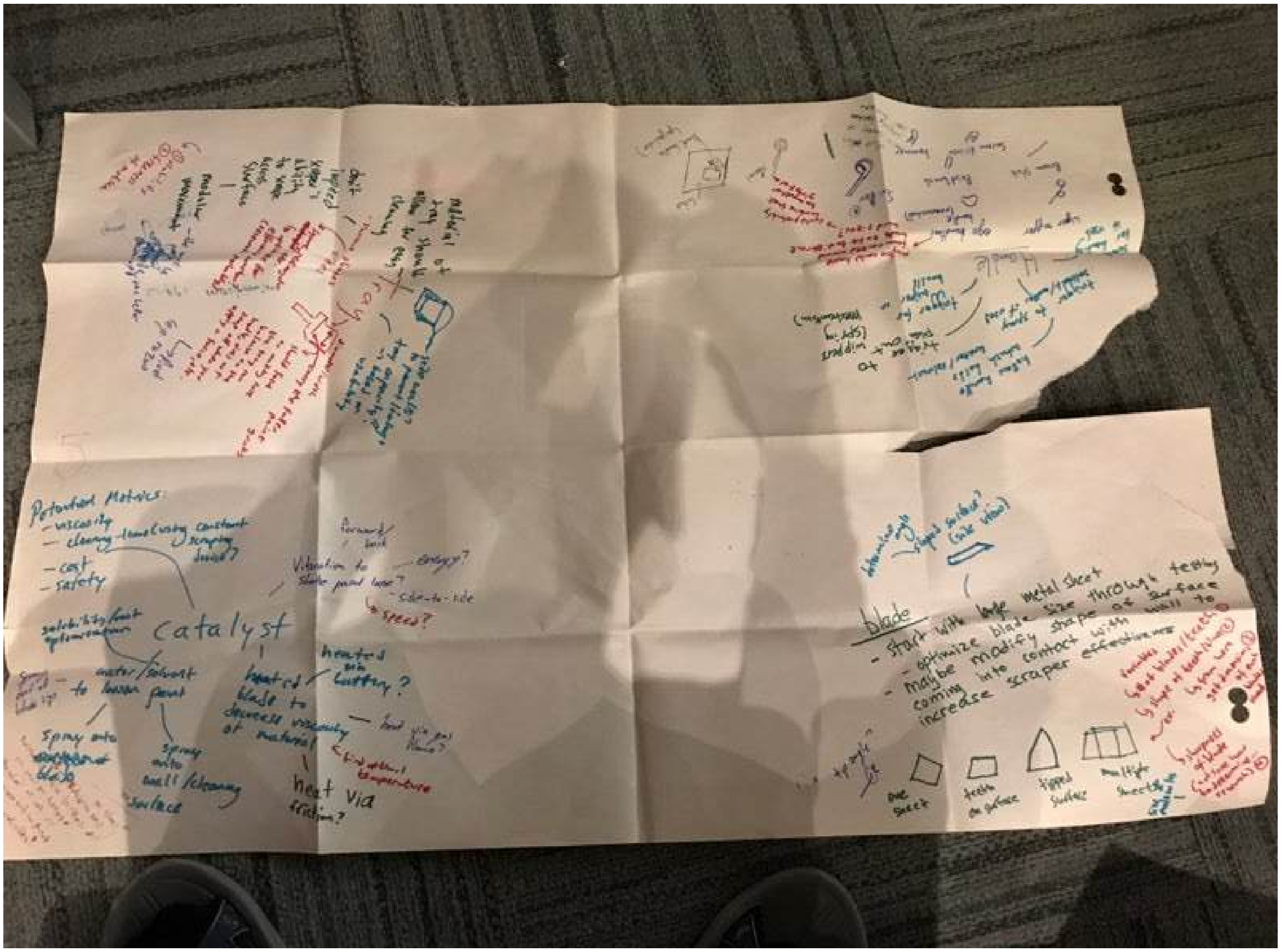


Figure 14. *Think/pair/share for our initial rounds of diverging.*

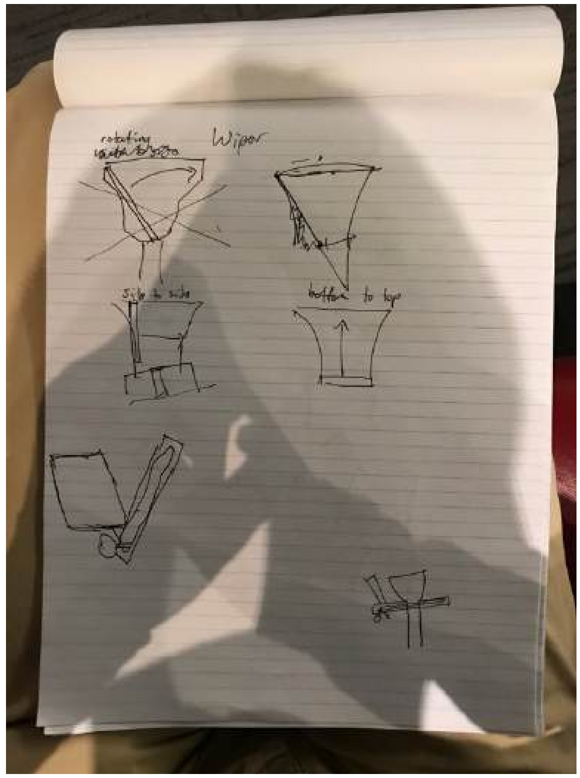


Figure 15. *An example of brainstorming for the paint scraper wiper.*

After scoping our project to the design of a custom paint scraper, we used a morph chart to communicate all of the functions we wanted our product to perform through a morph chart (Figure 16). We decided that each component of the scraper would be individually optimized, and at the end of the process we would “frankenstein” the pieces together to form our final product.

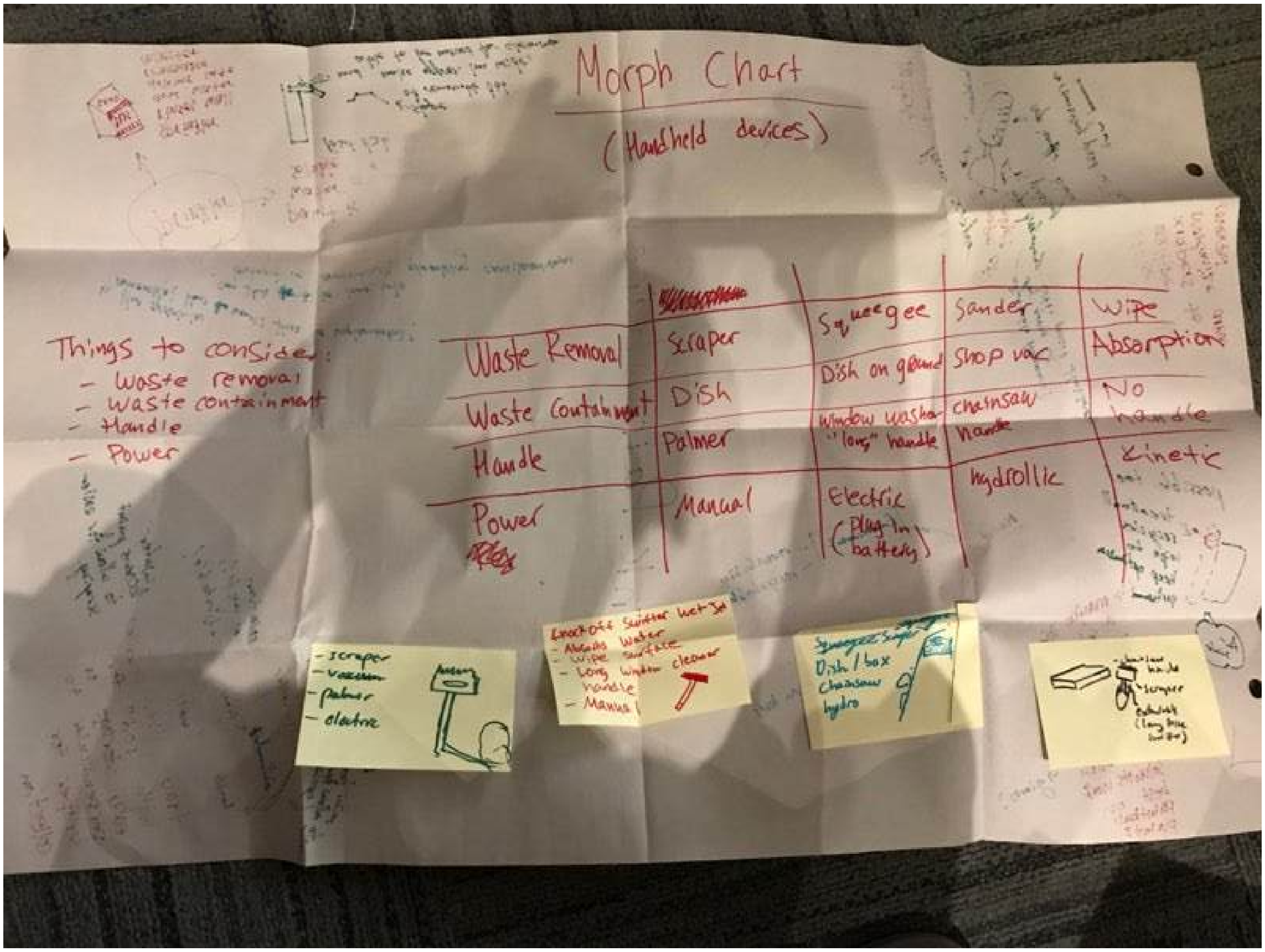
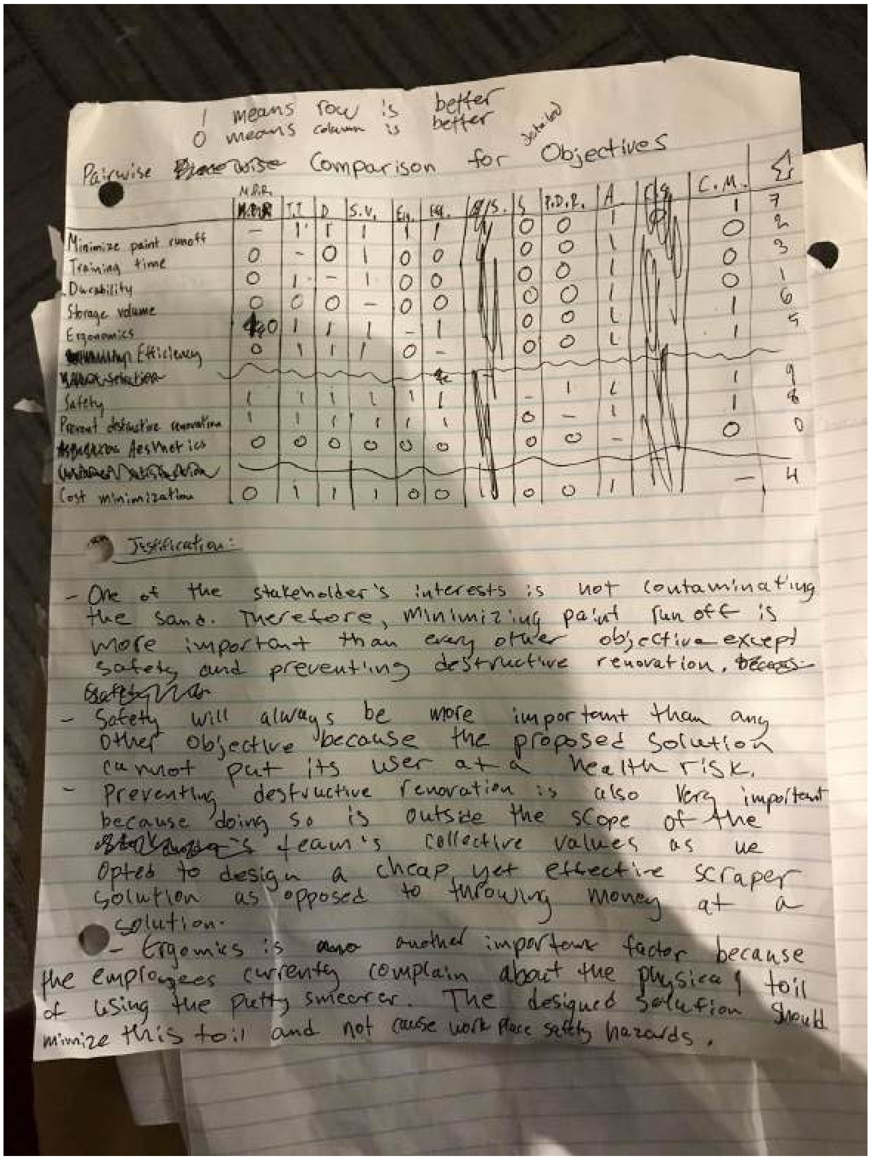


Figure 16. *The morph chart drew inspiration from tools such as scrapers, squeegees, sanders, and wipes. We also considered reference designs such as shovels, paint rollers, weed wackers, and swiffers later on in the design process.*

2.3.3 Converging

The first step we took in our converging process was the use of pairwise comparisons. We used system 1.5 thinking in pairwise comparisons (Figure 17) to converge to testable subsets from a large number of ideas for each component of the paint scraper.



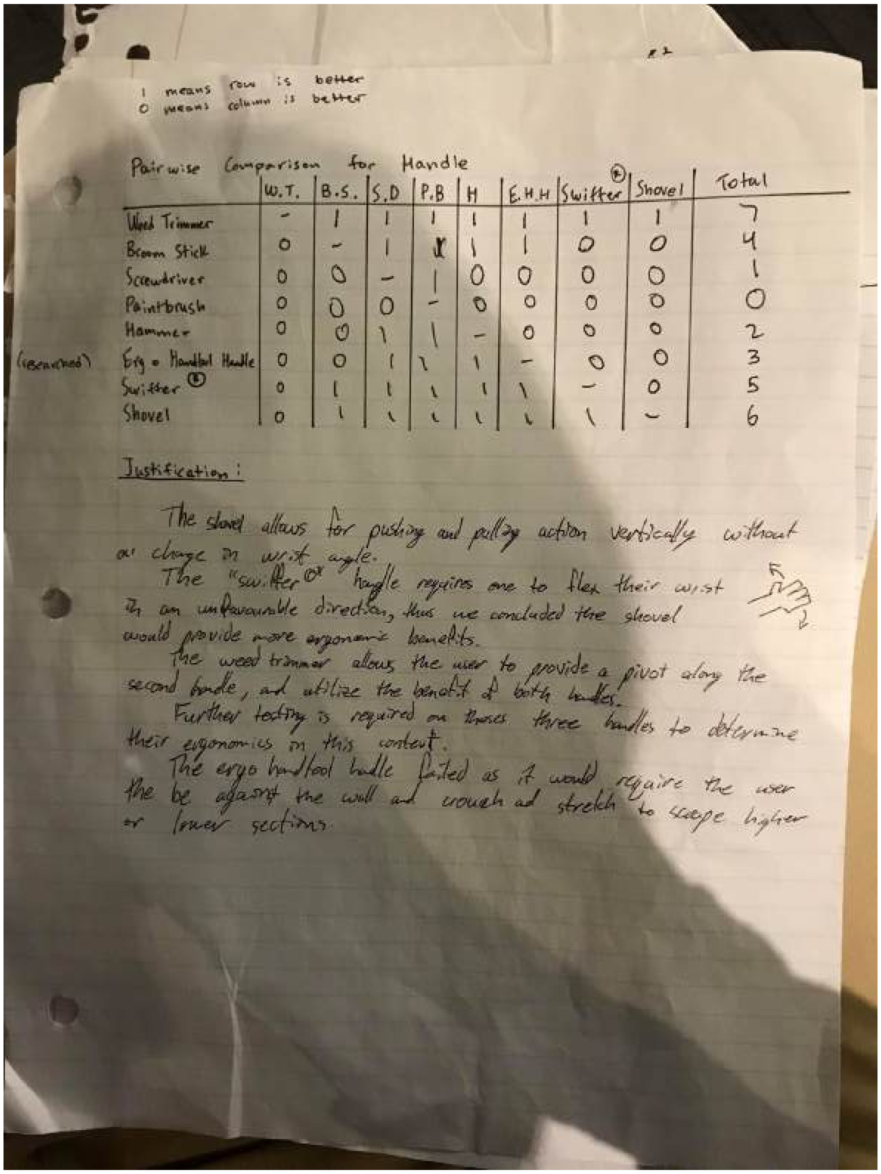
1 means row is better
0 means column is better

Pairwise Comparison for Detailed Objectives

	M.P.R.	T.T.	D	S.V.	Er.	Ef.	S	P.D.R.	A	C.M.	Σ
Minimize paint runoff	—	1	1	1	1	1	0	0	1	1	7
Training time	0	—	0	1	0	0	0	0	1	0	2
Durability	0	1	—	1	0	0	0	0	1	0	3
Storage volume	0	0	0	—	0	0	0	0	1	0	1
Ergonomics	0	1	1	1	—	1	0	0	1	1	6
Efficiency	0	1	1	1	0	—	0	0	1	1	5
Safety	1	1	1	1	1	1	—	1	1	1	9
Prevent destructive renovation	1	1	1	1	1	1	0	—	1	1	8
Aesthetics	0	0	0	0	0	0	0	0	—	0	0
Cost minimization	0	1	1	1	0	0	0	0	1	—	4

Justification:

- One of the stakeholder's interests is not contaminating the sand. Therefore, minimizing paint run off is more important than every other objective except safety and preventing destructive renovation,
- Safety will always be more important than any other objective because the proposed solution cannot put its user at a health risk.
- Preventing destructive renovation is also very important because doing so is outside the scope of the team's collective values as we opted to design a cheap yet effective scraper solution as opposed to throwing money at a solution.
- Ergomics is another important factor because the employees currenty complain about the physical toil of using the putty smearer. The designed solution should minimize this toil and not cause work place safety hazards.



1 means row is better
0 means column is better

Pairwise Comparison for Handle

	W.T.	B.S.	S.D	P.B	H	E.H.H	Swifter®	Shovel	Total
Weed Trimmer	–	1	1	1	1	1	1	1	7
Broom Stick	0	–	1	X	1	1	0	0	4
Screwdriver	0	0	–	1	0	0	0	0	1
Paintbrush	0	0	0	–	0	0	0	0	0
Hammer	0	0	1	1	–	0	0	0	2
(renamed) Erg = Handtool Handle	0	0	1	1	1	–	0	0	3
Swifter®	0	1	1	1	1	1	–	0	5
Shovel	0	1	1	1	1	1	1	–	6

Justification:

The shovel allows for pushing and pulling action vertically without a change in wrist angle.

The "swifter®" handle requires one to flex their wrist in an unfavourable direction, thus we concluded the shovel would provide more ergonomic benefits.

The weed trimmer allows the user to provide a pivot along the second handle, and utilize the benefit of both handles.

Further testing is required on theses three handles to determine their ergonomics in this context.

The ergo handtool handle failed as it would require the user the be against the wall and crouch and stretch to scrape higher or lower sections

Figure 17. *Pairwise comparisons brought large sets of ideas down to a testable number of choices.*

Given a testable number of alternatives we created system 1.5 Pugh charts (Figure 18) to (a) weed out particularly horrible alternatives that had survived the pairwise comparisons and (b) attain relatively accurate predictions for our ratings before performing physical tests.

+ better, - worse, = same as per criteria

Metric	**Flat blade**	**Sloped blade**	**Curved blade**
Time Efficiency	-	+	=
Force Required	-	+	=
Upfront Cost	-	-	=
Wood Runoff	-	=	=
Metal Runoff	-	=	=
Field Runoff	-	=	=
Volume Occupied	=	=	=
Borg Scale	-	+	=

Alternative	Snow Shovel Handle	Swiffer® Handle	Weed Trimmer Handle
Time Efficiency	=	=	+
Force Required	=	=	=
Upfront Cost	-	=	+
Wood Runoff	=	=	=
Metal Runoff	=	=	=
Field Runoff	=	=	=
Volume Occupied	=	=	-
Subjective Survey	+	=	+
Borg Scale	+	=	+
Safety Rubric	+	=	+

Alternative	Triangle	Box	Box without Top
Time Efficiency	=	=	=
Up Front Cost	+	=	-
Wood Runoff	=	=	+
Metal Runoff	=	=	+
Field Runoff	=	=	+
Volume Occupied	+	=	=
Borg Scale	+	=	-

Figure 18. *System 1.5 Pugh charts for scraper variables.*

At this point my team and I were prepared to do rigorous physical testing to optimize our scraper components. After gathering our data we compiled our ratings into small ratings matrices for each variable that required physical testing (Figure 19).

3.1.1 Blade Angle

Force (grams) measured vs. blade type

Blade Type	Hard Angle (30° C)	Curved	Straight
Rating	188	195	155

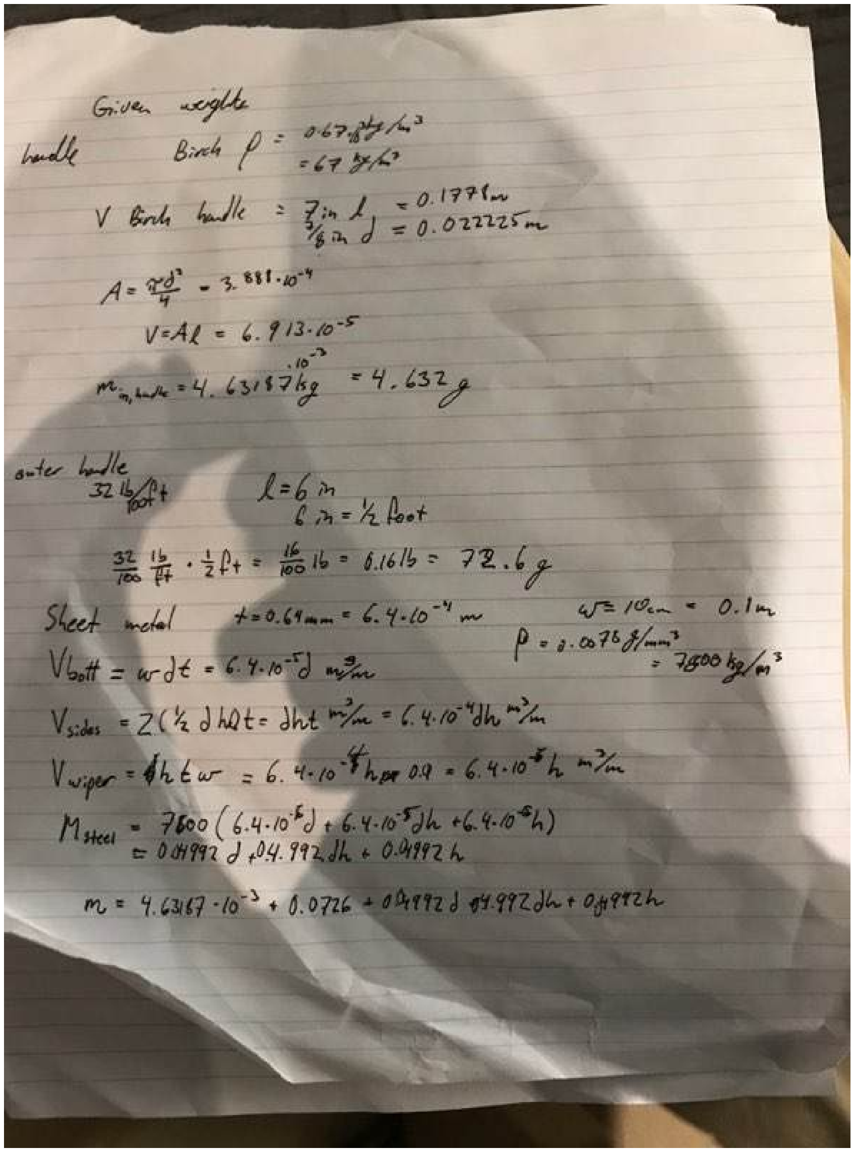
3.1.3 Catalyst

Force (grams) measured vs. catalyst applied

Catalyst	None	Water (0.5 mL / paintball)	Heat (50° C)
Rating	188	135	122

Figure 19. *Data and associated ratings matrix for our blade angle and choice of catalyst.*

Using these matrices my team and I decided on the most appropriate choices for our scraper variables. We also used research and mathematical models (Figure 20) to converge for variables that were highly constrained or that we could not physically test. During the final stages of convergence and preparations for the presentation, my team and I also used a Gantt chart (Figure 21) to organize our time.


Given weights

handle Birch $\rho = 0.67\,g/cm^3 = 67\,kg/m^3$

V Birch handle $= 7\,in\ l = 0.1778\,m$; $7/8\,in\ d = 0.022225\,m$

$A = \frac{\pi d^2}{4} = 3.881\cdot10^{-4}$

$V = Al = 6.913\cdot10^{-5}$

$m_{m,handle} = 4.63187\cdot10^{-3}\,kg = 4.632\,g$

outer handle

$32\,lb/100\,ft$ $\quad l = 6\,in$; $6\,in = 1/2\,foot$

$\frac{32}{100}\frac{lb}{ft}\cdot\frac{1}{2}ft = \frac{16}{100}lb = 0.16\,lb = 72.6\,g$

Sheet metal $t = 0.64\,mm = 6.4\cdot10^{-4}\,m$ $\quad w = 10\,cm = 0.1\,m$

$\rho = 0.0078\,g/mm^3 = 7800\,kg/m^3$

$V_{bott} = w d t = 6.4\cdot10^{-5} d\ m^3/m$

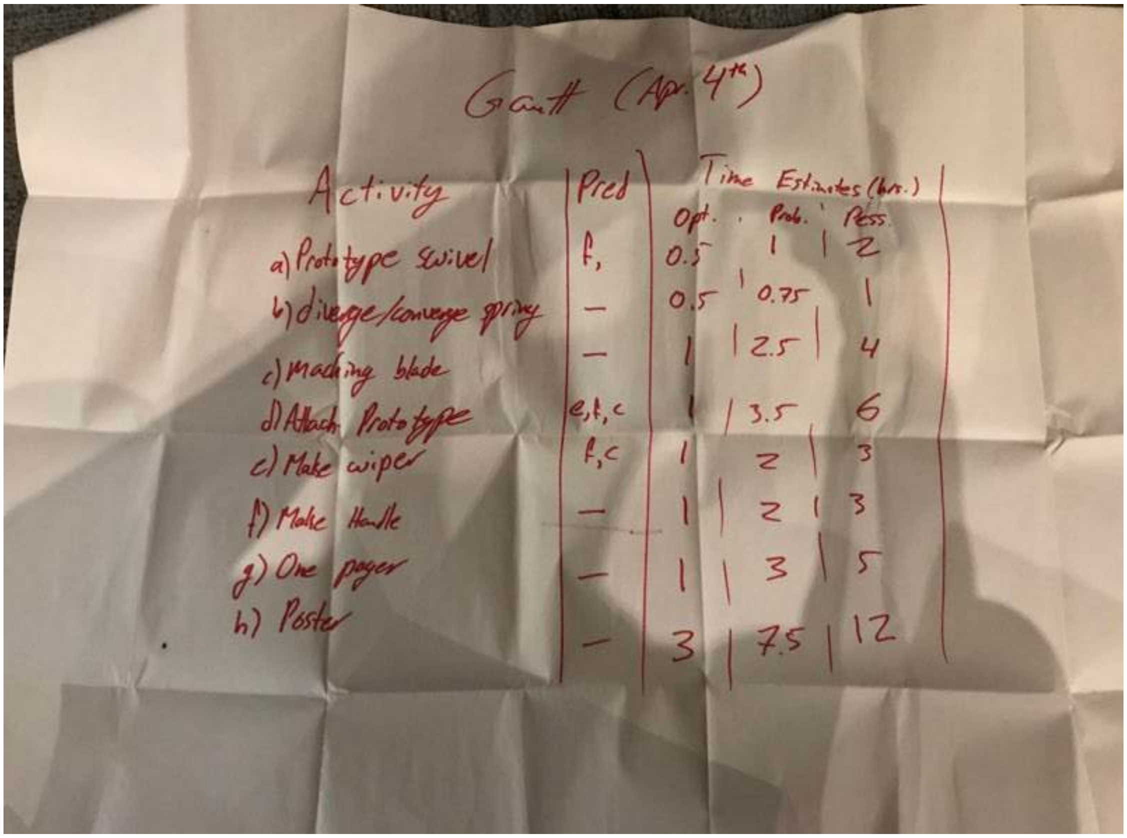
$V_{sides} = 2(\frac{1}{2} d h)t = dht\ m^3/m = 6.4\cdot10^{-4} dh\ m^3/m$

$V_{wiper} = dhtw = 6.4\cdot10^{-4} h\ per\ 0.1 = 6.4\cdot10^{-5} h\ m^3/m$

$M_{steel} = 7800(6.4\cdot10^{-5} d + 6.4\cdot10^{-5} dh + 6.4\cdot10^{-5} h)$
$= 0.4992\,d + 4.992\,dh + 0.4992\,h$

$m = 4.63187\cdot10^{-3} + 0.0726 + 0.4992\,d + 4.992\,dh + 0.4992\,h$

Figure 20. *Mathematical representation of our scraper, given a factor of safety of 2.0.*



Gantt (Apr. 4th)

Activity	Pred	Time Estimates (hr.) Opt.	Prob.	Pess.
a) Prototype swivel	f,	0.5	1	2
b) diverge/converge spring	—	0.5	0.75	1
c) machining blade	—	1	2.5	4
d) Attach Prototype	e,f,c	1	3.5	6
e) Make wiper	f,c	1	2	3
f) Make Handle	—	1	2	3
g) One pager	—	1	3	5
h) Poster	—	3	7.5	12

Figure 21. *Gantt chart used in the home-stretch of the project.*

My teammates and I then collaborated to build a high fidelity prototype of our product so that we could physically validate it by having the staff of Sgt. Splatters test it out. We had high hopes for this prototype and spent several days on it before bringing it to their site (Figure 22).

Figure 22. *Our initial prototype was about 1.2m long!*

On the day of physical testing my teammates and I were devastated to find out that the product barely met any of the requirements due to its massive size. Not only did the large surface area of the blade require a high input force, but the pivot of the scraper experience a high moment and twisting uncontrollably. My team and I realized that perhaps we had anchored too much on the morph chart while diverging. We had focused too much in the piecewise design process and failed to consider some factors that proved to be detrimental. With only a few days until showcase we quickly built another prototype (Figure 23) with a changed shaft length and trigger mechanism based on a new constraint we had discovered: the blade had to be small enough to clean the 6” shingles of some of the walls. We took this prototype to Sgt. Splatters the following day and found that the trigger mechanism was faulty. Still unfazed, we modified the prototype as in Figure 24for the final site visit.

Figure 23. *The second iteration of our design, scaled to be smaller.*

Figure 24. *The third and final iteration of our design.*

The final site visit we made to Sgt. Splatters was successful. The product worked and each staff member we consulted said they would use our product. This was very satisfying after three days of high stress and pressure. I believe that the team-building that occured in project 2.1 was critical to our success during this time. We were very fortunate to have had group experience designing and building last-minute prototypes under pressure as this made project 2.3 easier on us. We were very glad to present a successful prototype at Showcase and felt that the work in the homestretch of the project really paid off.

2.3.4 Representations

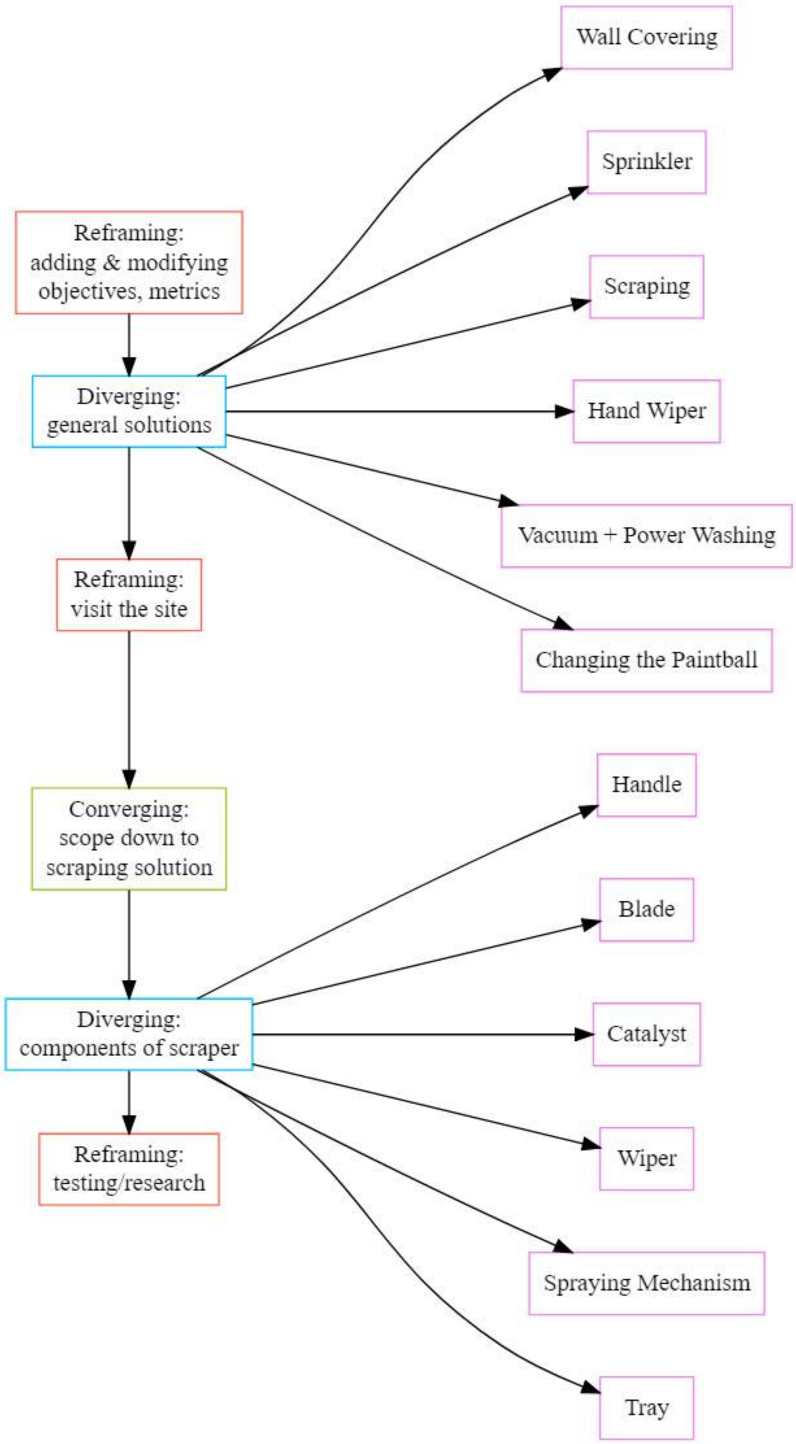


Figure 25. *A flowchart representation of our design process.*

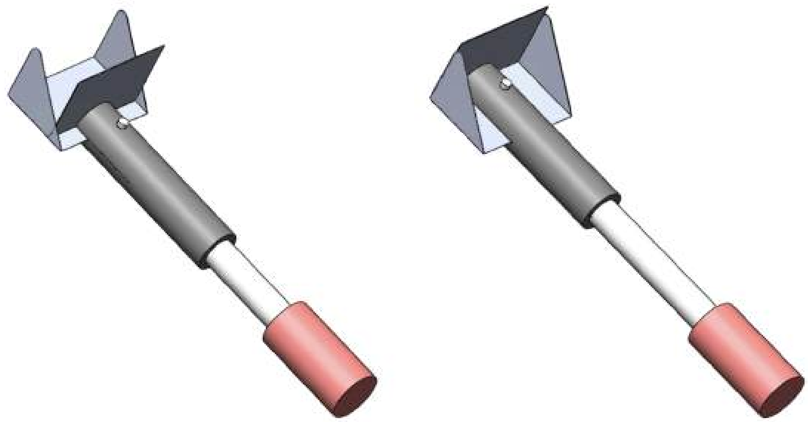


Figure 26. *A CAD model of our final product.*

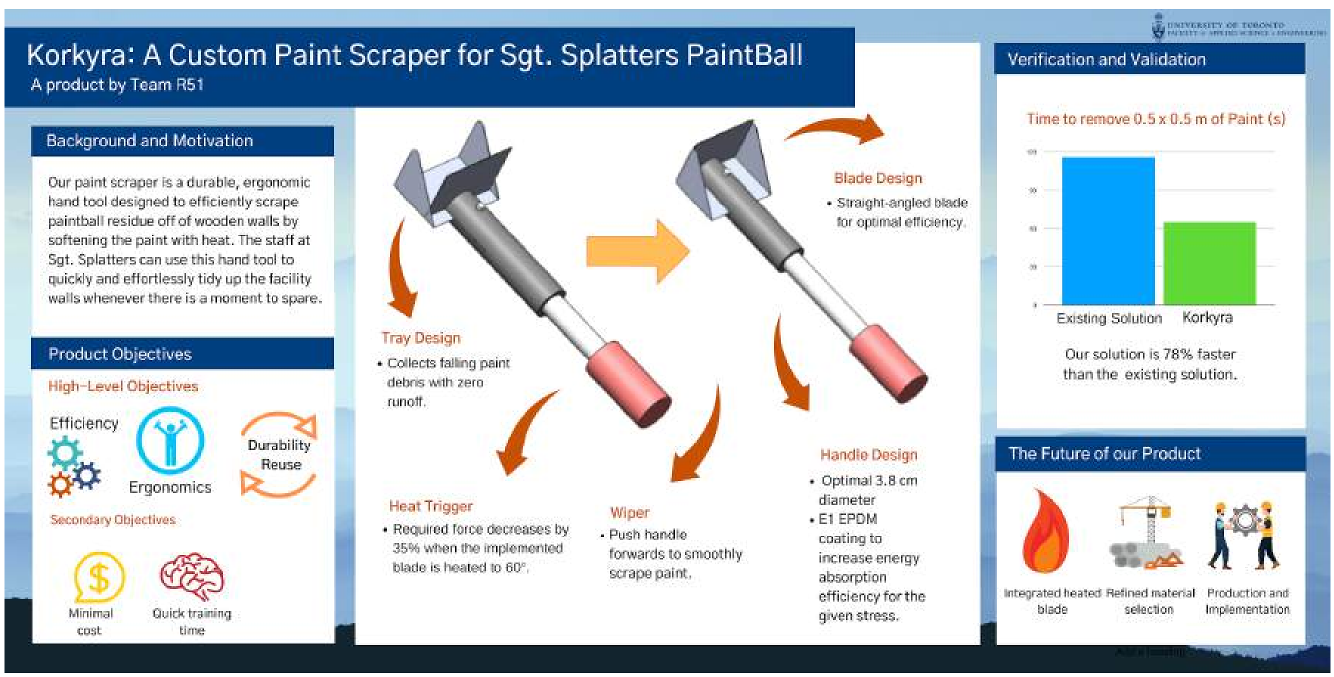


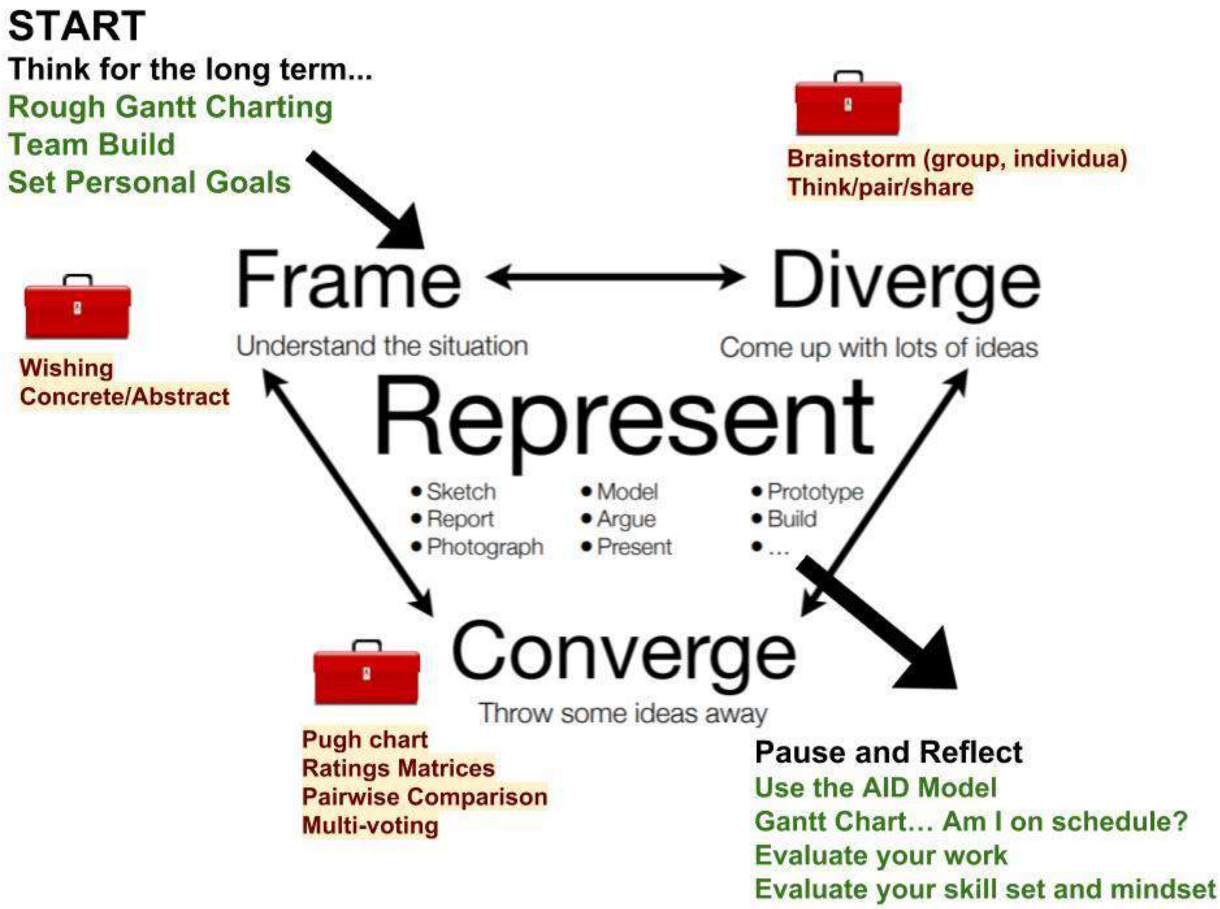
Figure 27. *The posterboard of our final product presented at Showcase. We named the final product "korkyra" (the name of Kronos' scythe) as a funny tribute to our initial design.*

3. Process-Focused Index

Based on my engineering design experience and knowledge of engineering design tools, models, frameworks, and processes, I have developed a Personal Engineering Design Process (PEDP). This process is highly based of off the FDCR (Frame, Diverge, Converge, Represent) design process [2].

3.1 Process Summary: S-FDCR-P

The S-FDCR-P design model takes a student engineer from the start to the end of any design project (individual or group) with a focus on risk management, organization, and personal growth. The model has very similar framing, converging, diverging, and representing to the FDCR model, but it has an added toolset associated with each stage in the cycle as well as a “start” and “pause” step in the cycle, as shown in Figure 28.



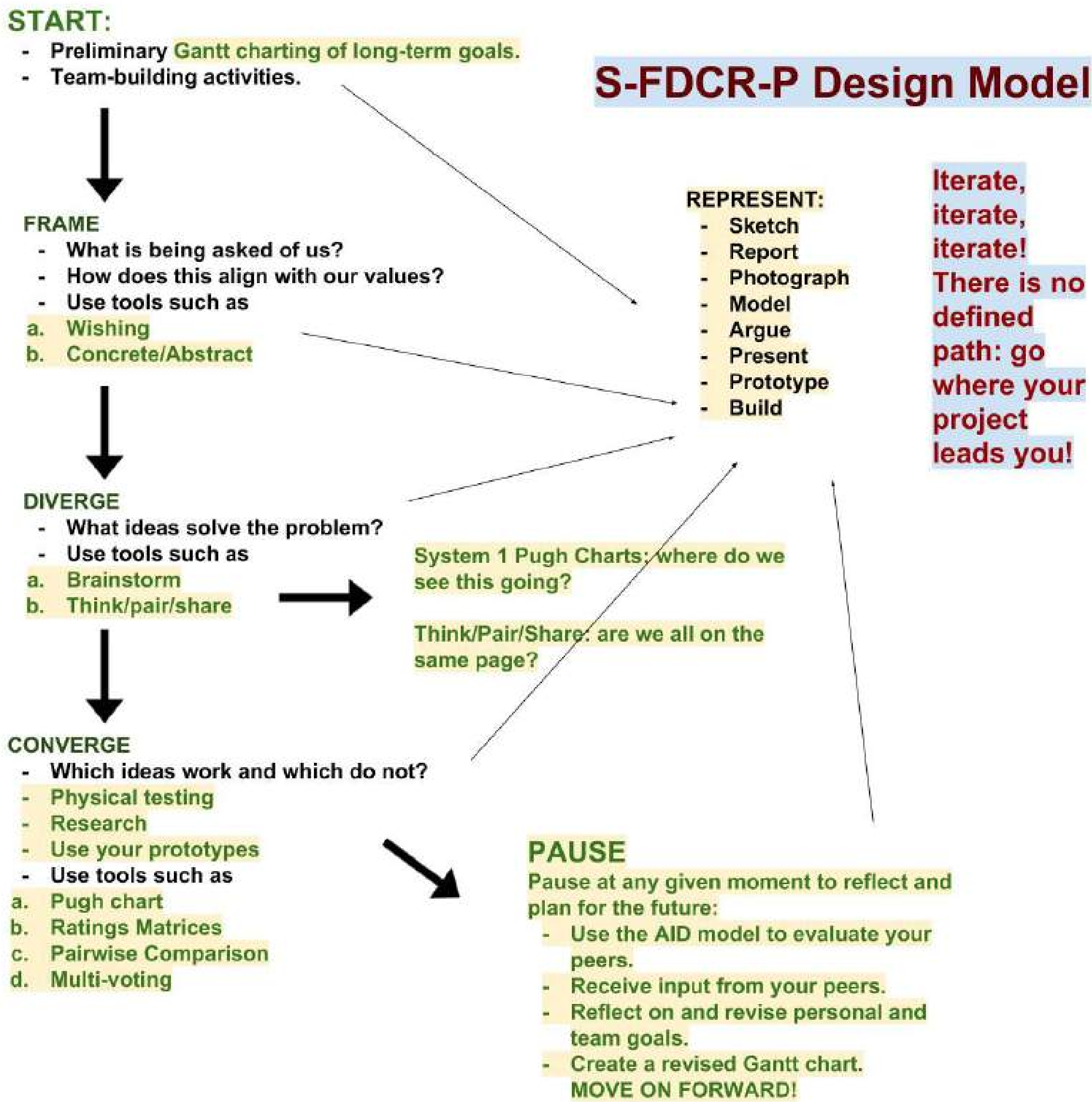


Figure 28. *A pictorial and graphical representation of S-FDCR-P.*

The "start" and "pause" phases are the most relevant to me as they align with my and values of organization and personal growth. The S phase of this design model is not necessarily a part of the cycle (ie, it only needs to happen once), while the P phase is meant to occur several times through the iterative design process.

The S phase includes all of the housekeeping tasks associated with the beginning of a design project. The team members must introduce themselves and have either

(a) a discussion of values, or

(b) a team-building project

to create a foundation for team relationships and solidify an inviting environment. After initial team-building activities, the team generates a very loose Gantt chart to set long term goals for

(a) the project at hand and its deadlines,
(b) the team as a whole, and
(c) personal/individual growth.

The team-building activities at the start of the S phase is greatly inspired by project 2.1, wherein my Praxis II team and I designed and tested a launcher together. This project shaped our semester working as a team. Working on a final iteration together last minute, building trust, and discovering shared values early on made working as a team easier in later projects, particularly project 2.3. We knew each other's team values and skills by the end of project 2.1 better than I knew any of my Praxis I teammates by the end of the first semester! Simple, quick, high-pressure/low-stakes projects like these can build a foundation for a really strong team.

The planning activities in the S-phase are inspired project 2.3 and my individual experiences and values. In project 2.3, my teammates and I used two Gantt charts in our design project: one near the start of the project and one near the end. Starting the project with a very rough timeline keeps teammates on the same page from day one, and as rough as it is, it is nice to have as a reference and demonstrates good risk management. Nearing the end of a design project, we used the Gantt chart to very closely organize our schedules. Having a very tight schedule with risk factored in made the final, stressful steps of our project easier to manage, as scheduling was already accounted for in even the worst case. Aside from this, before moving into framing, the S phase also includes a documentation of your personal and team goals. These can include goals such as:

- I want to practice cold-calling.
- I want to practice woodworking during prototyping.
- I want to learn how to use a new modelling software during prototyping.

Oftentimes, design projects are not just about the final product but are actually about the process you took to get there. By having a set of goals you are sure to take something away from the project that you can use in the future. Personal growth is really important to me so this step is invaluable to the S-FDCR-P process.

After the S phase of the design model, one goes through framing, diverging, converging, representing, and pausing in a sort of cycle. Framing involves understanding the situation by engaging with stakeholders, identifying the problem, and choosing a scope. Diverging involves the generation and refinement of solutions while converging involves the discarding of inadequate solutions. Representing includes activities such as prototyping, building, drawing, presenting, writing, and more [1]. The recommended toolboxes for these activities are highlighted in 3.2. These toolboxes are based off of my experience as a student engineer. I value organization, so havings an index of design tools for specific tasks is an asset. I like to be able to think "I am going to do some diverging", refer to my index, select a tool, and launch straight into diverging.

The added P phase of the design model is intended to keep an eye on risk management and remind the team of personal goals. The P phase should occur several times throughout the design process as a minor break to stop and summarize what has been accomplished and what needs to be accomplished. The creation of a revised Gantt chart is highly recommended at this time for the sake of organization. Schedules can change dramatically throughout the design process and require revision for the team to stay on track. Additionally, pausing is a great chance to evaluate individual and team efforts through self-reflection and the AID model for peer reviews. The AID model is a great tool for critique discussed further in 4.9. During the pause you can track your progress in your personal goals and update or revise your list of goals as you see fit. This should also be done for team goals during this time. Reminding yourself of your goals, receiving critiques, and setting new goals is critical to this phase. The general purpose of the pause phase is to promote personal growth for the team members while keeping them on an organized path to success for the long-term project goals.

3.2 S-FDCR-P Toolboxes

The S-FDCR-P process refines the actions of framing, diverging, converging, and representing by assigning toolboxes to each action. Each item in the toolbox was selected based off of my experience as an engineering student through several projects, including projects 2.1, 2.2, and 2.3.

3.2.1 Framing Tools

The framing toolbox includes but is not limited to:

- Wishing
- Concrete/abstract

The ideality of these tools is described in 4.5 and 4.9 respectively.

3.2.2 Diverging Tools

The diverging toolbox includes but is not limited to:

- Brainstorming (group, individual)
- Think/Pair/Share

The ideality of these tools is described in 4.3 and 4.4 respectively.

3.2.3 Converging Tools

The converging toolbox includes but is not limited to:

- Pugh charts
- Ratings Matrix
- Pairwise Comparisons
- Multi-voting

The ideality of these tools, with the exception of ratings matrices (as they are just compilations of data), is described in 4.6, 4.7 and 4.8 respectively.

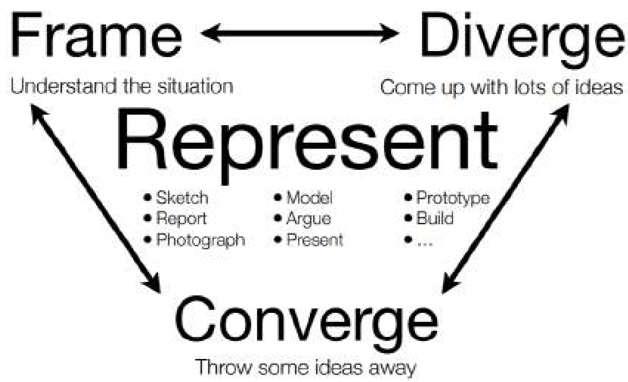
4. Tools, Models, and Framework

The following tools, models, and framework are up to discussion with reference to the S-FDCR-P process outlined above. These tools are presented through a discussion of their purpose, instructions, effectiveness.

4.1 FDCR

4.1.1 Description

FDCR is a cyclical process of framing, diverging, converging, and representing (in no particular order). It is a model used to approach design projects.



4.1.2 Experience

I have used FDCR in all design projects since I was exposed to it (I have used it in projects 2.1, 2.2, and 2.3; refer to these sections).

4.1.3 Analysis

FDCR is a very effective design tool. By separating phases of the design process, the process is less intimidating and easier to tackle. Additionally, it demonstrates the idea that engineering design is an iterative process by being cyclical; it is not overly forced or unnatural.

4.1.4 Recommendations

FDCR is a great tool to use in any design project. It is the basis to the S-FDCR-P process.

4.2 Morph Chart

4.2.1 Description

Morph charts are a diverging tool that generates a large number of ideas by combining smaller ideas inspired by reference designs. The top row of the chart lists reference designs and the leftmost column lists functions. Each slot of the chart explains how the given reference design meets the given function. A new product can be developed by selecting a one choice from each column.[3]

4.2.2 Experience

For project 2.3, my teammates and I used a morph chart. Using several reference designs we created the morph chart below and produced several possible permutations of the paint scraper.

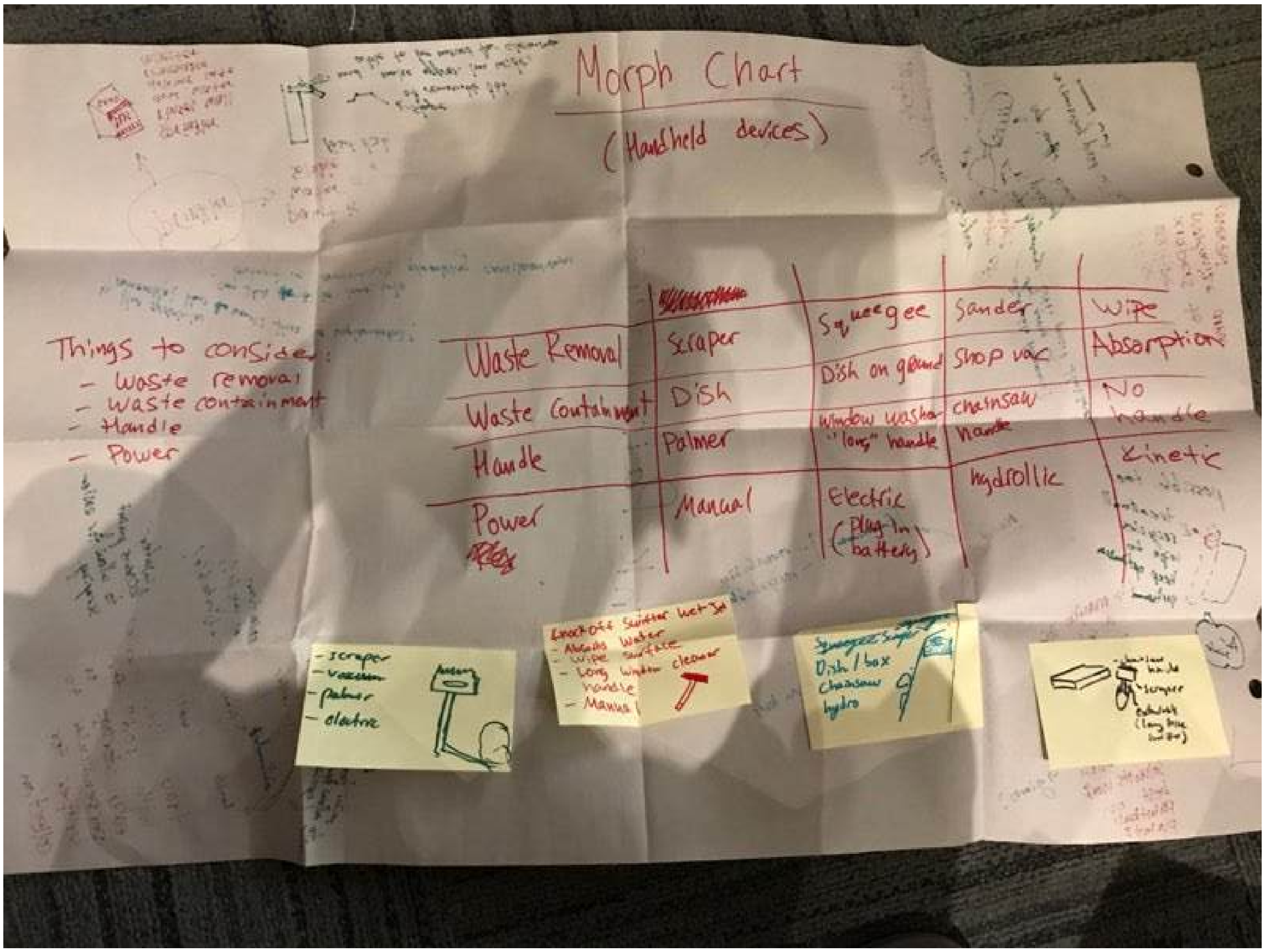


Figure 29. *The morph chart drew inspiration from tools such as scrapers, swiffers, sanders, wipes, and swiffers.*

The morph chart inspired my team and I to approach the design of our paint scraper in a piecewise fashion. We optimized each separable component in the morph chart and then put the pieces together. During the final validation of our product we found that the product did not work at all due to two detrimental components. This was a large disappointment and reminded our group not to anchor onto design tools too blindly.

4.2.3 Analysis

The morph chart compelled my team and I to approach the design of our paint scraper in a piecewise fashion. This made the design process very algorithmic which at first seemed beneficial. However, it put us in a fixed mindset and we did not often think about more than one thing at a time. There were times it felt unnatural and overly complex to continue with the morph chart and we ultimately regretted going with it.

4.2.4 Recommendations

I personally never intend to use the morph chart again. I find it very confusing, highly mechanical, and forced. I would not recommend the morph chart for a group project; oftentimes the results do not make sense and/or are not cohesive. Particularly for engineering students who value simplicity and clarity (such as myself), I recommend complete avoidance of these charts.

4.3 Brainstorming

4.3.1 Description

Brainstorming is very commonly known diverging tool. The general procedure is that you write down any immediate ideas that you have corresponding to a given question or project. [4]

4.3.2 Experience

I have used this design tool in every design project for as long as I can remember. My teammates and I used brainstorming for projects 2.1, 2.2, and 2.3. I have done brainstorming in the form of “individual” and “group” brainstorming.

Figure 30. *An example of individual brainstorming on sticky notes that each teammate later discussed as a group.*

Figure 31. *An example of notes from group brainstorming.*

My teammates and I usually performed individual brainstorming to gather our thoughts before group brainstorming. In the above examples, for project 2.2, we generated a large list of ideas from brainstorming that lasted for the whole design process. In fact, one of the broad ideas we came up with in our first diverging process is the product we rigorously designed and recommended.

4.3.3 Analysis

Brainstorming is a tool that is almost always the first thing a team uses when given a project or question. It is a useful tool that quickly communicates all of the ideas in your head so that you can develop them further in the future. My teammates and I found that it is most effective when done individually and then in a group setting. This way our ideas have a reasonable amount of definition before discussion starts. The easiness of the tool makes it a simple starting point for most projects. As simple as it is, one cannot deny its utility; in the above example, my team and I settled on an idea from initial brainstorming for our final design recommendation! Simple is always a good starting point, and it is oftentimes a good endpoint as well (after rigorous testing and validation though).

4.3.4 Recommendations

There is a reason brainstorming is as well known as it is. I recommend using this tool to “get the ball rolling” for any project, however there certainly are other diverging tools that are more effective discussed below. It is important to note the distinction between individual and group brainstorming as they have unique benefits. Brainstorming belongs in the diverging toolbox for S-FDCR-P.

4.4 Think/Pair/Share

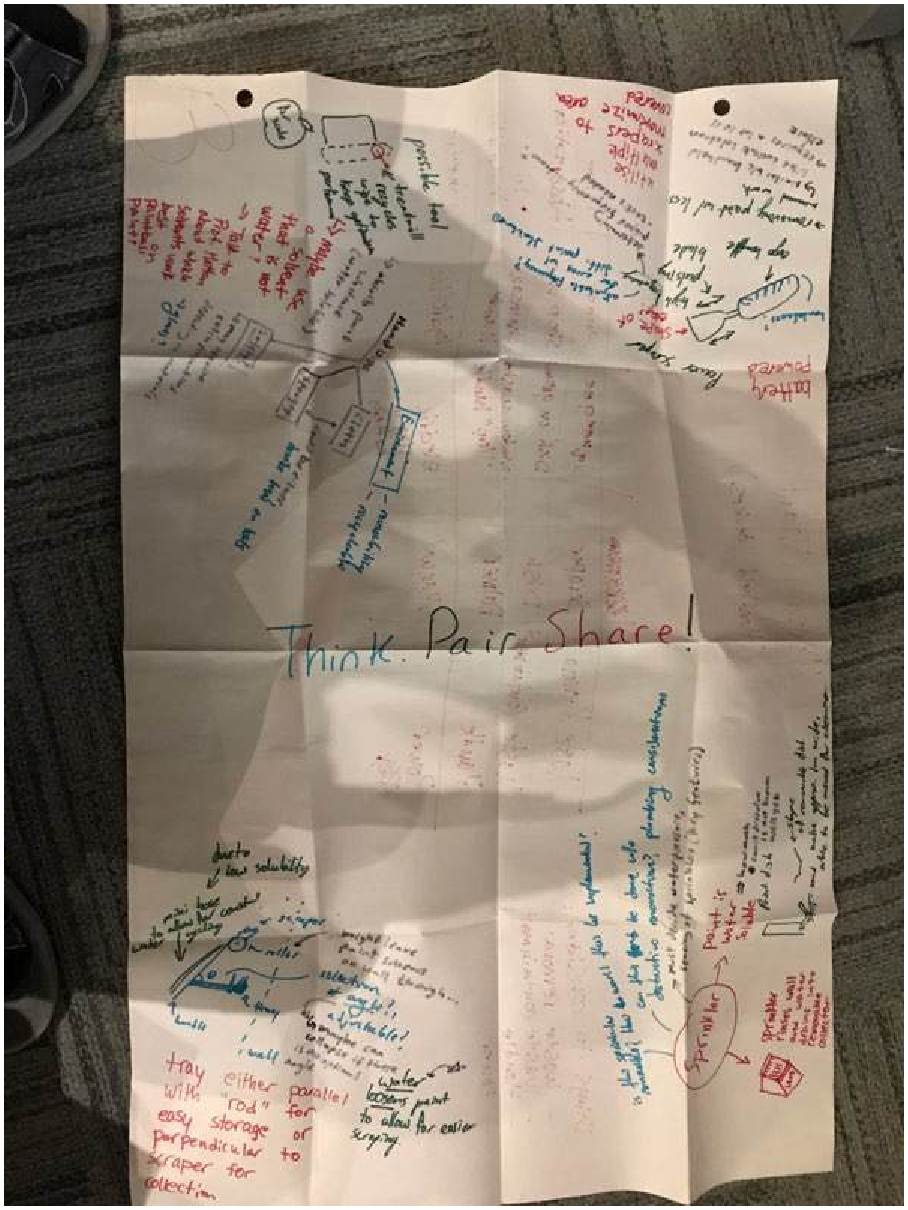
4.4.1 Description

Think/pair/share is a divergence tools that works as follows:

1. Each person on the team is assigned an alternative/idea.
2. In a given time frame each team member writes down anything they can think of related to their idea.
3. Reassign the alternatives the team and repeat steps 1,2, adding to the teammate's contributions until each team member has contributed to each idea. [5]

4.4.2 Experience

My team and I used think/pair/share in our diverging process for project 2.3. We repeatedly used this tool because it consistently produced new results.


Think Pair Share!
tray either parallel with "rod" for easy storage or perpendicular to scraper for collection
water loosens paint to allow for easier scraping
battery powered
sprinkler

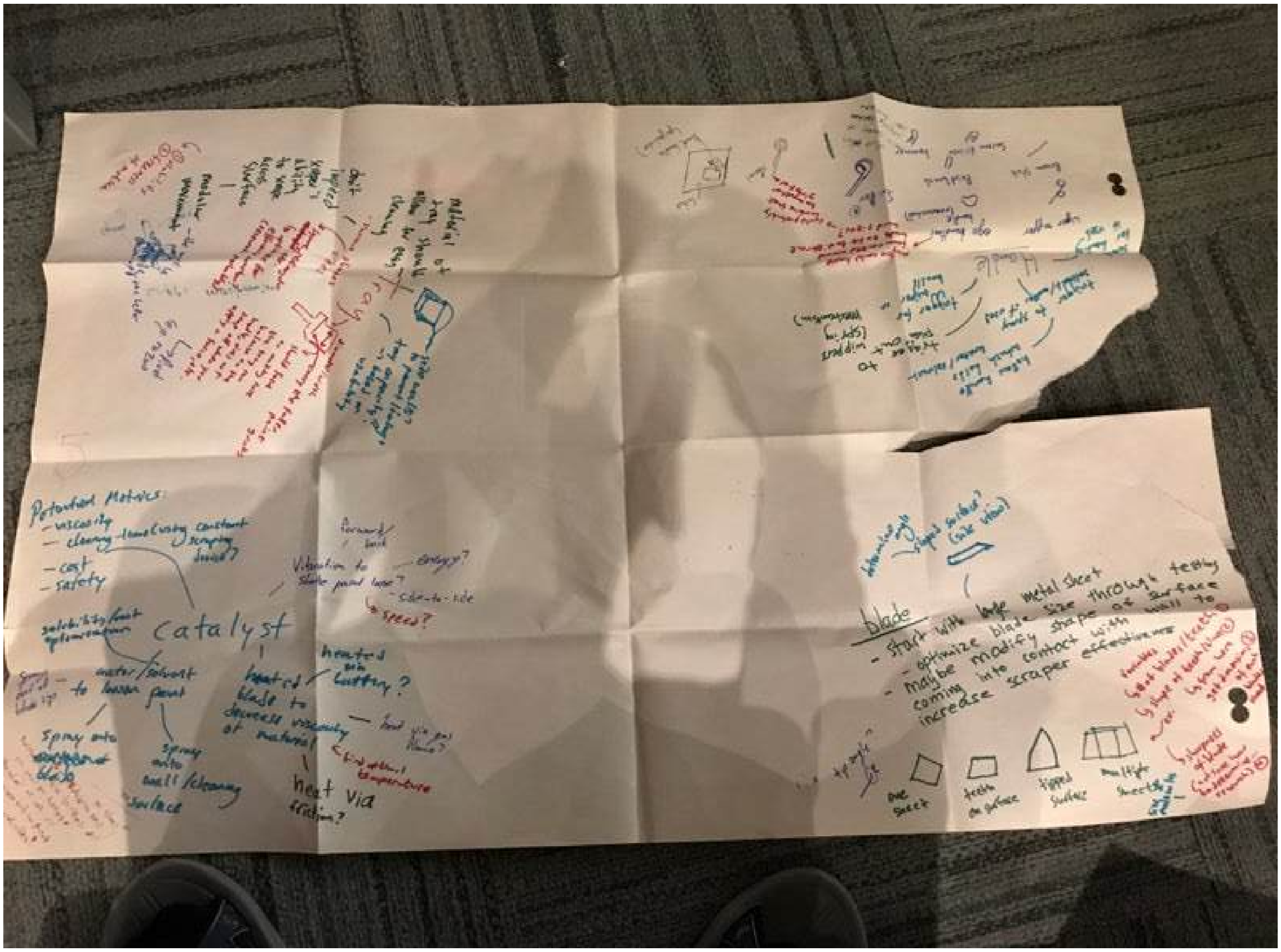


Figure 32. *Think/pair/share for our initial round of diverging.*

4.4.3 Analysis

Think/pair/share is a unique tool in that it represents the all of the ideas of every teammate in one succinct paper. I appreciate how clearly it communicates where the team is as a whole at a given point in the design process. When my team and I used this tool we found it to be very successful. As we explained what we wrote, I found that my teammates had ideas that they assumed we all shared that in fact we did not share and were very interesting to hear. Similarly, some of the ideas I had assumed my teammates shared had never before occurred to them. Think/pair/share brought all teammates up to date with each other and compelled us to think deeply about each other's idea.

4.4.4 Recommendations

Think/pair/share is a useful tool to keep teammates up to date at any given point in the design process. Having used think/pair/share during initial rounds of divergence, and having found success, I infer that it would also be successful at any given point in the engineering process for the following reasons:

- Think/pair/share is successful in that it clearly communicates where all teammates are up to date.
- This tool brings to light some ideas, issues, and next steps that perhaps not everyone had recognized.
- These benefits are useful at any given time in the process, as engineering design is an iterative and cyclical process.

I would highly recommend this tool for any design project; its simplicity and clarity perfectly aligns with my values as an engineering student. Think/pair/share belongs in the diverging toolbox for S-FDCR-P.

4.5 Wishing

4.5.1 Description

Wishing is a framing tool that can be described as follows:

"I wish…"

And then you finish the sentence. This tool can be used to summarize your design project or to lead you to a preferred scope [6].

4.5.2 Experience

I used wishing in projects 2.1, 2.2, and 2.3. In project 2.1, my team and I wished that we could have 100% accuracy from our launcher. We wished for this after building our first iteration of the launcher and it prompted us to come up with a solution that guaranteed our launcher's success.

In project 2.2, my teammates and I used wishing to draw out possible design projects related to our design brief. We wished for things such as:

"I wish having wet socks wouldn't ruin my day."

"I wish my backpack wouldn't get wet on rainy days."

"I wish my glasses wouldn't get foggy or wet on rainy days."

We eventually agreed that not having wet socks was what we wished for the most (as we did not like the look of rainboots, and as our survey showed, neither did our peers). In project 2.3 we used wishing by attempting to place ourselves in the shoes of the staff at Sgt. Splatters and think of the kinds of solutions they would like. This particular case of wishing was unsuccessful and did not produce any ideas we did not already have. We also tried to use wishing to diverge ideas but the ideas we produced were too crazy to actually be legitimate and were scrapped.

4.5.3 Analysis

Wishing can be a useful tool in framing a design project if you are one of the main stakeholders for the project. In the case of the launcher project 2.1, my teammates and I were the primary stakeholders.

In project 2.2, the project was aimed towards first year Engineering Science students, so my teammates and I were a part of that group. The wishes we made were highly relevant and actually addressed stakeholder needs. Wishing is generally a very fun tool that stimulates the imagination, which aligns with my personal values, so I use it whenever I can.

Wishing as a divergence tool, however, is not very effective as it led us to overly outlandish ideas. It produced no viable results for project 2.3.

4.5.4 Recommendations

I recommend the use of wishing during framing particularly if you are a major stakeholder in the beginning of the design process. If this is the case you know that what you are wishing for is relevant to stakeholders and to the problem at hand. Otherwise it becomes difficult because you have to put yourself in the shoes of stakeholders and becomes a waste of time when you could be engaging with stakeholders directly. Wishing during diverging is also not very effective as it promotes outlandish ideas that are rarely viable. Particularly if your team or stakeholder values include simplicity, wishing is not an appropriate diverging tool. Wishing belongs in the framing toolbox for S-FDCR-P.

4.6 Pugh Chart

4.6.1 Description

Pugh charts are converging tables with the top row indicating alternatives and the leftmost column indicating ratings. With one alternative being evaluated as neutral for each rating (this is usually a reference design/existing solution), each of the other alternatives on the chart has a rating for each allocated slot expressed as its relative goodness to the reference design with a + (better) or - (worse) for that specific rating [7].

4.6.2 Experience

I have used pugh charts for both projects 2.2 and 2.3 at various steps in the design process. I have used Pugh charts in the following scenarios:

- To get a system 1/1.5 idea of the relative goodness of alternatives (Figure 33). This was done for project 2.3 to predict the relative goodness of alternatives and weed out particularly bad alternatives before physical testing/prototyping.
- As a simplification of a ratings matrix to make the matrix easier to read (Figure 34). This was done in project 2.2 after producing fully fleshed out research and tests for our alternatives. Looking at the Pugh chart, one alternative stood out as highly superior so my group and I decided to rigorously design each component for that particular alternative.

+ better, - worse, = same as per criteria

Metric	**Flat blade**	**Sloped blade**	**Curved blade**
Time Efficiency	-	+	=
Force Required	-	+	=
Upfront Cost	-	-	=
Wood Runoff	-	=	=
Metal Runoff	-	=	=
Field Runoff	-	=	=
Volume Occupied	=	=	=
Borg Scale	-	+	=

Alternative	Snow Shovel Handle	Swiffer® Handle	Weed Trimmer Handle
Time Efficiency	=	=	+
Force Required	=	=	=
Upfront Cost	-	=	+
Wood Runoff	=	=	=
Metal Runoff	=	=	=
Field Runoff	=	=	=
Volume Occupied	=	=	-
Subjective Survey	+	=	+
Borg Scale	+	=	+
Safety Rubric	+	=	+

Alternative	Triangle	Box	Box without Top
Time Efficiency	=	=	=
Up Front Cost	+	=	-
Wood Runoff	=	=	+
Metal Runoff	=	=	+
Field Runoff	=	=	+
Volume Occupied	+	=	=
Borg Scale	+	=	-

Figure 33. *System 1.5 Pugh charts for scraper variables.*

Ratings Matrix

	1.2	**3.1**	**3.2**	**Reference Design**
Δwetness/Δtime	≈ 1 minute	≈ 5.86g/min	≈ 0.7g/min	(takes 2-3 hours)
Number of steps	1. put your shoes off 2. put the product on 3. put your shoes on 3 STEPS	1. Fasten the device on the leg 2. Adjust the direction to the shoes 3. Press "on" 3 STEPS	1. Insert feet in machine 2. Turn machine setting to sock 3. Press "on" 3 STEPS	1. Take shoes off (with socks) 2. Put the dryer in the shoe 3. Set the heat settings 4. Turn the dryer on 4 STEPS
noise	0 dB	65 dB	20 dB	
size	27cm tube with 10 cm diameter	Fasten: 7.9 x 9.4 x 5.6 cm, motor: 13.517x14.472x 11.700 cm	45x38x38 cm	7.2 x 2 x 2.1 inches
mass	0.1	≈95.27 g	≈ 10 lbs	10.1 ounces
Number of electric parts	0	1 heater	5 rectangular heaters	2 shoe heaters that contain several parts
Cost $CAD	≈ 4.68 / pair (w/ 3g of sodium polyacrylate, approx .3 yard of Zorb/pair)	$101.17+14.39= $115.56	$65.03x5 + $120.96 = $446.11	$58.04
Number of materials	2 (outer fabric, absorbent material)	3 (heating motor, plastic shell, fasten part)	3 (plastic shell, outer layer, heaters inside)	

	1.2 (absorbent sock)	**3.1 (air dryer)**	**3.2 (box heater)**	**Reference Design**
Δwetness/Δtime	+	+	+	N
Number of steps	+	+	+	N
noise	+	-	-	N
size	+	-	-	N
mass	+	+	-	N
Number of electric parts	+	+	-	N
Cost $CAD	+	-	+	N
Number of materials	+	+	+	N

Figure 34. *A Ratings Matrix converted to a Pugh Chart used to converge to one broad idea.*

4.6.3 Analysis

The Pugh chart is a very useful holistic tool. I have found that Pugh charts can be applied to a spectrum of situations; you can create a Pugh chart from a highly rigorous matrix to serve as a simplification, but you can also create a system 1 or 1.5 Pugh chart to get a loosely defined "predicted goodness" for each alternative. I have found that whenever I use the Pugh chart in the design process I have either:

a. Demonstrated good time management by removing poorly performing alternatives early on or by going with one excellent alternative before rigorous testing.
b. Gained a better holistic understanding of my alternatives.

The Pugh chart efficiently communicates how well the alternatives meet all of the objectives.

4.6.4 Recommendations

I would highly recommend the repeated use of Pugh charts throughout the design process. Pugh charts encourage proper time management at the start of the design process as system 1 evaluations cause holistically bad alternatives to be removed. They also encourage simplicity in later stages as they are literally simplifications of ratings matrices. Having a Pugh chart alongside its corresponding ratings matrix never hurts as it gives an easy to read holistic evaluation. The Pugh chart communicates information that may not be immediately obvious and facilitates decision-making. The simplicity of a Pugh chart is in great alignment with my values as an engineering student. Pugh charts belong on the converging toolbox for S-FDCR-P.

4.7 Pairwise Comparisons

4.7.1 Description

Pairwise comparison is a design tool used for narrowing down a set alternatives to a smaller group or to one favoured alternative. The process is as follows:

1. Select two items from the alternative list.
2. Compare the two items and choose which one you prefer with system 1 thinking.
3. Repeat steps 1-2 again with one of the two alternatives being the winner from this round and the other being an unevaluated alternative. Repeat until there is one winner [8].

4.7.2 Experience

I have used pairwise comparisons in the process of designing a solution to wet socks on a rainy day (2.2). My team and I used this tool to converge from a large set of ideas to a smaller set for which we could do research and physical testing/prototyping.

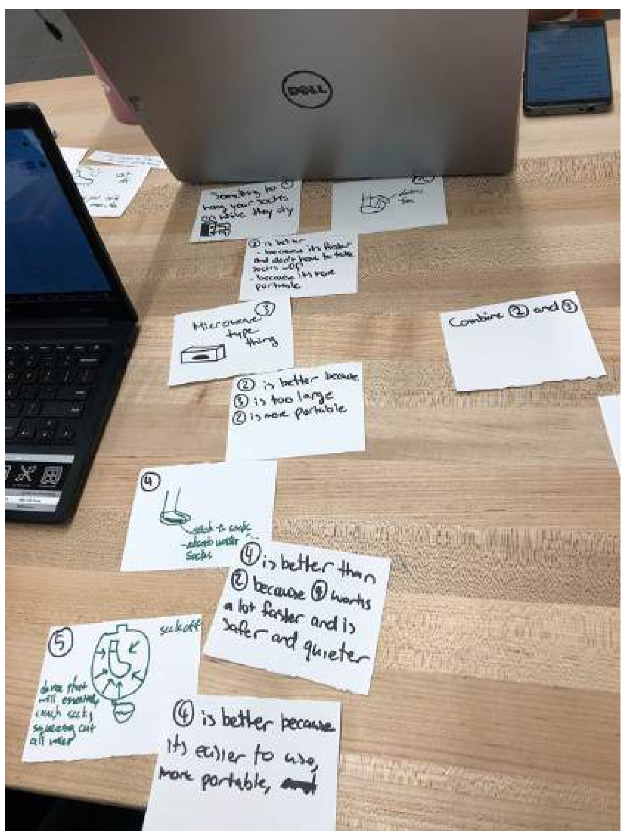


Figure 35. *Pairwise comparisons of broad ideas for a solution to wet socks on a rainy day.*

I have also used pairwise comparisons a great deal in the process of designing a paint scraper for Sgt. Splatters (2.3). My team and I used pairwise comparisons several times throughout the design process when large numbers of ideas were generated and only a few could be tested. For example, at the start of the project after initial diverging (when our RFP was not yet fully framed), we used pairwise comparisons of several broad ideas to quickly converge to a smaller subset of possible alternatives. This act of system 1 converging brought us to realize what was and was not feasible based on intuition.

Similarly, in the designing of handles and scraper blades, pairwise comparisons were used to determine a reasonable number of alternatives to be tested.

4.7.3 Analysis

Pairwise comparison is a very effective system 1 tool for converging ideas. With this tool one can easily narrow down a large set of ideas to a fraction of the set. In my experience I have found that this speeds up the initial converging process by eliminating some ideas that could never be feasible. Additionally, this makes Pairwise comparisons also force you to be honest with the general quality of each alternative which is otherwise difficult to do if you have a cognitive bias.

Pairwise comparisons can also be used in a system 1.5 mindset, as done for project 2.2. Given that you are relatively informed on the advantages, disadvantages, and numbers associated with the alternatives, pairwise comparisons can be used beyond initial rounds of convergence.

4.7.4 Recommendations

I highly recommend the use of pairwise comparisons during initial converging processes. Pairwise comparisons offer quick system 1 solutions to large sets of alternatives. Since you are only comparing two alternatives at any given time, it can make intimidating rounds of converging easier and makes it easier to collect your thoughts. I also recommend the use of pairwise comparisons in the later phases of projects where appropriate. Given a low-risk decision that you and your team are fairly informed about, pairwise comparisons can be quick and effective as well. Pairwise comparisons belong in the converging toolbox for S-FDCR-P.

4.8 Multi-voting

4.8.1 Description

Multi-voting is a converging tool. Given a set of X alternatives, each member in the team is given Y votes to choose their Y favorite ideas of the X possible choices. The least popular choices are then weeded out [9].

4.8.2 Experience

I used this tool with my team in Praxis I for project 2.2 to converge to a slightly smaller subset of alternatives, as shown in Figure 36.

- **2nd round converging (multi-voting)**

	1.1	1.2	1.3	2.0	3.1	3.2
Sheri		✓			✓	✓
Victoria		✓	✓		✓	
Mulan		✓	✓		✓	
Daniel		✓		✓		✓

Figure 36. *Multi-voting to converge to three key concepts (1.2, 3.1, 3.2). Note that the alternatives are represented as indices.*

When multi-voting we explained why we had preference for the ideas we voted for; this was especially important because two of our ideas had a tie and we had to discuss which of the two ideas to work on moving forward.

4.8.3 Analysis

Multivoting is a great system 1 tool to get group members to admit that they prefer certain alternatives for certain reasons. It gives each member a chance to voice their opinion and provides a very raw statistic for which alternatives are the most popular. In instances where there is a tie, the idea of multi-voting and decisions based on numbers becomes fuzzy and, from personal experience, the final decision becomes a matter of discussion and debate. Nevertheless my teammates found it to be a very effective tool that allowed us to move forward in our design process.

4.8.4 Recommendations

I highly recommend multi-voting during initial converging processes as it is based primarily on system 1. The use of multi-voting brings out team values by making personal preference a factor. This ensures that the alternatives that the team is working on is a good reflection of team values. However, the concept of multi-voting is probably not as effective for large sets of alternatives when choosing your votes becomes a difficult decision (multi-voting should be an easy, personal, system 1 decision). Being a system 1 tool, it is definitely not a good idea to use this tool too deep into the design process unless the differences in the alternatives is very low in significance. Multi-voting belongs in the converging toolbox for S-FDCR-P.

4.9 Action, Impact, Desired Outcome (AID)

4.9.1 Description

AID is a framework that I have used primarily in critiques/peer evaluations. When writing peer evaluations one can critique (as opposed to criticize) a teammate's work by discussing

- An action they performed.
- How that action affected you.
- How you would suggest they improve on that action in the future [10].

4.9.2 Experience

I have used this model in Tels I/II in Praxis I and Tels I in Praxis II. When reading Tels feedback from my peers I have likewise found this framework in their writing.

4.9.3 Analysis

This model is highly effective in getting a feelings across. In my personal experience it is useful when bringing up team issues that are otherwise awkward or difficult to write about. Taking a systematic approach to writing a critique ensures that I write down everything I want to say in a concise way that is backed up with telling evidence. I really appreciate this tool because:

a. I value clarity in my work.
b. I sometimes struggle with how to articulate problems to others

I also appreciate seeing it in critiques about my group skills as it gives me a better understanding of my strengths and weaknesses. By providing specific examples of actions and explanations of feelings I get a much better idea of where my teammates are coming from and it gives me a better understanding of where to improve.

4.9.4 Recommendations

This model is very effective when used in peer evaluations and I recommend that it is used (or at the very least considered) during any peer evaluation.

4.10 Concrete/Abstract

4.10.1 Description

The concrete/abstract tool is used for framing. Starting with an abstract idea, the team comes up with increasingly concrete ideas that all pertain to the original abstract idea. This tool is used to identify stakeholders, opportunities, and even solutions [11].

4.10.2 Experience

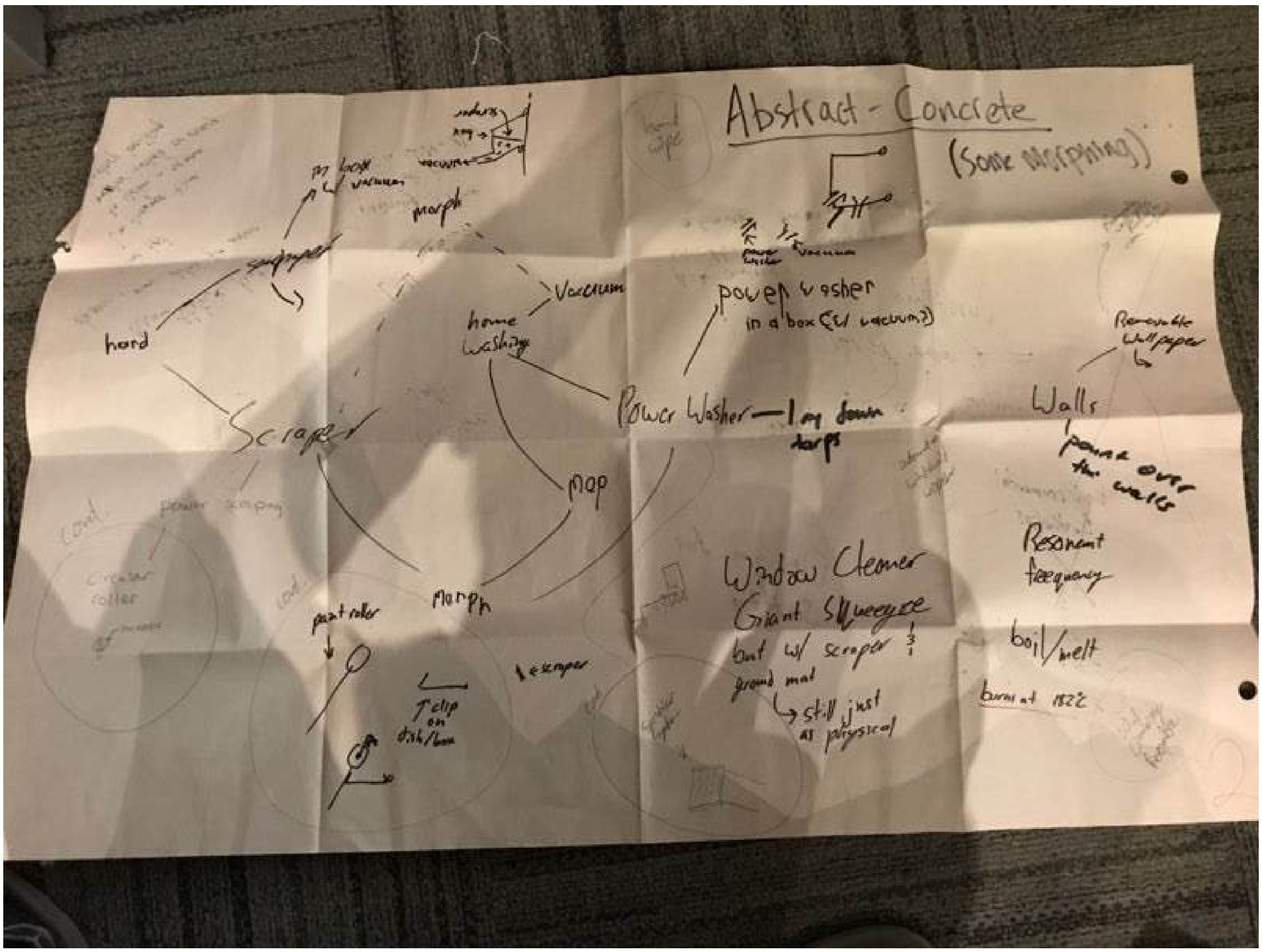


Figure 37. *Abstract/concrete tool in project 2.3.*

For project 2.3, my teammates and I used concrete/abstract in our initial framing process. From our RFP we drew concrete scopes and from there drew out broad ideas to solve the problem. This design tool gave us a taste for all of the possible routes we could take with the RFP.

4.10.3 Analysis

As stated above, the concrete/abstract tool gives a good taste for all of the possible routes an abstract opportunity can lead to. Abstract ideas can be intimidating, and this tool works to combat that. The tool sheds light on where the team could actually end up at the end of the project. If the team agrees on concrete ideas that they all like, then concrete/abstract provides a great opportunity to choose a lens.

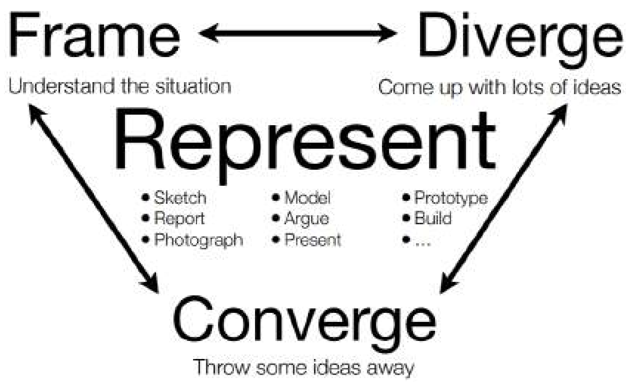
4.10.4 Recommendations

I highly recommend using concrete/abstract during framing. The tool is best used as early in the design process as possible (ie, when you are still working with abstract ideas). However, the tool becomes useless when working with ideas that are already concrete. Concrete/abstract is in the framing toolbox for S-FDCR-P.

5. Bibliography

[1] Cover Photo: sketches by Leonardo Da Vinci
"Scans of 'blank' sheets of paper reveal Leonardo da Vinci's long-faded drawings," *9Pickle*, 01-Apr-2019. [Online]. Available:
https://pickle.nine.com.au/2018/02/15/12/18/leonardo-da-vinci-invisible-drawing-revealed-scan
[Accessed: 01-Apr-2019].

[2] Lecture 01, ESC101, 2018/09/07.



[3] "Method," *Morphological charts*. [Online]. Available:
https://www.ifm.eng.cam.ac.uk/research/dmg/tools-and-techniques/morphological-charts/.
[Accessed: 14-Apr-2019].

List product functions

List the features (or functions) that are essential to the product. The list should not be too long, but should encompass the major product functions, at a appropriate level of generalisation. Ideally, there should be no more than 10. It can be useful to list functions according to a predetermined order - most important, position in structure, energy flow, information flow. Care should be taken to list functions and not components - e.g. 'warning indicator' rather than 'bell'. Always ask 'what function is this component fulfilling?' Each function should be mutually exclusive. Possible functions for a mobile phone could include: holding, storage, dialing, display, power supply, signal reception, signal processing, sound output, sound input etc.

List the possible 'means' for each function

For each function, list the 'means' or possible solutions by which it might be achieved. Think about new ideas, as well as known solutions or components and where possible ideas should be expressed visually as well as in words. Any important characteristics of the solutions should be recorded. Try to maintain the same level of generality for each possible solution - for example, it may be beneficial to consider different power sources or perhaps it may be more relevant to just investigate different battery options. Possible means of achieving 'holding' for a mobile phone could be a stopwatch-type grip, attached to clothing, watch style, gun grip etc.

Chart functions and means & explore combinations

Draw up a chart containing all possible sub-solutions. This is the 'morphological chart' which should represent the total 'solution space' for the product - made up of combinations of sub-solutions. Try wherever possible to express all options visually. It is now possible to identify feasible combinations of sub-solutions. The total number of combinations may be very large, so they may need to be limited to the most feasible or attractive options. Name each viable combination as a potential solution for further evaluation later. An example is shown below.

[4] "What is Brainstorming?," *The Interaction Design Foundation*. [Online]. Available: https://www.interaction-design.org/literature/topics/brainstorming. [Accessed: 14-Apr-2019].

What is Brainstorming?

Brainstorming is a method for generating ideas to solve a design problem. It usually involves a group, under the direction of a facilitator. The strength of brainstorming is the potential participants have in drawing associations between their ideas in a free-thinking environment, thereby broadening the solution space.

What UX Designers do with Brainstorming

Brainstorming is an extremely popular ideation technique for design teams because of the freedom they have to expand in all directions, using out-of-the-box and lateral thinking in search of the most effective solutions – rough answers they'll refine later. Marketing CEO Alex Osborn, brainstorming's "inventor", captured the refined elements of creative problem-solving in his 1953 book, *Applied Imagination*. In brainstorming, we aim squarely at a design problem and produce an arsenal of potential solutions. By not only harvesting our own ideas but also considering and building on colleagues' notions, we cover the problem from every angle imaginable.

> It is easier to tone down a wild idea than to think up a new one.
>
> - Alex Osborn

Before a design team gather (preferably in a room with a large board/wall for pictures/Post-Its) for a brainstorming session, the target problem must be *clearly* defined. A good mix of participants will expand the experience pool, thus broadening the idea space.

[5] "All About Adolescent Literacy: Think Pair Share," *AdLit.org*. [Online]. Available: http://www.adlit.org/strategies/23277/. [Accessed: 14-Apr-2019].

Background

Think-Pair-Share (TPS) is a collaborative learning strategy in which students work together to solve a problem or answer a question about an assigned reading. This technique requires students to (1) think individually about a topic or answer to a question; and (2) share ideas with classmates. Discussing an answer with a partner serves to maximize participation, focus attention and engage students in comprehending the reading material.

Benefits

The Think-Pair-Share strategy is a versatile and simple technique for improving students' reading comprehension. It gives students time to think about an answer and activates prior knowledge. TPS enhances students' oral communication skills as they discuss their ideas with one another. This strategy helps students become active participants in learning and can include writing as a way of organizing thoughts generated from discussions.

Create and use the strategy

The teacher decides upon the text to be read and develops the set of questions or prompts that target key content concepts. The teacher then describes the purpose of the strategy and provides guidelines for discussions. As with all strategy instruction, teachers should model the procedure to ensure that students understand how to use the strategy. Teachers should monitor and support students as they work.

1. **T** : (Think) Teachers begin by asking a specific question about the text. Students "think" about what they know or have learned about the topic.
2. **P** : (Pair) Each student should be paired with another student or a small group.
3. **S** : (Share) Students share their thinking with their partner. Teachers expand the "share" into a whole-class discussion.

[6] “Wishing,” *creatingminds.org*. [Online]. Available: http://creatingminds.org/tools/wishing.htm. [Accessed: 14-Apr-2019].

How to use it

Wishing helps expand thinking.

Think wishfully

Think of the situation in a wishful, fantastic sense. Think beyond sensible, beyond practical and feasible. Just think about what would be really nice or simply interesting. Think playfully, as a child. Step outside the box. Act as if the box wasn't there. Be wishful, wistful, wonderful.

Offer ideas as 'I wish...'

Frame ideas by starting with 'I wish'.

In writing down ideas (which you often want to do quickly), you can abbreviate 'I wish' as 'IW'.

Offer ideas as 'Wouldn't it be nice if...'

Another variant of 'I Wish' is 'Wouldn't it be nice if'. You can use this as a variation or if it seems more appropriate.

In writing down ideas, you can abbreviate 'Wouldn't it be nice if...' as 'WIBNI'.

You can also use any other variant of wishing, of course, such as 'I wonder if' or 'It would be great if'.

[7] *Study.com*. [Online]. Available: https://study.com/academy/lesson/pugh-chart-definition-example.html. [Accessed: 14-Apr-2019].

In the top row we have spots for four empty spaces. There can be as many empty spaces as we want, but in this example we have four. One of these options needs to be a control, or the option that will be '0' for every criteria.

The first column is criteria. Here we list off everything of interest that we need to compare, such as price, distance, etc.

The second column is weight. Some criteria is more important than other criteria. For example, if it is your friend Jen's birthday, then perhaps her favorite place to eat will carry a heavier weight than every other criteria.

At the bottom of the chart we add everything up. We add up how many pluses, zeroes, and minuses each option got. Then we multiply the pluses by 1, the zeroes by zero, and the minuses by -1. Each of these get added up for the total.

[8] "Pairwise comparison," *Wikipedia*, 10-Feb-2019. [Online]. Available: https://en.wikipedia.org/wiki/Pairwise_comparison. [Accessed: 14-Apr-2019].

Pairwise comparison generally is any process of comparing entities in pairs to judge which of each entity is preferred, or has a greater amount of some quantitative property, or whether or not the two entities are identical. The method of pairwise comparison is used in the scientific study of preferences, attitudes, voting systems, social choice, public choice, requirements engineering and multiagent AI systems. In psychology literature, it is often referred to as **paired comparison**.

Overview [edit]

If an individual or organization expresses a preference between two mutually distinct alternatives, this preference can be expressed as a pairwise comparison. If the two alternatives are *x* and *y*, the following are the possible pairwise comparisons:

The agent prefers *x* over *y*: "$x > y$" or "xPy"

The agent prefers *y* over *x*: "$y > x$" or "yPx"

The agent is indifferent between both alternatives: "$x = y$" or "xIy"

[9] S. Thakur, "The Multivoting Technique Explained," *Bright Hub PM*, 18-Nov-2018. [Online]. Available: https://www.brighthubpm.com/six-sigma/112358-explaining-the-multivoting-technique/. [Accessed: 14-Apr-2019].

Assign every item on the list a reference number, which the team can use on the voting cards. Before the voting can begin, the team is required to set the number of items that can be voted for by the team members. As a rule of thumb, this number is either one third or one fourth of the number of items on the list. For instance, if the initial list contains 40 options this number can be set to 10 or 12.

. To begin with the voting process, all participants are asked to build up their personal list containing the set number of items, from the complete list. Going with the above example every participant will be required to choose 12 options that according to them are the most significant ones, from the list.

5. With that done, its time to tally the votes, and add up the totals to see how much each option has scored. After the tally, the list needs to be recompiled. For this it's best to keep only the top 30-40% options that have scored the highest, on the new revised list.
6. With the new list in hand; the procedure will need to be repeated until finally the list has condensed down to no more than 3 options.
7. As a final step the final options are discussed and analyzed to assign each of them a priority.

[10] *Coaching: Effective Feedback >> AID Model - Action, Impact, Desired Outcome*. [Online]. Available: http://www.1000ventures.com/business_guide/crosscuttings/feedback_aid_ml.html.

[Accessed: 14-Apr-2019].

→ Coaching

Max Landsberg, the author of *The Tao of Coaching*, suggests that in providing → feedback, you should ensure that you address the three AID topics:

- **Action**: The things the player is doing well, or poorly, in the area under review
- **Impact:** The effect these actions are having
- **Desired outcome:** The ways in which the player could do things more effectively

[11] "Abstract and concrete," *Wikipedia*, 05-Apr-2019. [Online]. Available: https://en.wikipedia.org/wiki/Abstract_and_concrete. [Accessed: 14-Apr-2019].

Abstract and **concrete** are classifications that denote whether the object that a term describes has physical referents. Abstract objects have no physical referents, whereas concrete objects do. They are most commonly used in philosophy and semantics. Abstract objects are sometimes called ***abstracta*** (sing. ***abstractum***) and concrete objects are sometimes called *concreta* (sing. *concretum*). An abstract object is an object that does not exist at any particular time or place, but rather exists as a type of thing—i.e., an idea, or abstraction.[1] The term *abstract object* is said to have been coined by Willard Van Orman Quine.[2] The study of abstract objects is called abstract object theory.