@dropdown

TASKS

1.0 Identify the roles of each: client, users, design team members, and mentors.

STAKEHOLDER	NAME/DESCRIPTION	INVOLVEMENT
Client	Rice Robotics Club	URC
Users	Rice Robotics Club	URC
Design Team	Wheelders	EDES 120 Project

Contributor	Date	Hours

2.0 Prepare 20 client interview questions (ref Workbook page 17):

1	Can you give us an introduction to the competition that you are competing in, and what are some of the basic guidelines for Rover construction?
2	What is yalls expected budget and timeline for a prototype and solution, do we need to hasten our efforts to have the wheel ready for something like a qualifier for the competition?
3	What wheel design systems have you looked into before? What is yall's reasoning behind your 6 wheel design as opposed to more or less wheels on the rover?
4	You mentioned in your presentation that other teams within the competition use non-pressure wheels, what's a popular trend or design you see among the other competitors? What are their strengths and weaknesses?
5	What do you see as the most important functions the rover wheels must accomplish during the competition?
6	How easy should it be to replace or repair a wheel in the field?
7	How would you prioritize between speed, durability, cost, and maneuverability?
8	What diameter/thickness are we looking for?
9	How does the part that connects to the wheel look like, can we get its deminsions, and its CAD design?
10	What was the thinking behind a wheel based system as opposed to a track based rover?
11	What materials are in common use among other competitors in the competition?
12	How heavy of a payload do you expect to carry for the rover?
13	Do you have any idea what percent of the overall weight the wheels should be?
14	What speeds and pressures do the wheels need to handle?
15	What are some common problems with other teams' wheels?
16	Are there specific terrain types (sand, gravel, rocks, slopes) that concern you more than others?
17	What are some common problems with other teams' wheels?
18	What is the most important feature of the wheel?
19	Are we expected to design the hub for the wheel, or the stokes, or just the outer part?
20	What materials are banned/supported in the competition?

Contributor	Date	Hours

Link full interview questions and responses (right click, smart chips, file): https://docs.google.com/document/d/1EVB-gLgPmVP5xv69bDuHJDMN3beIEKG8oPTA6K9pWqM/edit?usp=drive_link

3.0 Organize Team

Select Team Name:	Wheelders
Set up Team Email:	wheelders2025@gmail.com | EDES120odek77005
Register for an OEDK worktable.	

Contributor	Date	Hours

3.1 List Team Members, Client, and other Stakeholders contant information:

Name and Role	Email	Phone
Antony Saleh	as610@rice.edu	346-298-5570
Connor Gumbs	cg162@rice.edu	305-321-4199
Hongyu Guo	hg68@rice.edu	346-932-3804
Luke Van Leeuwen	lv35@rice.edu	281-223-6693

Contributor	Date	Hours

3.2 Create a Doodlepoll and set a weekly team meeting:

Day of Week	Time	Location
Monday	6:00 PM	OEDK Conference Room

3.3 Take a team photo and label each member:

Figure, From left to right: Antony, Hong, Luke and Connor

4.0 Project Summary

Who is your client? What is the context and background of the problem? What are your client's objectives as it relates to this project?

The Rice Robotics Club is participating in the University Rover Challenge (URC). This is their first year participating in the competition and thus they are trying to construct an initial design to participate. The objective our client holds for our project is to make a non-pressurized Mars Rover Wheels that will perform well in the Delivery Challenge which has a diverse amount of rough terrain that the rover must navigate over.

Contributor	Date	Hours

Describe your client's/user's challenge. What are they trying to accomplish and what are the limitations they currently face? What devices have they tried, and why are they not sufficient? What devices are on the market, and why do they not meet your client's needs?

Rice Robotics needs a set of rover wheels that let a 50 kg rocker-bogie rover complete the URC Delivery mission across Mars-like terrain (soft sand, gravel, rocky/ boulder fields, steep/loosely consolidated slopes and vertical drops). Constraints: rover mass limit (50 kg), six-wheel rocker-bogie geometry, no air-breathing/pneumatic solutions preferred (non-pressurized), extreme temperature tolerance, easy field replacement, low cost and manufacturability with limited resources. Current temporary wheels are low-performance and don't provide reliable traction, durability, or ease of replacement for competition conditions.

Contributor	Date	Hours

What would a newly designed device allow your client/user to accomplish? What would the impact of this be for them?

A new device (wheels) would allow them to replace their temporary wheels, which are on the lower end of performance. This could allow their rover to be more competitive, which could allow them to place better in the competition, and this success could bring the club more engagement from the Rice community with the club.

Contributor	Date	Hours

What functions or features (e.g., power, size, safety) would your client/users like to see incorporated into potential design solutions?

The client listed some features of the wheels that they would like to see. This includes: traction on steep sandy inclines, easily replaceable, easily fabricated, durable, interchangeable, low weight, nonpressurized, and similarity to already well-established designs that have proven to be effective.

Contributor	Date	Hours

Summarize other key findings from the project proposal and client interview that were not already mentioned in the prior responses.

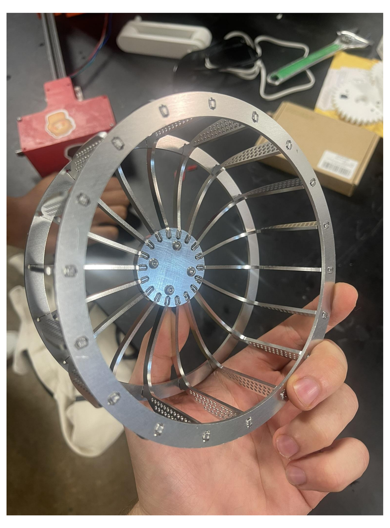
This Rover will be competing in the URC competition. The wheels must be done around early December due to the qualifying event for the competition. Rice Robotics Chief Engineer encourages us to look at some more out there designs to consider when making our wheels. We may need to participate in a system acceptance review video for the competition, which is basically a long video where the whole design concept of the rover, including our part, the wheels, is explained. The rover for this competition does not exist yet, as it is also in development, but a similar rover that isn't eligible for this competition but shares similarities in the design is available to use for testing our wheels once made. The total rover weight is supposed to be 50kg, while our client didn't give us any specific parameters for our wheel weight, we should just be considerate with how much weight we make our wheels. The connection between the leg and the wheel is still in development, so our CAD design concept for the wheel should be flexible to adjust to whatever attachment our client decides on.

Contributor	Date	Hours

Insert images that describe your project and team (e.g. team logo, client logo, images that represent the problem, current or past solutions/status quo, users

WHEELDERS

RICE ROBOTICS CLUB - RICE ROBOTICS CLUB -



Contributor	Date	Hours

5.0 Define Team Mission and Problem Statements

Write a Team Mission Statement that succinctly states the overall purpose of your design project (1 sentence). See Handouts Prob_Statement_Accel and Mission_Statement.

Design a set of wheels for the rover that can be built under 500 USD for 6 wheels, have high maneuverability and traction, can stand extreme conditions, and can be easily replaced. The wheels we design can help the rover perform better on the delivery mission, where terrain is a huge obstacle. This will get Rice Robotics more points for the competition to better their chances at winning.

Contributor	Date	Hours

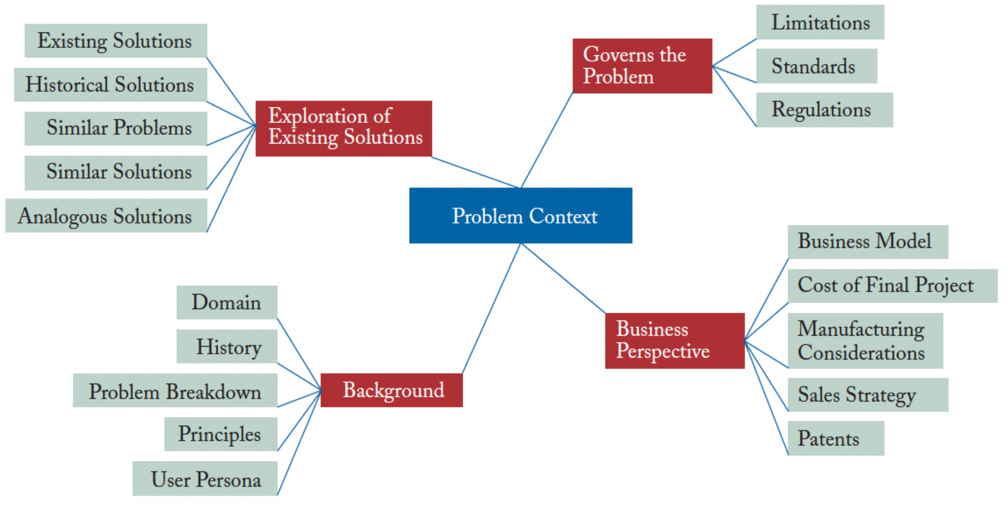
Write a Problem Statement that defines the problem and describes general points around which quantifiable design criteria will later be established (4-5 sentences). See Handouts available in Google Drive Prob_Statement_Accel and Problem Statement Instructions.

The Rice Robotics Club is preparing to participate in the University Rover Challenge (URC), where rovers travel on terrain that imitates conditions on Mars, such as soft sand, gravel, rocky slopes, and steep inclines. A wheel design that is lightweight, non-pressurized, easily fabricated, affordable, durable, and interchangeable has the potential to improve the rover's traction on difficult terrain, reduce the likelihood of failure, and allow for quick replacement, while maintaining high traction. Such a solution would enhance rover maneuverability and increase the chances of success in competition.

EDP Action 2: Understand Problem and Context

TASKS

1.0 Create a need-to-know-list: Identify a minimum of 30 unique research questions (ref Workbook pg 24 & 29). Focus on Exploring Existing Solutions category for over half.



	Research Question	Problem Context Quadrant	Assignee
1	How have previous competitors' rubbers wheels performed?	Exploring Existing Slns.	
2	How have previous competitors' metallic wheels performed?	Exploring Existing Slns.	
3	What are some of the most abstract wheel designs from past teams and what worked and what didn't?	Exploring Existing Slns.	
4	What wheel material designs and ideas have the most successful teams over the years used?	Exploring Existing Slns.	
5	What wheel material designs and ideas have been consistently the worst performing over the years?	Exploring Existing Slns.	
6	How are current teams making efforts to lower cost and weight of their wheels?	Exploring Existing Slns.	
7	Outside of the competition what have actual Lunar or Mars rovers utilized?	Exploring Existing Slns.	
8	What solutions have had critical fails or problems in the field?	Exploring Existing Slns.	
9	What is the history of the wheel design in regards to the Robotics Competition?	Background	
10	What are light materials that can handle the stress in the inner part of the wheel	Background	
11	What is a wheel, and what is the hisotry of the wheel?	Background	
12	What is traction, how does it work physically?	Background	
13	What is a method to maxmise traction in a wheel, what are the lossees?	Background	
14	How to make a wheel fast and simple to switch out?	Background	
15	What materials are wheels be made out of?	Background	
16	How does the radius of a wheel affect speed, weight and traction?	Background	
17	What is the maximum temperature the wheel will have to experience?	Background	
18	Are there any regualtions on pressure based wheels versus track based wheels?	Governs the Problem	
19	Are there any solutions that adhere to the competition rules but conflict with the goals /vision of the club	Governs the Problem	
20	Are there any wheel designs that do not adhere to the competition rules	Governs the Problem	
21	Are there any limitations for the size of each wheel?	Governs the Problem	
22	What are the reasons for the lack of good solutions?	Governs the Problem	
23	Are there any material related restrictions?	Governs the Problem	
24	How much is the material cost for each wheel?	Business Perspective	
25	What are some designs of wheels that have similar performance to the rover wheel on the existing market?	Business Perspective	
26	How many set of rover wheels should be produced to meet the needs of the Rice Robotics club?	Business Perspective	-
27	How much is the labor cost for each wheel?	Business Perspective	
28	How much will the manufacturing cost be for existing designs on the market or designs similar to rover wheels?	Business Perspective	
29	What are some types of design or material that can maximize the performance of the wheel while minimizing the cost?	Business Perspective	
30	Is the performance of the wheel directly proportional to the cost for the existing designs on the market?	Business Perspective	

Contributor	Date	Hours
Deirdre Hunter	*Jan 4, 2025*	*0.5*

2.0 Narrow the list to the 16 most critical questions to research (*for a 5-person team, 20 questions and for a 3-person team, 15 questions*) [Highlight these questions above.]

Balance the questions between (8) Exploration of Existing Solutions and (8) in the other three problem context spaces (Governs the Problem, Business Perspective, Background).

Speak with instructors and DM to identify the focus of your research and review questions

Critical research questions vary among projects, some might need more background knowledge while others have applicable regulations which are critical to understand.

3.0 Complete the DCR tables, 1 question per table with a minimum of 1 source, some questions might require multiple sources. Research must relate back to the problem and project. Please organize the DCRs by topic, not by author! 5-person teams will need to make additional copies of this table below.

All team members should review each others DCRs.

Research Question	Outside of the competition what have actual Lunar or Mars rovers utilized?	
Team Member	Antony Saleh	Relevant Images
Research	The Mars Rover appears to have an aluminium tire with wedges allowing for more traction; however, over the long term, the wheels have suffered damage, causing cracks and holes in the metal[1]. NASA plans to send the Perseverance rover, which will also use aluminium; however, the wheels will have a thicker diameter[3]. There is some research into the applicability of "Shape Memory Alloys" [2], which, when under specific conditions, return to their original shape, allowing them to handle more stress and strain without losing their shape.	
Citation(s)	[1] A. Rankin, N. Patel, E. Graser, J. Freddy Wang, K.Rink, Assessing Mars Curiosity Rover Wheel Damage. Jet Propulsion Laboratory, California Institute of Technology, 2022. [2] NASA, Mars 2020: Perseverance Rover – Wheels and Legs, Jet Propulsion Laboratory, California Institute of Technology, Jul. 22, 2025. [3] S. Lilly, NASA Sets Sights on Mars Terrain with Revolutionary Tire Tech. NASA, 2025	
Most significant learning & Why, in 1 sentence.	Aluminimium is the material most commonly used right now for the Mars Wheels, this is important to take as an example for our design as aluminium is light but can handle stress	

Contributor	Date	Hours

Research Question	What are some of the most abstract wheel designs from past teams and what worked and what didn't?	
Team Member	Luke Van Leeuwen	Relevant Images
Research	The OSU team (top image) uses abnormally large wheels made of a polymer composite with strips of rubber for some added traction. This larger and chunkier wheel design yielded them a 1st place finish in the 2024 Canadian international finals. This could be a design that we take influence from; they are using a non-pressurized wheel system. However, our client seems to be more interested in metal-based wheels than rubber ones like this. The Sooner Rover team (bottom left) uses a cone-like wheel design with a multiple-jointed rover. This design got them invited to compete against the top 34 teams. Despite their rover's success with rough terrain in a video on their website, the concept of this design is not replicable by us because it would require a complete rover redesign, which extends beyond our influence on the Rice Robotics team. The West Virginia University team (bottom right) uses the most abstract design from what I've seen in the competition. They use a star design with a flattened tip of the star with a rubber tread on it. This design is very strong at grabbing onto large obstacles and pulling their rover up. It has yielded them amazing results in the worldwide competitions: 1st 2023, 2nd 2024, and 2nd 2025. This design is extremely promising and hasn't been done by many other teams, so I'd designate using it as an influence on our design as a high-risk, high-reward option. Across all of these designs, they all attract more attention from the selection committee that chooses which teams are going to be invited to the competition.	
Citation(s)	[1]"Rover," Osurobotics.club, 2017. -(accessed Sep. 11, 2025). [2]"Sooner Rover Team," Ou.edu, 2024. https://ou.edu/soonerrover/ (accessed Sep. 11, 2025). [3]"University Rover Challenge Team | Home," Wvu.edu, 2024. https://urc.orgs.wvu.edu/ (accessed Sep. 11, 2025)	
Most significant learning & Why, in 1 sentence.	The abstract wheel designs can perform at a high level, and they attract more attention from the selection committee, meaning that you are more likely to be invited to participate in the regional and international competitions.	

Contributor	Date	Hours

Research Question	What is traction, how does it work physically?	
Team Member	Connor Gumbs	Relevant Images
Research	Traction is the frictional force between a wheel (or track) and the ground that enables motion without slipping. It depends on the normal force (the rover's weight pressing down on the wheel) and the coefficient of friction between the wheel material and terrain. On loose surfaces like sand or gravel, traction is also influenced by how well the wheel can interlock with the particles and prevent them from shearing under load. The greater the surface contact area and the more effective the tread or grousers at engaging the soil, the more traction the rover achieves. However, if too much slip occurs, wheels can dig in and lose effectiveness, so traction is a balance between grip and controlled slippage[1][2].'	
Citation(s)	[1] M.A. Elsheikh, "Design of a special rigid wheel for traversing loose soil," Scientific Reports, 2023. https://www.nature.com/articles/s41598-022-27312-6 [2] J. Ding, A. Moussa, H. Li, "Slip-Based Traction Control of a Planetary Rover," Springer Lecture Notes in Control and Information Sciences, 2006. https://link.springer.com/chapter/10.1007/3-540-36268-1_59	
Most significant learning & Why, in 1 sentence.	Traction is the frictional interaction between wheels and terrain, and understanding it is critical because it directly determines whether our rover can climb slopes and maneuver effectively without getting stuck.	

Contributor	Date	Hours

Research Question	What are some designs of wheels that have similar performance to the rover wheel on the existing market?	
Team Member	Hongyu Guo	Relevant Images
Research	There is a similar design from Georgia Tech's Robonav team. They shared the basic structure of the rover, which will also be used to engage in the University Rover Challenge. Specifically, they changed the rover chassis from the common six-wheel rocker-bogie system, which is a NASA's typical suspension arrangement used in many different Mars rovers, to a four-wheel rocker system. Some benefits of it are reducing weight, lowering complexity, and mitigating potential failure points. [1]	
Citation(s)	[1] I. Pinto and Z. Gan, "Design and fabrication of a Mars rover four-wheel rocker system," 2025 Regional Student Conferences, 2025. [Online]. Available: https://arc.aiaa.org/doi/10.2514/6.2025-94707	
Most significant learning & Why, in 1 sentence.	Low-cost 3D printing can be used first for prototyping. After the structure is proved to be strong and endurable enough, use carbon fiber and metal to produce the final design.	

Contributor	Date	Hours

Research Question	Are there any material related restrictions?	
Team Member	Connor Gumbs	Relevant Images
Research	The University Rover Challenge 2025 (previous years rules) include several material-related restrictions on rovers. Air-breathing propulsion systems are prohibited to simulate Mars conditions, meaning no combustion engines or systems that ingest ambient air for energy. Any chemicals used onboard must be pre-approved and follow a strict no-spill containment policy, with hazardous materials requiring detailed safety plans for transportation, usage, and disposal. Beyond these specific restrictions, rovers must be capable of withstanding extreme desert conditions including temperatures up to 100°F, high winds, and dust storms.[1]	
Citation(s)	[1]"Requirements & Guidelines," University Rover Challenge. [Online]. Available: https://urc.marssociety.org/home/requirements-guidelines. [Accessed: 11-Sep-2025]	
Most significant learning & Why, in 1 sentence.	Air breathing systems are not allowed meaning the wheel designs need to be more abstract.	

Contributor	Date	Hours

Research Question	What wheel material designs and ideas have the most successful teams over the years used?	
Team Member	Antony Saleh	Relevant Images
Research	It seems that the involvement of rubber is a crucial part of adding traction to the design, while some teams have a rubber core and metal outsides such as Talos by S&T Missouri [1], other teams have a rubber core surrounded by metal parts such as the Sooner Robotics team by Oklahoma University [2]. Or even a full rubber body such as BYUs Rover[3]. Notabely, teams varry in whether they use rubber or metal, how much they use and how heavy that causes the wheels to be.	

Contributor	Date	Hours

Citation(s)

[1] Mars Rover Design Team, Talos. Missouri S&T, 2025.
[2] The Mars Society, University Rover Challenge, Oklahoma University.
[3] BYU Mechanical Engineering, BYU Mars Rover. BYU, 2023

Most significant learning & Why, in 1 sentence.

Rubber is a very crucial part in adding to traction and is common in most winning designs

Contributor	Date	Hours

Research Question

How does the radius of a wheel affect speed, weight and traction?

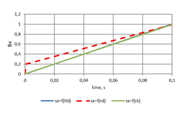
Team Member

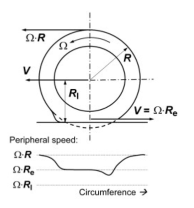
Luke Van Leeuwen

Research

A larger radius allows the vehicle to cover more ground per revolution, increasing speed at the same wheel RPM. Under load, the larger tire deforms, and tire deformation reduces the radius slightly, which shows the effect of weight on the wheels. The radius difference increases vehicle stability. In terms of traction, the friction–slip curves from [1] show that the larger wheel deformation will increase, and this will increase contact area which will lead to more traction.

Relevant Images





Citation(s)

[1] Balakina, Ekaterina & Lipatov, Evgeniy & Sarbayev, D.. (2020). Advantages of Using Wheel Rolling Radius for Calculating Friction Characteristics in Wheel-to-Road Contact Patch. 10.1007/978-3-030-22041-9_107.
[2]R. He et al., “Updated Standards of the International Society for Terrain-Vehicle Systems,” Journal of Terramechanics, vol. 91, pp. 185–231, Oct. 2020, doi: https://doi.org/10.1016/j.jterra.2020.06.007.

Most significant learning & Why, in 1 sentence.

A bigger wheel radius means better speed, weight, and traction only when the wheel material allows for a certain amount of tire deformation to increase the area of contact between wheel and surface.

Contributor	Date	Hours

Research Question

What is a method to maxmise traction in a wheel, what are the lossees?

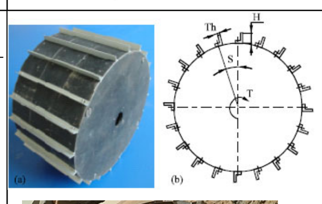
Team Member

Antony Saleh

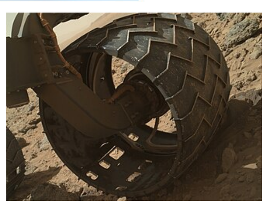
Research

A common method of increasing traction which can be seen in many of the robot designs used in the competition in addition to the Lunar Wheel Design Optimisation[1] is adding grousers to the wheel, this allows for the grousers to get stuck in sand/gravel providing more friction and thus traction with the floor. The grousers however, need to have edges which allow for extra traction in order for the wheels to not slip on flat ground. One example could be using rubber tipped grousers.

Relevant Images



(a) (b)



Citation(s)

[1] Q. Michalski, D. Downing, M. Leary, J. Dash, M. Watson, R. Das, P. Jessadatavornwong, J. Kenrick, K. Doyle, B. Nichols, G.E. Dorrington, Lunar Wheel Design Optimisation. RMIT University, Lunar Outpost Oceania, RocketLab, 2019. ISBN: 978-1-925627-90-9.

Most significant learning & Why, in 1 sentence.

Grousers are a very strong addition to our wheel design which allows them to gain more traction.

Contributor	Date	Hours

Research Question

How have previous competitors' metallic wheels performed?

Team Member

Luke Van Leeuwen

Research

The 2025 URC world champion team, the Missouri University of Science and Technology, used a predominantly rubber design, but used metal to make multiple tips to the wheels that gave this extra grip and durability on difficult terrain. The University of West Virginia team has mainly metal wheels, but with rubber tipping for added grip. This yielded them a 2nd-place finish in 2025; however, they took 1st place in 2023 with the same design. The top teams from 2025 and previous years all have metallic wheels in some sense, but the most successful teams have been the ones that blend both rubber and metal materials together.

Relevant Images

Citation(s)

[1]“Mars Rover Design Team,” Mars Rover Design Team, 2025. https://marsrover.mst.edu/ (accessed Sep. 14, 2025).
[2]“University Rover Challenge Team | Home,” Wvu.edu, 2024. https://urc.orgs.wvu.edu/ (accessed Sep. 14, 2025).
[3]Team Info, “Team Info,” Marssociety.org, 2025. https://urc.marssociety.org/home/team-info (accessed Sep. 14, 2025).

Most significant learning & Why, in 1 sentence.

The most successful teams aren't the ones that use just rubber-based or just metal-based based but blend the 2 together.

Contributor	Date	Hours

Research Question

What solutions have had critical fails or problems in the field?

Team Member

Connor Gumbs

Research

Two teams at URC have reported significant wheel issues in the field: Brigham Young University’s report of the 2024 competition notes that their rover suffered three wheels falling off during the event, forcing on-the-spot fixes and affecting mission performance. Cal Poly team’s 2023 design report documents that their initial 3D-printed PLA wheels lacked sufficient traction and durability on the desert course, so they replaced them with store-bought plastic wheels with rubber tires to avoid failures in the field. Both examples illustrate two common failure modes at URC, wheels detaching and material/traction failures.

Relevant Images

Citation(s)

[1] BYU College of Engineering, “Mars Rover Team places 3rd at University Rover Challenge,” BYU Engineering News, Jun. 27, 2024. [2] T. Impassability (Cal Poly team), “ME 2023 F56 FDR” (team Final Design Report — notes wheel replacement due to PLA wheel traction/durability issues), Cal Poly DigitalCommons, 2023.

Most significant learning & Why, in 1 sentence.

The most important point is the robustness of the wheel attachment and appropriate wheel material/traction are both critical to the mission, because a detached wheel or a wheel with insufficient traction can immediately halt a rover’s ability to complete tasks under timed competition conditions.

Contributor	Date	Hours

Research Question

What are some designs of wheels that have similar performance to the rover wheel on the existing market?

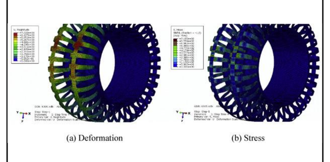
Team Member

Hongyu Guo

Research

A "flexible metal wheel” is an alternative to air-filled tires for rovers under heavy loads. The design introduces a novel idea by using a flexible geometry to allow some elastic deformation while keeping stiffness and strength high enough so that the heavy loads will not permanently deform the wheel. This design is optimized for durability, which is more cost-effective over time.[1]

Relevant Images



(a) Deformation (b) Stress

Citation(s)

[1] M. Zou, Y. Gao, Z. Zhan, J. Zhang, and S. Li, “Design and mechanical behavior evaluation of flexible metal wheels for crewed lunar rovers,” Acta Astronautica, vol. 177, pp. 659–670, 2020. doi: 10.1016/j.actaastro.2020.08.001.

Most significant learning & Why, in 1 sentence.

This design explored a design that focuses on the idea that the more durable the wheel, the less often it will need to be replaced or repaired. That reduces maintenance/replacement costs over time.

Contributor	Date	Hours

Research Question

What are some types of design or material that can maximize the performance of the wheel while minimizing the cost?

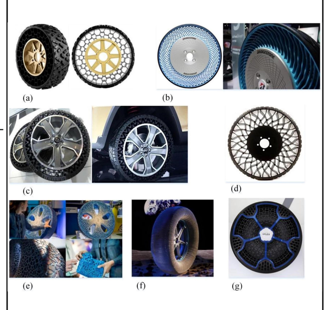
Team Member

Hongyu Guo

Research

Generally, a new design called Non-pneumatic tyres provides the wheel with puncture resistance by using elastic support structures instead of air, However, their service lives are generally shorter compared with traditional tyres. Conventional tyres last about 50,000 km, while Tweel-type NPTs average 6,000 km, mechanical elastic wheels 7,700 km, and multi-spoke NPTs up to 23,000 km. However, considering that the rover involved in the competition does not require a long service life, NPTs are still a feasible solution. Manufacturing methods of NPTs vary: centrifugal casting produces strong, low-cost polyurethane NPTs, while 3D printing (e.g., FDM or SLS) enables rapid prototyping and complex geometries but differs in cost and performance—FDM is cheaper but weaker, SLS is stronger but expensive.[1]

Relevant Images



(a) (b) (c) (d) (e) (f) (g)

Citation(s)

[1] J. Zeng, Z. Chen, Q. Jin, and Q. Ma, “A comprehensive review on non-pneumatic tyre research,” Materials & Design, vol. 227, p. 111661, Mar. 2023. doi: 10.1016/j.matdes.2023.111661.

Most significant learning & Why, in 1 sentence.

The review’s quantitative fatigue-durability benchmark gives a clear comparison between different wheel structures, which helps to predict the downtime and replacement cost

Contributor	Date	Hours

Research Question

How much will the manufacturing cost be for existing designs on the market or designs similar to rover wheels?

Team Member

Hongyu Guo

Research

A similar rover wheel design for the NASA Human Exploration Rover Challenge emphasizes low cost and the use of locally available materials, and they provided a clear material price list. The main structure of the wheel combines alloy steel tubes, thin steel sheets, and an outer truck-tire rubber layer. Performance tests showed it could sustain a 2000 N static load and withstand a 5 m drop, with overall weight about 28 kg, though issues such as traction and deformation on soft terrain remained. The detailed cost breakdown shows the material expenses: tubes ($32), L-section steel ($12), outer rubber ($29), plus machining ($16), welding ($12), and hub ($16), for a total of $117 per wheel. This transparent costing illustrates how design choices affect both performance and affordability.[1]

Relevant Images

Citation(s)

[1] F. Rashid, M. A. Hossain, M. M. Rahman, and A. H. M. S. Iqbal, “Design, simulation and manufacture of wheel for human exploration rover,” in Proc. Int. Conf. Mechanical, Industrial and Materials Engineering (ICMIME), Rajshahi Univ. of Eng. & Tech., Rajshahi, Bangladesh, Dec. 2019, pp. 1–6.

Most significant learning & Why, in 1 sentence.

The standout feature is the “local manufacturability + low-cost materials” strategy, which provides a practical pathway for reference.

Contributor	Date	Hours

Research Question

How are current teams making efforts to lower cost and weight of their wheels?

Team Member

Connor Gumbs

Research

Current URC teams are lowering the cost and weight of their wheels through material choice, integration, and optimization. Utah State University’s Adventure Rover project reduced rover mass by 12 kg by adopting inflatable wheels and redesigning wheel hubs to house gearboxes internally, which eliminated excess brackets and lowered material usage [1]. Similarly, the Boston University Mars Rover Team uses finite element analysis (FEA) to optimize wheel and axle designs, removing unnecessary material and simplifying motor mounts to cut weight while staying within the competition’s 70 kg limit [2]. These strategies show how lighter, simpler wheel systems can both save costs and improve overall rover performance.

Relevant Images

Citation(s)

[1] Utah State University, “USU URC Adventure Rover,” Senior Design Projects, Mechanical & Aerospace Engineering, 2023. [Online]. Available: https://engineering.usu.edu/mae/students/senior-projects/fall2022-spring2023/projects/usu-urc-adventure-rover.php
[2] BU Mars Rover Team, “BU Mars Rover Team: Rover Development,” Gilbert’s Webpage Blog, 2023. [Online]. Available: https://www.gilbertswebpage.com/post/bu-mars-rover-team-rover

Most significant learning & Why, in 1 sentence.

ntegrating lighter wheel structures (such as inflatable designs or optimized hubs) is critical because wheel systems account for significant mass and cost, directly affecting rover durability and compliance with strict URC weight limits.

Contributor	Date	Hours

Research Question

How have previous competitors' rubbers wheels performed?

Team Member

Antony Saleh

Research

It is obvious that the use of rubber in wheels is a major factor in the success of top teams. In Fact, as can be seen by the Mars Rover Design Team [1], in the competition last year, they were able to achieve one of the highest scores for the Delivery mission (a score of 70[2]), which involved traversing different difficult terrains. However, Teams that commit to a 3D printed design, such as the ARES2025[3] Team, achieved a score of 0 on the Delivery mission. Thus, it can be seen that designs that do not use rubber to some extent face difficulties in the delivery mission.

Relevant Images

Citation(s)

[1] Mars Rover Design Team, Talos. Missouri S&T, 2025.
[2] URC2025 Scores, University Rover Competiton, The Mars Society, 2022
[3] Our Rover, ARES 8, Tohoku University, 2025

Most significant learning & Why, in 1 sentence.

The use of rubber is correlated with better performace.

Contributor	Date	Hours

Research Question

What wheel material designs and ideas have been consistently the worst performing over the years?

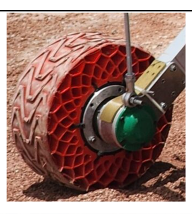
Team Member

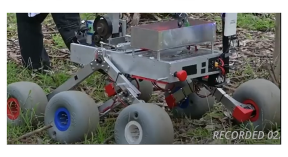
Luke Van Leeuwen

Relevant Images

Research

The consistently worst-performing team in Yildiz University. The use of a rubber design with a mesh structure. This design resulted in non-durable wheel, which also has minimal traction. The mesh design they use struggles because objects such as sand and small rocks get lodged in the gaps and cause the wheels to be damaged or not function as intended. The next worst performing team in Yonder Dynamics from UCSD. They use an all rubber wheel that is smooth. This design has wear problems on rough terrain so they have to replace wheels a lot as well as the wheel not providing ideal grip on surfaces.





Citation(s)

[1]URC2025 Scores, “URC2025 Scores,” Marssociety.org, 2025. https://urc.marssociety.org/home/about-urc/urc2025-scores (accessed Sep. 14, 2025).
[2]Y. Rover, “Yıldız Rover | YTU Interdisciplinary Robotics Team,” Yildiz.edu.tr, Sep. 17, 2019. https://rover.yildiz.edu.tr/ (accessed Sep. 14, 2025).
[3]“Yonder Dynamics,” Yonderdynamics.org, 2025. https://yonderdynamics.org/#/ (accessed Sep. 14, 2025).

Most significant learning & Why, in 1 sentence.

The worst wheel designs use only rubber materials and are either more oversimplified or overcomplicated than the wheels should be.

#VALUE!

4.0 Synthesized Summary

Identify the top 4 to 7 most significant learnings from your team's research. Summarize these learnings and why it is important to understanding the problem. 1 to 2 paragraphs.

From our research, we learned that traction is a key factor in rover mobility, relying on a balance between wheel-soil interaction and controlled slippage to prevent digging in or loss of motion. We have further discovered that the most common method of increasing traction is the use of rubber in wheels. However, some alternative options could be the use of grousers. Throughout the competition, though, the most successful teams are the ones that have used both metal and rubber materials together, and that some far-out designs work, such as Missouri University of Science and Technology's wheel design work but that most of the top teams take a standard wheel design approach. We also discovered that for the delivery mission that having a larger radius wheel would be beneficial. The tradeoffs of this are, of course, increased weight and cost to produce a bigger wheel, but the larger radius improves not only speed but also the ability to scale large objects such as rocks and hills in the delivery mission. On the business side, we learned that the standout feature of the “local manufacturability + low-cost materials” strategy provides a practical pathway for reference. Besides, Low-cost 3D printing can be used first for prototyping. After the structure is proven to be strong and endurable enough, we can start to produce the final design. We also found that common field failures at URC include wheels detaching and wheels made from weak or poorly chosen materials, which directly compromise performance. These findings highlight the importance of designing wheels that maximize grip on loose terrain while also being durable and securely attached, since failures in either area can stop a rover from completing its mission. The successful combination of both rubber and metal materials in the wheel is a significant design trend among the top teams, so we should follow this example in some regard. It has helped these teams improve durability, traction, and maneuverability performance in the difficult delivery mission.

Contributor	Date	Hours

EDP Action 3: Define Design Criteria

TASKS

1.0 Complete the Design Criteria Table (ref Workbook pg 41)

NOTE: Determine which criteria are Constraints and Objectives; Set quantifiable values (with units); justify the criteria and value.

NOTE: A reasonable list of design constraints is typically 1–2 and objectives is typically 4–7. Delete unused rows.

Design Criteria Table

	Criterion	Target Value (units)	Justification
Constraints	Regulations	Be eligible	Must follow regulations established by the URC rulebook
	Replaceablity	< 1 min per wheel	The wheels should be consitent in taking a minimal time to replace
	Durability	Handles 75 kg	Handles the maximum weight outlines in the regulations
	Size	~ 9.5 Inches	As requested from the Rice Robotics team
	Traction	> 62N per wheel	Minimum force for robot have the grip to be able to move under the 50kg rover weight + 10kg mission package on a steep incline (30 degrees)
	Weight	~ 6 pounds per wheel	As requested from the Rice Robotics team
	Coolness	Values from UDS	Wheel design should resemble rice and look menacing
	Replicability	Values from UDS	Amount of effort taken to assemble another wheel using the design

Contributor	Date	Hours

2.0 Complete a User Defined Scale (UDS) for any DC which needs a user-defined scale to capture feelings or opinions. (ref Workbook pg 49)

Table, Coolness

Level	Attribute
1	People feeling Boring with the design of the rover wheel
2	When looking at the rover, people tend to focus more on the wheels
3	The design of the wheels are memorable, and the decoration stands out
4	People start to chat and discuss the wheel, and they started to compare it with other team's design
5	People start to take photos, calling their friends or other teams to come and see the unique design

Contributor	Date	Hours

Table, Replicability

Level	Attribute
1	People feel exhausted and give up from replicating the rover wheel
2	People spending large amount of effort trying to figure out the structure of the design inorder to replicate
3	Eventhough it takes a some time, replicating the wheel is still feasible
4	The design is relatively easy to replicate, assembling the wheel does not take much time
5	The wheel is modular in structure. The parts can be easily obtained and can be assembled in a short time.

Contributor	Date	Hours

3.0 Complete a Pairwise Comparison Chart (PCC) to rank your DC Objectives. Add more rows/columns if needed. (ref Workbook pg 59)

	Replace	Dura	Weight	Traction	Cool	Size	Replica	Total
Replace	–	0	1	0	1	1	0	3.0
Dura	1	–	1	0	1	1	1	5.0
Weight	0	0	–	0	1	1	0	2.0
Traction	1	1	1	–	1	1	1	6.0
Cool	0	0	0	0	–	0.5	0	0.5
Size	0	0	0	0	0.5	–	0	0.5
Replica	1	0	0	0	1	1	–	3.0

Co	Date	Hours

3.1 Show the rank of your DC Objectives

Table, DC Objectives

Rank	Objective
1	**Traction**
2	**Durability**
3	**Replicability**
3	**Replaceablity**
5	**Weight**
6	**Size**
6	**Cool**

4.0 Design Critieria Conclusions

Introduce your Design Criteria Table, describe how many criteria were developed, what motivated and/or guided these criteria and their values. This can be summative, yet descriptive. Highlighting key examples. (Do not reguritate the above tables.) (LUKE)

Our Design Criteria Table has 8 criteria that we identified as important for the success of our project. These criteria, in order from most important to least important, are traction, durability, replicability, replacability, weight, size, and coolness. We designated traction as our most important factor (score: 6.0) because, for the delivery mission, it is the most important factor playing into the success of the wheels. If the wheels don't have sufficient traction, then the rover will not be able to navigate the rough terrain in the given time, resulting in a damaging score towards the performance of the Rice rover team. Second, we designated durability as important (score 5.0) but a bit below traction in terms of criticality. If the wheels are durable, they do not need to be replaced often, therefore saving money and manufacturing time. Durability will also be important during the competition itself, as the wheels will need to survive the forces and wear applied to them during missions. Following this, we have replicability and replacability as medium to high importance criteria (scores: 3.0). The Rice Robotics club needs to be able to easily replicate and then replace the wheels on the rover so that the team can function self-sufficiently without needing us to make the wheels and attach it for them. Also, in the field during competition, the wheels need to be easily replaceable in case something happens to them, so that the team doesn't miss any events while spending time replacing wheels. Following this weight (score: 2.0) and size (score: 0.5) are both lower priority because they are not directly regulated in any way by the competition or by Rice robotics. The weight would be better if it were on the lower end because the rover does have a maximum weight limit of 50kg, so the less we take of that, the better, but we don't want to sacrifice any performance in pursuit of this. Size is purely a trade-off criterion, as a bigger wheel will be faster but more expensive and heavier, and a smaller wheel is cheaper and lighter but slower. Next is coolness, which we also designated as low priority (score: 0.5). We would like our wheel to be interesting and perhaps have something to make it stand out, but we aren't willing to sacrifice much, if anything, to do this. Lastly, a criteria that we designated in our Design Criteria table but did not include in our Pairwise Comparison Chart is regulations. We did not include this since it is a constraint that we must satisfy. If our wheels break regulation rules then the robotics team will not be able to use them at all.

Contributor	Date	Hours

For each UDS table, describe how the attibutes were choosen to describe a range of feelings/opinions that define your DC and what target value was choosen and why.(Hong)

Generally, we designed two User-Defined Scales: Coolness and Intimidation, and Replicability. For coolness and Intimidation, the range was chosen from 1 to 5 in order that people would not be attracted by the design and decoration on the wheel, to that people would start to take photos of the wheel, discuss the design of the wheel, or even be a bit nervous to compete with our team with this rover having an intimidating wheel design. Our target value is around 3.5, as we expect people to be attracted by the design. However, more effort should still be put into the structure of the wheel instead of the decoration. For replicability, the range of feeling is also from 1 to 5, and the attribute was ranked from people feeling exhausted and giving up trying to replicate the wheel to the wheel being modular in structural design, the parts can be easily obtained locally, and the whole wheel is easy to assemble. Our target here is to aim for a level of 4.5 to 5 because modularity is relatively important in assembling the wheel, and we hope that our design helps the robotics team achieve success in the URC competition.

Contributor	Date	Hours

State concise and applicable key points about how your team ranked the DC criteria. How will the selected DC guide the team to meet the needs of the problem statement?(Add regulation in order to compete must etc)

We ranked the design criteria based on what was important to our client. In this case, this meant traction was the top priority because it directly affects the rover's ability to move and complete tasks. Durability was next, as we need wheels that can withstand the terrain of the competition. Replicability and replaceability are also important so that the team can easily produce or swap out wheels when needed. In order to compete, the wheels must also abide by all competition regulations. Weight, size, and coolness are lower priorities, which will allow us to focus on the criteria that have the biggest impact on performance and practicality. By prioritizing these factors, our wheel design will support the team in having reliable, functional, and easy-to-replace wheels for the competition.

Contributor	Date	Hours

EDP Action 4: Brainstorming

TASKS

1.0 Spend 10 to 15 minutes decomposing your problem into design blocks (ref Workbook pg 67). (double click diagram to edit, add block, rename, etc…)

- Rover Wheels
  - Inner Tyre
    - Spoked
    - Full center
    - Hollow Center
  - Outer Tyre
    - Made of rubber
    - Made of metal
    - Has grousers
  - Handles diverse terrain
    - Durable
    - Tractive
    - Stable

Contributor	Date	Hours

1.1 In one paragraph, summarize Features and Functions. Be descriptive in how you describe each one and the interaction/connection between them.

Our rover wheel concept combines structural flexbility along with durability, using a core that could either be hollow for lightness or solid for added strength. It could include an outer layer made of rubber for traction or aluminum for toughness. Grousers would be added to the surface to increase grip on slope terrain, and the shape would be round to ensure stable rolling. Since the wheel cannot be pressurized, it can't pop or crack, but must remain lightweight, yet strong enough to support the rover's weight.

Contributor	Date	Hours

2.0 Brainstorming Round 1, set 45 minute timer use the slip method (ref Workbook pg 74)

How much time did you spend for round 1 brainstorming?	20 minutes
How many total ideas did your team generate?	87 ideas
After sharing ideas, how many unique ideas did your team generate?	80 ideas

Contributor	Date	Hours

2.1 Categorize Round 1 brainstormed ideas by design block, function, features, or comparable ideas, etc… Capture images of the brainstormed ideas either individually or by category. Ensure images are well lit, clear, and legible, then post images below!

Note: for each categorized group of images, add a caption that describes the grouping and range of ideas. [insert more rows if needed]

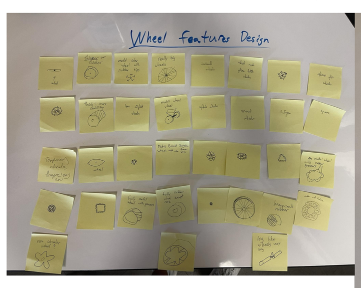


Figure 1: Grouped these ideas as Wheel feature designs. This group is all of the more common design ideas in terms of what we think of as a wheel now. These ideas range from being a simple bike like wheel to wheels that have complicated spoke and grouser designs.

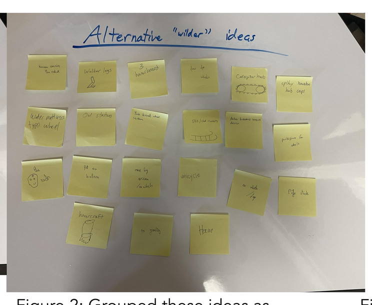


Figure 2: Grouped these ideas as Alternative/wilder wheel ideas. This group has more atypical wheel designs or designs that aren't wheels at all. We have ideas ranging from tank treads to walker legs and much more.

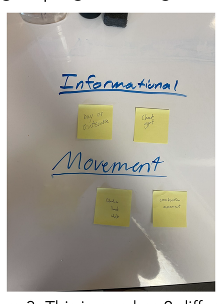


Figure 3: This image has 2 different groups of ideas in it. The first group, informational, represents the ideas we had in the ways we will learn more about designing and manufacturing our wheel outside of our research. The second group, Movement, represents the ideas we had to elicit movement from the tires or other alternative movement methods. Ranging from typical treads to a combustion reaction producing movement. We have decided to move away from the design block name in the picture and change it to Modes of movement.

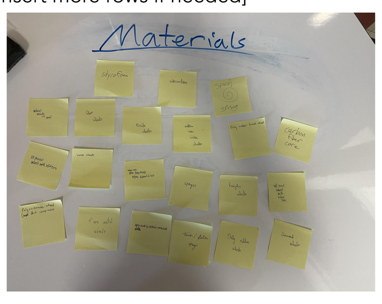


Figure 4: Grouped these ideas as varying Material ideas. This group consists of all of the different materials we could think of to use to make the parts of our wheel such as the core, spokes, grousers, treads, inner wheel, and outer wheel. These ideas range from cheap and weaker materials like styrofoam to strong and expensive materials like carbon fiber.

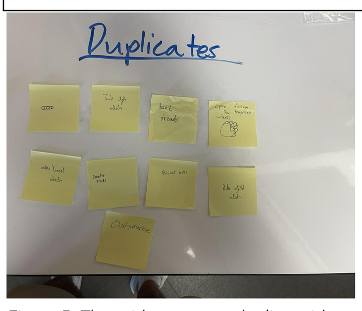


Figure 5: These ideas are our duplicate ideas from across the other 4 groups.

2.2 Reflect on Round 1. How many ideas were generated in each category? What gaps are there in either breadth or depth of ideas across all design blocks? What should your team focus on in Round 2 of brainstorming and what strategy will you employ to fill gaps and increase breadth and depth?

In total the team had: 35 ideas which correlated with a wheel's feature design, 21 ideas correlated with alternate idea to a wheel, 2 ideas related to informational analysis of the wheel, 2 ideas dedicated to ways the wheel can move. 21 ideas for different materials we can use within the wheel, and 9 duplicates. Giving us a tota of 88 ideas. Upon further thought we realised we had not included wheel manufcaturing, thus this will be part of our agenda for the next brainstorming session. Morever, our team felt that we could generate some more ideas in regards to materials. We were satisfied with the results in regards to different feature ideas as there was plenty of diverse designs from spoked cores, to grousers, to cone shaped wheel. Our team will look into applying the same level of creativity onto the other categories in the next brainstorming session.

Contributor	Date	Hours

2.3 Brainstorming Round 2, set 45 minute timer use any method you team prefers (ref Workbook pg 74)

How much time did you spend for round 2 brainstorming?	10 minutes
How many total *new* ideas did your team generate?	20 ideas
After sharing ideas, how many total unique ideas did your team generate, combining both rounds?	20 ideas

Contributor	Date	Hours

2.4 Add Round 2 brainstormed ideas by to your previous grouped ideas Capture new images of the brainstormed ideas either individually or by category. Ensure images are well lit, clear, and legible, then post images

Note: for each categorized group of images, add a caption that describes the grouping and range of ideas.

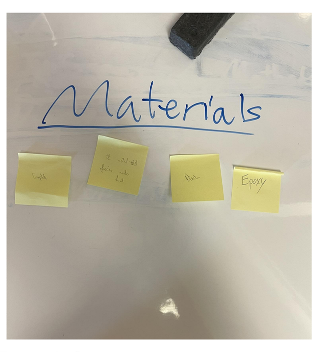


Figure 6: Grouped these ideas as varying Material ideas. This group of new materials that we brainstormed consists of more diverse and far out ideas than what we brainstormed in our first session. These materials will be used to make the core and the inner and outer part of our wheels. This new set ranges from cheap and weaker plastic to expensive and stronger metals.

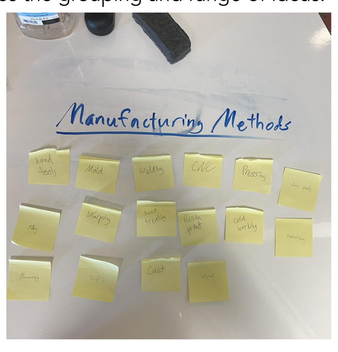


Figure 7: Grouped these ideas as manufacturing method ideas. This group consists of all the ways that we have brainstormed to make our wheel. These ideas range from CNC machining to methods as simple as just using hand tools.

3.0 Brainstorming Summary

In a paragraph, describe your brainstorming process and results, be quantitative and specific in your description. (i.e. goal for each round, how many rounds, how much time in each round, how many total ideas from each round, how ideas were sorted in each round, name of the groupings/categories (specify if a grouping is for complete or componet/partial ideas), number of unique ideas in each, how were overlapping or repeated ideas handled?)

Throughout the entire brainstorming process, there are a total of two rounds. For the first round, we spent 20 minutes generating ideas about the rover wheels that came to mind. After the end of the first round, we had a total of 88 ideas. All the ideas are sorted into 5 main parts: wheel's feature design, alternative idea to a wheel, informational analysis of the wheel, ways the wheel can move, and different materials we can use within the wheel. The wheel feature design category contains complete ideas, and all the other categories contain partial ideas. We sorted duplicated ideas into one separate part. In the second round, we focused more on methods of wheel production and materials. We spent 10 minutes brainstorming and generated 20 new ideas. The ideas were sorted into materials and manufacturing methods. Overall, we have a sufficient diversity of wheel designs in two brainstorming rounds, and the unique ideas contributed to our selection of design, ways to manufacture, and types of materials.

Contributor	Date	Hours

Where did inspiration for the ideas come from (i.e. any connections to first 3 steps of EDP)

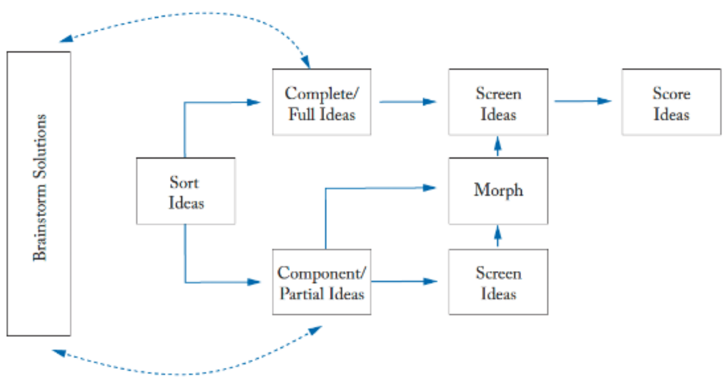
The inspiration for our ideas came from a combination of research and direct feedback from our client. Earlier in in EDP, we gathered information about the problem and explored possible solutions and also researched what failed. So, some of our ideas were inpsired by research into existing rover wheels and technologies, while others were thought of with features the client wanted and did not want in mind. This combination helped us guide our brainstorming toward solutions that were both practical and aligned with the client's needs.

Contributor	Date	Hours

EDP Action 5: Evaluating Ideas

TASKS

1.0 Follow the flowchart for engineering decision making (ref Workbook pg 91)



2.0 Pugh Screen your partial brainstormed solutions on the tab PUGH SCREENING PARTIAL (ref Workbook pgs 85 & 91). ONLY if there are 5 or more solutions in one design block.

Category of Partial Ideas	Number of Intial Ideas	Number of Ideas After Screening
Manufacturing Methods	16	5
Materials	25	4
Modes of movement	23	1
Movement	2	2

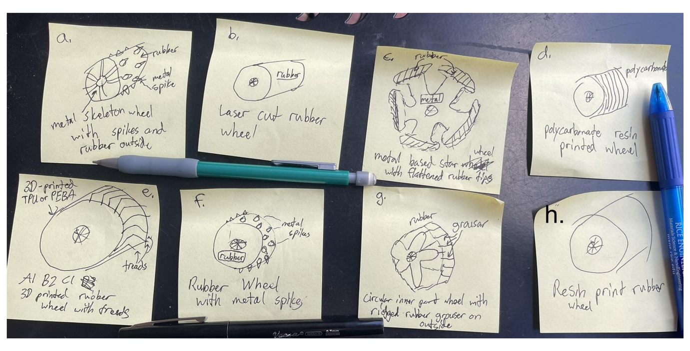
3.0 Morph your partial ideas into complete ideas using the tab MORPH CHART (ref Workbook pg 95 & 99).

How many complete ideas did you generate with your Morph Chart? 25

4.0 Pugh Screen your 30 to 50 complete ideas down to 5 to 10 solutions in the tab PUGH SCREENING COMPLETE IDEAS (ref Workbook pg 85 & 91).

Category of Complete Ideas	Number of Intial Ideas	Number of Ideas After Screening
Morphed Ideas	25	4
Complete Brainstormed	35	4

5.0 Draw detailed and labeled sketches of each of your 5 to 10 screened ideas. Post them here and give each one a name in the caption



Sketch a: Metal skeleton wheel with metal spikes and a rubber outside
Sketch b: Laser cut rubber wheel
Sketch c: Metal star shaped wheel with flattened rubber ends
Sketch d: Polycarbonate resin printed wheel
Sketch e: 3D printed rubber wheel with tire treads
Sketch f: Rubber wheel with metak spikes
Sketch g: Circular inner part wheel with ridged rubber grousars on outside
Sketch h: Resin printed rubber wheel

6.0 Develop scoring matrices, and proxies if needed, for each Design Criteria using the tab PUGH SCORING (ref Workbook pg 103).

7.0 Pugh Score your 5-10 ideas down to 1 or 2 ideas on the tab PUGH SCORING (ref Workbook pg 102 & 109).

Identify the rank of your top scoring ideas

1	rubber wheel with metal spikes
2	A1 B2 C1 3D Printing + Only Rubber Wheel + Tire treads
3	metal star wheel with flattened rubber tips
4	A2 B2 C2 Resin Print + Only Rubber Wheel + Combustion Movement
5	metal-based skeleton wheel with spikes and rubber outside
6	circular inner part wheel with ridged rubber grouser on the outer side
7	A4 B2 C2 Laser Printing + Only Rubber Wheel + Combustion Movement
8	A2 B1 C2 Resin Print + Polycarbonate Wheel + Combustion Movement

8.0 Recreate the Engineering Decision Making flowchart, shown in 1.0 above, only include the steps/path you followed, include the number of ideas before and after each action.

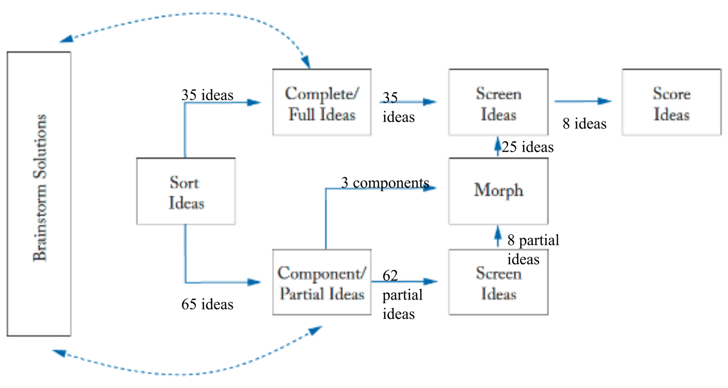


Figure. [Our engineering Decision making flowchart]

8.1 Describe the screening process, explain the results and key features that helped distinguish between solutions. Discuss the number of ideas, full or partial, you started with and the number of ideas you had after screening. Desrcibe any salient process decisions that were made during screen (e.g. choosing not to evaluate a D.C., modifying D.C., not screening a particular category, etc.)?

Our screening process spanned 3 days during this time we narrowed down 100 initial brainstormed ideas to 8 solutions that advanced to the scoring phase. We started by sorting our ideas into two categories. The first category was complete/full ideas and we had 35, and the second category was partial/component ideas and we had 65. We then spread partial ideas across four design blocks. Manufacturing methods had 16 ideas, materials had 25 ideas, modes of movement had 23 ideas and movement types had 2. Then, we screened these partial ideas against our seven design criteria: traction, durability, replicability, replaceability, weight, size, and coolness factor. This initial screening reduced our partial ideas to 12 options. We ended up with 5 manufacturing methods, 4 materials, 1 mode of movement, and we kept both movement types. A decision we made was not to screen the movement category, because we wanted to keep both combustion-based and vibration-based movement (tire treads). The "modes of movement" category underwent the most aggressive screening, we reduced 23 ideas to just one (normal wheels), which indicated a clear winner on this design element. We then used a morph chart to combine the 12 screened partial ideas into 25 complete solutions, which we added to our original 35 complete ideas, resulting in a total of 60 complete ideas. After screening these 60 complete ideas, we reduced them down to eight solutions. Four solutions were from morphed combinations and the other four from brainstormed ideas. Some of the features that distinguished successful solutions from eliminated ones were their performance on critical criteria, such as durability and replicability, as well as manufacturing feasibility through methods like 3D printing and molding. Additionally, the material selection favored polycarbonate wheels and rubber-based options that balanced traction while keeping weight in mind. This approach allowed us to evaluate a large quantity of ideas while making sure the most promising concepts advanced based on measurable design criteria rather than our subjective preferences.

8.5 Describing your Scoring Process. Identify your selected design(s) and explain why this design scored highest. What key features or functions that helped distinguish between solutions (i.e. Design components that influenced scoring either higher or lower)? How did features of your process heavily influenced solution selection (e.g. design criteria weighting, quantified 1-5 values)? What salient process decisions were made during solution selection (e.g. choosing not to score a D.C., modifying D.C., etc.)? Reference the scoring table.

Overall, we evaluated eight wheel designs using the Pugh screening method to sort out complete ideas and partial ideas. We weighted the criteria by mission priorities: traction 25%, durability 25%, replicability 20%, replaceability 15%, weight 5%, size 5%, and "coolness" 5%. The most important factors are durability and traction, which will help the team to succeed in the URC competition. Then, the replicability and replaceability are a bit less important. Lastly, the weight, size, and coolness are weighted the least because they are not crucial in determining the wheel's performance. Each criterion was rated on a scale of 1–5, multiplied by its corresponding weight to obtain a weighted score, and then summed to determine the total score. The first winning design is the rubber wheel with metal spikes, with the highest score of 3.6. It wins not by maximal traction score, but because it combines top durability from the combined use of rubber and metal with high coolness and replicability while keeping replaceability, mass, and size at a relatively acceptable value. The main feature that affects the score was durability and replicability. Among combined partial ideas, A1 B2 C1: 3D-printed rubber wheel + tire treads placed second on high traction and replicability, but was weakened for durability.

Morph Chart -- EDP Action 5: Evaluation of Design Solutions

TASK

3.0 Morph your partial ideas into complete solutions (ref Workbook pg 95 & 99).

Add more

Design Block	Option 1		Option 2		Option 3		Option 4		Option 5	
Manufacturing Method	3d Printing	A1	Resin Print	A2	Mold	A3	laser printing	A4	Pressing	A5
Materials	Polycarbonate Wheel	B1	Only rubber wheel	B2	Off-road wheel with rubber tires	B3				
Movement	Combustion movement	C1	Vibration based wheels	C2						
Alrernative Designs	Normal wheels	D1								

3.1 Draw sketches of each of your morphed ideas, include them below with captions.

1	A1	B1	C1	A1 B1 C1	3D Printing + Polycarbonate Wheel + Tire Treads
2	A1	B2	C2	A1 B2 C2	3D Printing + Only Rubber Wheel + Combustion Movement
3	A1	B3	C1	A1 B3 C1	3D Printing + Off-Road Wheel with Rubber Tires + Tire Treads
4	A1	B1	C2	A1 B1 C2	3D Printing + Polycarbonate Wheel + Combustion Movement
5	A1	B2	C1	A1 B2 C1	3D Printing + Only Rubber Wheel + Tire Treads
6	A2	B3	C2	A2 B3 C2	Resin Print + Off-Road Wheel with Rubber Tires + Combustion Movement
7	A2	B1	C1	A2 B1 C1	Resin Print + Polycarbonate Wheel + Tire treads
8	A2	B2	C2	A2 B2 C2	Resin Print + Only Rubber Wheel + Combustion Movement
9	A2	B3	C1	A2 B3 C1	Resin Print + Off-Road Wheel with Rubber Tires + Tire treads
10	A2	B1	C2	A2 B1 C2	Resin Print + Polycarbonate Wheel + Combustion Movement
11	A3	B2	C1	A3 B2 C1	Mold + Only Rubber Wheel + Tire treads
12	A3	B3	C2	A3 B3 C2	Mold + Off-Road Wheel with Rubber Tires + Combustion Movement
13	A3	B1	C1	A3 B1 C1	Mold + Polycarbonate Wheel + Tire treads
14	A3	B2	C2	A3 B2 C2	Mold + Only Rubber Wheel + Combustion Movement
15	A3	B3	C1	A3 B3 C1	Mold + Off-Road Wheel with Rubber Tires + Tire treads
16	A4	B1	C2	A4 B1 C2	Laser Printing + Polycarbonate Wheel + Combustion Movement
17	A4	B2	C1	A4 B2 C1	Laser Printing + Only Rubber Wheel + Tire treads
18	A4	B3	C2	A4 B3 C2	Laser Printing + Off-Road Wheel with Rubber Tires + Combustion Movement
19	A4	B1	C1	A4 B1 C1	Laser Printing + Polycarbonate Wheel + Tire treads
20	A4	B2	C2	A4 B2 C2	Laser Printing + Only Rubber Wheel + Combustion Movement
21	A5	B3	C1	A5 B3 C1	Pressing + Off-Road Wheel with Rubber Tires + Tire treads
22	A5	B1	C2	A5 B1 C2	Pressing + Polycarbonate Wheel + Combustion Movement
23	A5	B2	C1	A5 B2 C1	Pressing + Only Rubber Wheel + Tire treads
24	A5	B3	C2	A5 B3 C2	Pressing Off-Road Wheel with Rubber Tires + Combustion Movement
25	A5	B1	C1	A5 B1 C1	Pressing + Polycarbonate Wheel + Tire treads

x

TASK 2.0

Pugh Screen your partial brainstormed solutions (ref Workbook pgs 85 & 91). ONLY if there are 5 or more solutions in one design block. In the caption describe the data and results of each matrix.

Duplicate the tables below if you need to screen more than one design blocks and/or have more than 10 ideas in one design block. Make sure each matrix has a descriptive caption that serves as a brief, yet complete, explanation of the data, written as full sentences, tell the reader what to look for, and clearly indicate what results are shown in the context of the work.

he prior to + or - symbol so that sheets sees it as text and not an operator

Table 5.2.0, [Manufactoring methods]

Design Crieria	Hand Tools	Recylcing	Cold Working	Welding	Heat Treating	3d Printing	Resin Print	Cnc	Hammering	Milling	Warping	Mold	Laser Printing	Pressing	Woodworking	Cast
traction	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
durabilty	-	-	+	0	+	-	-	0	0	0	0	-	0	0	-	-
replicability	+	-	-	+	-	+	+	0	+	0	-	+	+	+	+	+
replaceabilty	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
weight	0	0	0	0	0	+	+	0	0	0	0	0	+	0	+	0
size	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
cool	-	-	0	-	0	+	+	0	-	0	0	+	0	0	-	0
SUM/TOTAL	-1	-3	0	0	0	2	2	0	0	0	-1	1	2	1	0	0
RANK	t-4th	t-5th	t-3rd	t-3rd	t-3rd	t-1st	t-1st	Standard	t-3rd	t-3rd	t-4th	t-2nd	t-1st	t-2nd	t-3rd	t-3rd
CONTINUE						Yes	Yes					Yes	Yes	Yes		

Table 5.2.1, [Materials]

Design Crieria	Molten iron inside the wheel	Polycarbonate Wheel	brick wheel	styrofoam	Carbon Fiber Core	watermelon	tension/flexion spring	Only rubber wheel	Diamond Wheel	Pinjata wheels	Off-road wheel with rubber tires	Pure Metal Wheels	sponges	Wheel with Non-Pheumatic tyres	3D printed wheels with solid tires	water wheels	Wheel made of steels	glass wheels	Plastic	Organic Materials	spiral Spring	Graphite	Metals that fix under heat
traction	0	+	-	-	0	-	0	+	-	-	+	0	-	0	0	0	0	-	0	0	0	0	0
durabilty	-	-	+	-	+	-	+	+	+	-	0	0	-	0	-	-	0	-	0	-	-	0	+
replicability	-	+	-	+	-	+	-	+	-	0	+	0	+	0	+	+	-	-	+	-	-	-	-
replaceabilty	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
weight	0	+	-	+	+	+	+	+	0	+	+	0	+	0	+	0	0	+	+	+	+	+	0
size	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
cool	+	+	-	-	+	-	+	0	+	-	0	0	-	0	+	+	0	-	0	+	+	-1	+
SUM/TOTAL	-1	3	-3	-1	2	-1	2	4	0	-2	3	0	-1	0	2	1	-1	-3	2	0	0	1	1
RANK	t-6th	t-2nd	t-8th	t-6th	t-3rd	t-6th	t-3rd	t-1st	t-5th	t-7th	t-2nd	t-5th	t-6th	Standard	t-3rd	t-4th	t-6th	t-8th	t-3rd	t-5th	t-5th	t-4th	t-4th
CONTINUE		Yes						Yes			Yes												

Table 5.2.2, [Modes of movement]

Design Crieria	Normal Wheels	Fans For Wheels	Sled Runners	Caterpillar Tracks	Tank Based System	Owl Statues	Hoverboards	Walker Leg	Human Carried	Hovercraft	No Gravity	Ham	Pogo Stick	Legs	Porcupines For Wheels	Airless Basketball Hexagrid Design	Spikey Houston Hub Caps	The Rock	Unicycle	Hot Air Balloon	Water Movement Boat	Water Mattress Type Wheels
traction	0	0	-	+	+	-	0	0	0	0	0	-	-	0	+	0	0	0	-	0	0	0
durabilty	0	-	-	0	+	-	0	-	0	-	-	-	-	-	-	-	-	-	-	-	-	-
replicability	0	-	-	-	-	-	-	-	-	-	-	+	0	-	-	-	0	-	0	-	-	-
replaceabilty	0	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-
weight	0	0	0	-	-	-	-	0	-	-	0	+	0	0	+	+	+	-	-	-	-	-
size	0	-	-	-	-	-	-	0	-	-	0	-	-	0	0	0	0	0	0	0	0	0
cool	0	+	-	+	+	+	+	+	-	+	+	-	-	+	-	-	-	-	-	+	+	-
SUM/TOTAL	0	-3	-6	-2	-1	-5	-3	-2	-3	-4	-2	-3	-5	-2	-2	-2	-6	-5	-5	-3	-3	-5
RANK	Standard	t-3rd	t-6th	t-2nd	t-1st	t-5th	t-3rd	t-2nd	t-3rd	t-4th	t-2nd	t-3rd	t-5th	t-2nd	t-2nd	t-2nd	t-6th	t-5th	t-5th	t-3rd	t-3rd	t-5th
CONTINUE	Yes																					

Epoxy
-
-
+
0
+
0
0
0
t-5th

PUGH SCREENING COMPLETE -- EDP Action 5: Evaluation of Design Solutions

TASK

4.0 Pugh Screen your 30 to 50 complete ideas down to 5 to 10 solutions (ref Workbook pg 85 & 91). In the caption describe the data and results of each matrix.

Duplicate the tables below if you need to screen more than one design blocks and/or have more than 10 ideas in one design block. Make sure each matrix has a descriptive caption that serves as a brief, yet complete, explanation of the data, written as full sentences, tell the reader what to look for, and clearly indicate what results are shown in the context of the work.

Note: use an apostrophe prior to + or - symbol so that sheets sees it as text and not an operator

Table, [Brainstormed Complete Ideas]

Design Criteria	Current temporary wheels	square	spheres	circle with smaller circles around it	bike spoke wheel	honeycomb rubber/3d printed	rubber with holes/mesh	metal wheel with rubber grousers	fully rubber and flat wheel	full metal wheel with grousars	long log like wheels	square with small circles around it	lemon shaped wheel	sun shaped wheel	metal based skeleton wheel with spikes and rubber outside	wheel with rounded and pointed grousars
Traction	0	-	0	-	0	0	0	+	+	+	+	-	-	-	+	+
Durabilty	0	-	0	-	-	-	-	+	+	+	-	-	0	-	+	0
Replicability	0	+	-	-	-	+	+	0	0	0	-	-	-	-	0	0
Replaceabilty	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0
Weight	0	0	0	+	-	+	+	0	0	0	0	0	0	0	0	0
Size	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0
Cool	0	-	+	-	0	+	+	0	-	0	-	-	-	-	+	+
SUM/TOTAL	0	-2	-1	-3	-3	2	2	2	1	2	-3	-4	-3	-4	3	2
RANK	Standard	t-6th	t-5th	t-7th	t-7th	t-2nd	t-2nd	t-2nd	t=3rd	t-2nd	t-7th	t-8th	t-7th	t-8th	t-1st	t-2nd
CONTINUE															yes	

Table, [Morphed Complete Ideas]

Design Criteria	A1 B1 C1	A1 B2 C2	A1 B3 C3	A1 B1 C2	A1 B2 C1	A2 B3 C1	A2 B1 C2	A2 B2 C2	A2 B3 C2	A2 B1 C1	A3 B2 C1	A3 B3 C2	A3 B1 C3	A3 B2 C2	A3 B3 C1	A4 B1 C1
Traction	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-
Durabilty	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Replicability	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0
Replaceabilty	0	0	0	0	0	0	0	0	0	0	-	-	-	-	-	-
Weight	0	+	-	0	+	-	0	+	-	0	+	-	0	+	-	0
Size	0	0	-	0	0	-	0	0	-	0	0	-	0	0	-	0
Cool	0	+	0	0	+	0	0	+	0	0	-	-	-	-	-	0
SUM/TOTAL	0	-1	-3	-1	2	-4	0	1	-3	-1	-1	-6	-2	-3	-5	-2
RANK	Standard	t-3rd	t-5th	t-3rd	t-0th	t-6th	t-2nd	t-1st	t-5th	t-3rd	t-3rd	t-8th	t-4th	t-5th	t-7th	t-4th
CONTINUE					Yes			Yes								

oval wheel with spiked grousars	triangle wheel with rounded grousers	octagon wheel	circular wheel with 8 pointed grousars	wheel with metal spikes	side by side circular wheel	metal cone shaped wheel	thick rubber wheel	spoked bike wheel with spike grousars	bar wheel	thin rubber bike like wheel	metal star wheel with flattened rubber tips	large bike spoked wheel	windmill blade shaped wheels	wheel made from series of smaller wheels	circular inner part wheel with ridged rubber grosar on outer side	rounded star wheel	double spoked wheel
+	+	-	+	+	0	-	+	+	-	-	+	0	-	-	+	-	0
0	+	0	0	+	-	+	+	-	-	-	+	-	0	-	+	0	-
0	0	0	0	0	-	-	0	-	+	-	-	-	-	-	0	+	-
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	-	0	-	+	+	+	+	+	0	0	+	0	+
0	0	0	0	0	-	-	-	0	0	+	0	-	0	0	0	0	0
+	-	0	+	+	0	-	0	+	-	0	+	0	0	-	0	+	0
2	1	-1	2	3	-4	-3	0	1	-1	-1	3	-2	-2	-4	3	1	-1
t-2nd	t-3rd	t-5th	t-2nd	t-1st	t-8th	t-7th	t-4th	t-3rd	t-5th	t-5th	t-1st	t-6th	t-6th	t-8th	t-1st	t-3rd	t-5th
				yes							yes				yes		

A4 B2 C2	A4 B3 C3	A4 B1 C2	A4 B2 C1	A5 B3 C1	A5 B1 C2	A5 B2 C3	A5 B3 C2	A5 B1 C1
0	-	0	-	0	-	0	-	0
0	0	0	0	0	0	0	0	0
0	-	0	0	-	0	0	-	0
-	-	-	-	-	-	-	-	-
+	-	0	+	-	0	+	-	0
0	-	0	0	-	0	0	-	0
+	0	0	+	0	0	+	0	0
1	-5	-1	0	-4	-2	1	-5	-1
t-1st	t-7th	t-3rd	t-2nd	t-6th	t-4th	t-1st	t-7th	t-3rd
Yes						Yes		

PUGH SCORING -- EDP Action 5: Evaluation of Design Solutions

TASK

6.0 Develop scoring matrices, and proxies if needed, for each Design Criteria (ref Workbook pg 103).

Duplicate the table below for each DC

Table, [caption]

Design Criterion	Proxy	Scoring Matrix Rating	Description
Durabilty	Number of manufactured parts	1	Handles 30 kg
		2	Handles 40 kg
		3	Handles 50 kg
		4	Handles 60 kg
		5	Handles 75 kg

Design Criterion	Proxy	Scoring Matrrix Rating	Description
Weight	Mass per wheel	1	< 400g per wheel
		2	400-600g per wheel
		3	600-800g per wheel
		4	400-600g per wheel
		5	< 400g per wheel

Design Criterion	Proxy	Scoring Matrix Rating	Description
Replaceabilty	Number of tools required for wheel removal/installation	1	5+ tools
		2	4 tools
		3	3 tools
		4	2 tools
		5	1 tool

Design Criterion	Proxy	Scoring Matrix Rating	Description
Size	Wheel Diameter Size	1	> 350mm or < 80mm (extremes)
		2	300-350mm or 80-100mm
		3	250-300mm or 100-120mm
		4	200-250mm or 120-150mm
		5	150-200mm

Design Criterion	Proxy	Scoring Matrix Rating	Description
Replicabilty	Number of manufacturing processes required to make one wheel	1	6+ processes
		2	5 processes
		3	3-4 processes
		4	2 processes
		5	1 process

Design Criterion	Proxy	Scoring Matrix Rating	Description
Coolness Factor	Visual appeal and attention drawn based on design uniqueness	1	Unappealing or crude appearance; looks unfinished or poorly designedRetry
		2	Plain or generic design; minimal visual interest; purely utilitarian
		3	Clean, functional appearance; standard engineering aesthetic
		4	Notable visual appeal with unique features; interesting and polished appearance
		5	Highly distinctive and innovative design; immediately draws attention; memorable aesthetic

7.0 Complete 1-2 Pugh Scoring matrices to reduce your 8-10 ideas to 1 or 2 ideas (ref Workbook pg 102 & 109). In the caption describe the data and results of the matrix.

Make sure each matrix has a descriptive caption that serves as a brief, yet complete, explanation of the data, written as full sentences, tell the reader what to look for, and clearly indicate what results are shown in the context of the work.

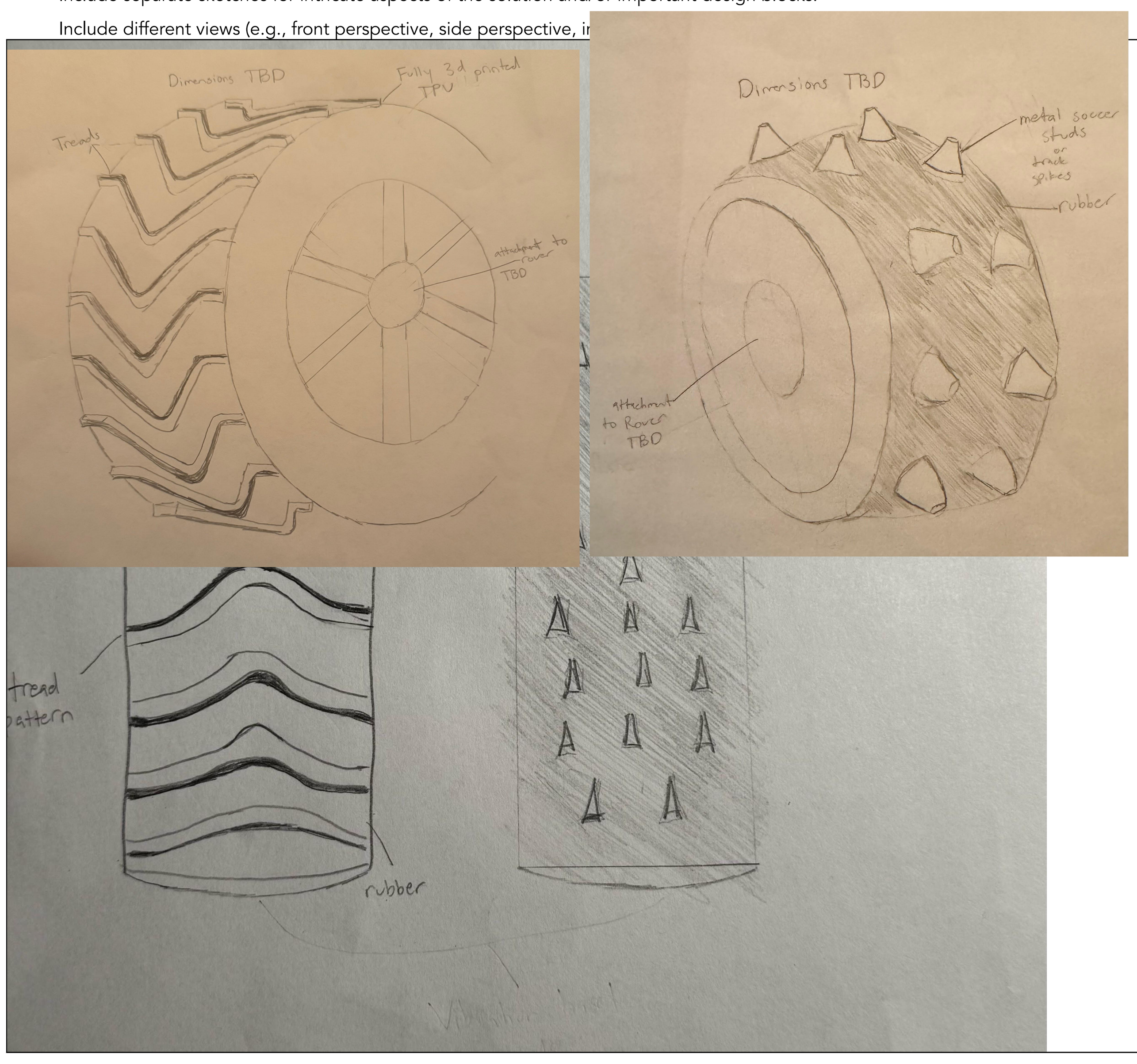
Table, Pugh Scoring Table

		Metal-based skeleton wheel with spikes and rubber outside		Rubber wheel with metal spikes		Metal star wheel with flattened rubber tips		Circular inner part wheel with ridged rubber grouser on the outer side		3D Printing + Only Rubber Wheel + Tire Treads		Resin Print + Only Rubber Wheel		Resin Print + Polycarbonate Wheel		Resin Print + Only Rubber Wheel	
Design Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Traction	25%	5	1.25	5	1.25	4	1	4	1	3	0.75	3	0.75	2	0.5	2	0.5
Durability	25%	3	0.75	3	0.75	3	0.75	3	0.75	4	1	3	0.75	4	1	4	1
Replicability	20%	2	0.4	3	0.6	3	0.6	3	0.6	4	0.8	4	0.8	4	0.8	4	0.8
Replaceability	15%	4	0.6	5	0.75	3	0.45	5	0.75	5	0.75	5	0.75	5	0.75	5	0.75
Weight	5%	3	0.15	3	0.15	4	0.2	3	0.15	5	0.25	4	0.2	4	0.2	4	0.2
Size	5%	4	0.2	5	0.25	4	0.2	4	0.2	2	0.1	3	0.15	3	0.15	3	0.15
Cool	5%	4	0.2	3	0.15	5	0.25	3	0.15	3	0.15	2	0.1	2	0.1	2	0.1
Total Score	100%	3.55		3.9		3.45		3.6		3.8		3.5		3.5		3.5	
Rank		4		1		6		3		2		5		5		5	

TASKS

1.0 Create a series of annotated sketches of your selected solution in detail. Include the following: (ref Workbook pg 127)

- Identify your design blocks in the sketch and label components
- Label dimensions for the overall solution and key features
- Call out attachments, joints, or fasteners required in your solution.
- Identify materials (i.e; wood, plastic, metal, felt, rubber, etc...).
- Identify components which will be purchased, i.e electronics.
- Include separate sketches for intricate aspects of the solution and/or important design blocks.
- Include different views (e.g., front perspective, side perspective, i



Contributor	Date	Hours

2.0 Create a flowchart which describes the serial flow of any function(s) the solution will perform, including electrical and software functions. (Luke)

Wheels are powered by a motor and motor receives signal from controller → Motor causes wheels to turn or rotate → Wheel's treads and spikes dig into the ground giving added traction with the surface

Contributor	Date	Hours

3.0 Identify user input and detail how a user will interact with the design, flow chart, diagram, or additional sketch encouraged.

The users will interact physically with the design by attaching and detaching the design from the larger rover. With a controller the user will interact with the design by sending speed and turning inputs. The motors on the rover will recieve the inputs and then this will perform an action on the wheel. The wheels will be pivotted and rotatated faster based on the inputs from the controller.

Contributor	Date	Hours

4.0 Describe how components will be manufactured and then integrated.

In regards to the 3D printed wheel, Firstly, we will produce the core of the wheel using a CAD design. This will be initially done using PLA as we are producing a medium fidelity prototype, then we will use adhesive to connect rubber treads onto the 3d printing design.

For the second design, we will purchase metal and build a wheel frame, then we will enguld and connect that with rubber. Finally, we will use adhesive to attach metal spikes to the rubber.

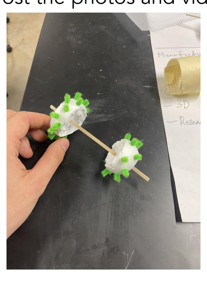
Contributor	Date	Hours

5.0 Identify any training your team will need to obtain and dates where possible.(Hongyu Guo)

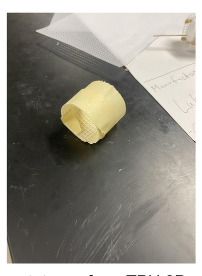
Regarding the training of equipment, we need to get trained for three of them: the 3D printer, laser cutter, and band saw. 3D printers will be used to print our CAD design of the wheel, a laser cutter will be helpful when processing the PLA wheel frame for the medium fidelity prototype, and the band saw is needed as we need to cut the metal to build the wheel frame for our high fidelity prototype. We need to get all the training done by November 7th, which is the day when we start to construct our medium fidelity prototype.

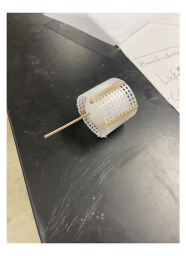
Contributor	Date	Hours

6.0 Create low-fidelity prototypes. Start with spending 1 hour or less where all teammates create their own prototype (ref Workbook pg 129). You may focus on a complete design or components. Take a photo of your prototype and record a short video where you describe what you have built. Post the photos and videos below with captions.



Lo-fi prototype of our rubber wheel with metal spikes, used styrofoam ball and used pipe cleaners for spikes





2 Lo-fi prototyes of our TPU 3D printed whels using plastic mesh as the wheel and rubber bands to simulate the treads

Contributor	Date	Hours

7.0 Reflect on your lo-fi prototypes (ref. Workbook pg 130). (i.e. category of prototype, strengths, weaknesses, goals of next iteration)

Our initial prototypes are visual prototypes, in order to cement what the wheel will resemble in our brain. Furthermore, they show the main features of the wheel and its main capability of holding our most important design criteria, traction. However, these models are uneven, which causes them to roll unevenly, this is a huge functionaility flow, and thus the next iteration will focus on making the design more functional. This will be done through 3D-printing to establish a medium fidelity prototype.

Contributor	Date	Hours

8.0 Reflecting on what you learned from your lo-fi prototypes. Describe how you will prototype the next iteration of key features and functions (to be completed for your prototype evaluation in 2 weeks). Envision and describe this next iteration of prototype as a low/medium fidelity that will move you towards high fidelity prototypes. A low/medium fideilty prototype might be different in scale, materials, or manufacturing methods from your envisioned final prototype. It may also be built by component and not integrated. Describe each task for building this next prototype, which team members will work on what tasks and estimate when each task will start and end and the estimated time on task. Keep in mind that the goal of each iteration is to gain insight into constructing higher fidelity prototypes of your solution.

	Key Feature or Function	Description of Next Iteration	Tasks	Task Owner	Time Frame
1	Wheel Structure	3D printed wheel made from PLA with proper mounting capability	Design CAD model, source PLA materials, create basic axle mount		2-3 Days
2	Functional Tread/Spike System	Develop a realistic tread or spike pattern that can be tested for traction usign materials closer to the final design	Source track spikes or metal soccer studs, design tread pattern, find adhesive to attach to wheel		3-4 Days
3	Scale Refinement	Move closer to intended final size and weight	Calculate dimensions, scale cad model to new dimensions		1-2 Days
4					
5					

Contributor	Date	Hours

EDP 6b : Prototype Solution- Iterations

TASK

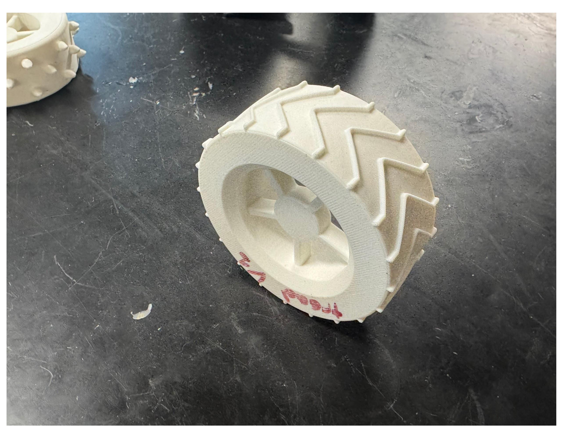
1.0 Document your prototype interations (ref Workbook pg 130 & 136)

Copy this table for each iteration of component or sub-system or overall integrated design

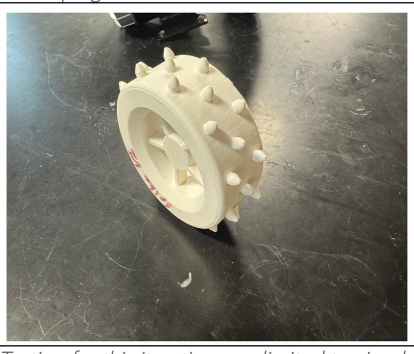
You may link documents that include more detailed information

Contributor	Date	Hours
Contributor		

Figure, [caption]

Iteration Wheel with Treads v1	*3D Printed PLA wheel design with treads not to scale*
Purpose of iteration ie: Increase durability	The purpose of this prototype was to test the initial wheel design and geometry at a small scale before developing a functional version
Prototype Visuals	
Testing Include testing design, validation, and results	*Testing for this iteration was limited to visual validation. The prototype was not full scale, so we focused on assessing the overall shape and tread concept rather than performance. This helped confirm that the general design was feasible before creating a functional, full-size version.*
Lessons Learned weaknesses, needed imrovements or refinements	*For our first 3D printed prototype we discuss possibly increasing the width of the wheel and the height and width of the treads to make the more prominent.*
Next Steps	Our next iteration of the wheel with treads is going to be another small scale wheel but printed with TPU instead of PLA to test the feasbiality of 3D printing with TPU as it can be hard to work with.

Figure, [caption]

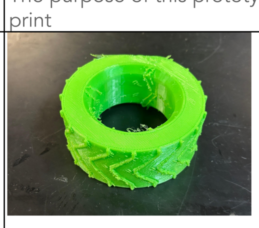
Iteration ie: Wheel with Spikes v1	*3D Printed PLA wheel design with treads not to scale*
Purpose of iteration ie: Increase durability	*The purpose of this iteration was to test the initial wheel design and geometry at a small scale before developing a functional version*
Prototype Visuals	
Testing Include testing design, validation, and results	*Testing for this iteration was limited to visual validation. The prototype was not full scale, so we focused on assessing the overall shape and spike concept rather than performance. This helped confirm that the general design was feasible before creating a functional, full-size version.*
Lessons Learned weaknesses, needed imrovements or refinements	From this prototype, we learned that the overall concept appears promising. However, the main challenge will be ensuring that the spikes stay embedded in the rubber, as durability may be a concern.
Next Steps	Are next iteration of the wheel with spikes, will be a full size functional prototpye, we ordered 9 inch solid rubber wheels and plan to drill holes into the rubber and insert socccer studs to act as the spikes.

Figure, [caption]

Iteration ie: Wheel with Spike v2	*To scale - solid rubber wheel with spikes*
Purpose of iteration ie: Increase durability	*The next iteration was a full-size rubber wheel where we drilled holes to insert soccer studs, allowing us to test traction and durability with real spikes*
Prototype Visuals	
Testing Include testing design, validation, and results	*The testing relied on ensuring the wheels are up to scale. We measured the wheel to be 8 inches in diameter, accurate to what the Rice Robotics team desires. In addition, we tested the durability of the spikes and their implantation intop the rubber by dropping the wheel from a height of 5 feet.*
Lessons Learned weaknesses, needed imrovements or refinements	*Something we learned from this iteration was the fact that the spikes seemed to stay in the rubber wheel without the use of adhesive, in our next iteration of the spike wheel we will use the same drill bit to ensure the same results.*
Next Steps	Test the traction of the spiked wheels on different terrains that will come up in the URC.

Figure, [caption]

Iteration ie: Wheel with Spike v1.5	*Not to scale - solid rubber wheel with dull spikes*
Purpose of iteration ie: Increase durability	The purpose of this prototype was to construct an intermediate wheel design between v1 and v2 at a larger scale by using a rubber wheel and dull metal studs as the material
Prototype Visuals	
Testing Include testing design, validation, and results	*Testing for this iteration was limited to visual validation. The prototype was not full-scale, and the metal spikes are not functional, so we focused on assessing the overall shape and spike concept rather than performance. This helped confirm that the general design was feasible before creating a functional, full-size version.*
Lessons Learned weaknesses, needed imrovements or refinements	From this intermediate prototype, we learned that the concept of attaching spikes to solid rubber wheels is feasible. However, the metal spikes of this version are dull, meaning that the spikes will not provide enough traction as we need. Therefore, we have to change the types of spikes to the ones with a sharper end.
Next Steps	Our next step will be constructing a full-size rubber wheel with sharper metal spikes. The soccer studs will be installed by drilling holes into the 9-inch solid rubber sheels.

Iteration Wheel with Treads v1	*3D Printed TPU wheel design with treads not to scale*
Purpose of iteration ie: Increase durability	The purpose of this prototype was to test the feasabilty of a TPU printed wheel before attempting a full size print
Prototype Visuals	
Testing Include testing design, validation, and results	*Testing for this iteration was limited to visual validation. The prototype was not full scale, so we focused on assessing the overall shape and tread concept rather than performance. This helped confirm that the general design was feasible before creating a functional, full-size version.*
Lessons Learned weaknesses, needed imrovements or refinements	*Our first 3D TPU printed prototype was not very refined the material seemed to have good traction but the print was not very successful*
Next Steps	Becuase we were not happy with the way the TPU wheel turned out we decided to focus soley on the wheel with spikes

EDP 6c: Prototype Solution- Refined Solution

TASK

1.0 Document your prototype interations (ref Workbook pg 130 & 136)

You will continue to document your interations of your prototype. Additionally there is space below to document the final refined prototyped solution.

Copy this table for each iteration of component or sub-system or overall integrated design

You may link documents that include more detailed information

Figure, [caption]

Iteration ie: Needle Holder v1	
Purpose of iteration ie: Increase durability	
Prototype Visuals	
Testing Include testing design, validation, and results	
Lessons Learned weaknesses, needed imrovements or refinements	
Next Steps	

Contributor	Date	Hours

2.0 Final Refined Prototype

Final Design Solution Sketches. Label dimensions for the overall solution and key features. Include multiple perspectives and seperate skectches for intricate components.

Contributor	Date	Hours

Final Prototype Solution Images. Include many images of your device from multiple perspectives and zoomed in on key features. Label the photos. Make sure the phtos are well lit.

Contributor	Date	Hours

Final Prototype Solution Demonstration Video. Include a video that demonstrates the prototype in action. Explain the the viewer all steps, action, components, features of the device.

Contributor	Date	Hours

What did this prototpye accomplish? What are the limitiations and areas for future work on the prototype (please try to be as reflective as possible)?

Contributor	Date	Hours

EDP Action 7: Testing Plan and Test Results of Refined Solution

TASK

1.0 For each Design Criteria, define a Testing Plan. (ref Workbook pg 149)

Table, Design Criteria Tests

Design Criteria and Target Value	Category of Test	How will the measurement be made?	How many times will the test be repeated?	Who will conduct the test? Will clients/users be involved?
Traction - Be able to scale a 6-20 degree sandy hill	Constructed - Surrogate	Put the rover wheel on an inclined plane covered by sand to simulate sandy terrain. Adjust the plane between 6-20 degrees and see if the static friction forces can hold the wheel on the inclined plane.	5 times	Luke, Connor, Antony, Hong
Durability - withstand a continued load of 60kg for a hour	Constructed - Direct	Drop the wheels from varius heights (Impact Testing from 10 to 50 inches increments of 10 inches)	3 times per height	Luke, Connor, Antony, Hong
Replicability - can construct a set of wheels within a week	Standard - Surrogate	Time it takes to 3D print a set of 4 wheels	1 time	Luke
Replaceability - takes less than a minute to change 1 wheel out	Standard - Surrogate	Measure the time taken (Using a stopwatch) to replace the wheel.	Conduct 20 runs.	Repeat the following for 20 people. Explain how to replace the wheels one time, make the tester remove and replace the wheel 3 concurrent times.
Weight - target .8kg	Standard - Direct	Use a scale to find the weight of each individual wheel.	3 times	Connor, Hong
Size - 125mm	Standard - Direct	Use a calliper to measure the diameter and width of each individual wheel.	3 times	Luke, Antony
Coolness - design standsout	Constructed - Surrogate	User-defined scale, done by some of the rice robotic students and some by random people.	The goal is 25 people.	Members of Rice Robotics and EDES 120 class

Contributor	Date	Hours

2.0 Which tests will be most critical to conduct on intermediate prototypes and how might they aide design decisions/iterations?

Durability, Replicability, and Traction will be the most critical tests to conduct. Starting with Durability, if our wheels cannot withstand a load of at least 50 kg, they will need to be redesigned, since that is the maximum weight of the rover. Next is Replicability. During competition, there is a chance that wheels could become damaged, so it is important that our wheels are easy to reproduce quickly and consistently. Finally, Traction is the most important test, as it will guide potential design iterations. For example, the results could lead us to explore different materials, tread patterns, or surface textures to improve grip and performance on various terrains.

Contributor	Date	Hours

3.0 Test Results Summary

Where applicable, you may link to other documents that contain full testing data.

Table, [caption]

Criteria	Target Value (units)	Justification	Summary of Test Results (color code these cells)
Durability	The wheels should survive being dropped from height of at least 30 inches 3x times	The test simulates the high-impact forces the wheel will experience during use on URC terrain. Dropping the wheel from a set height provides a simple, controlled way to evaluate its structural strength and identify potential failure points.	The wheels survived drops from 10 to 50 inches increasing by 10 inches Link to Drop Test Videos
Traction	The static friction forces should hold the wheel to a incline with maximum degree of 15	For a single wheel assembly of mass 3.40 kg (weight ≈ 33.3 N), the static friction forces required to hold the wheel in place on sand-covered ramps of 6°, 10°, 12°, and 15° are approximately 3.48 N, 5.79 N, 6.93 N, and 8.63 N, respectively.	

Contributor	Date	Hours

4.0 For any DC that was not met or was not tested, provide a reccomendation of how the prototype could be completed or changed such that it can be tested and meet each DC.

Contributor	Date	Hours

EDP 1 Clarify Assn	
Contributor	SUM of Hours
	0
Contributor	0
Grand Total	**0**

EDP 2 Understand Problem	
Contributor	SUM of Hours
	0
Contributor	0
Deirdre Hunter	0.5
Grand Total	**0.5**

EDP 3- Design Criteria	
	SUM of Hours
	0
Contributor	0
Grand Total	0

EDP 4- Brainstorming	
Contributor	SUM of Hours
	0
Contributor	0
Figure 5: These i	0
Grand Total	**0**

EDP 5- Evaluating	
	SUM of Hours
	0
Grand Total	**0**

EDP 5- Pugh Partial	
	SUM of Hours
	0
-5	0
-1	0
0	0
1	0
-	0
+	0
Graphite	0
t-4th	0
t-5th	0
Water Mattress T	0
Grand Total	**0**

EDP 5- Morph Chart	
	SUM of Hours
	0
Grand Total	**0**

EDP 5- Pugh Scr
square with smal
-6
-4
0
-
A3 B3 C2
t-8th
Grand Total

een Complete
SUM of Hours
0
-3
-4
0
0
0
0
-7

EDP 5- Pugh Scoring
SUM of Hours
3.5

EDP 6a- Prototype Concept	
Contributor	SUM of Hours
	0
	0
Contributor	0
Grand Total	**0**

EDP 6b- Prototype Iterations	
Contributor	SUM of Hours
	0
Contributor	0
Grand Total	**0**

EDP 6c- Refined Prototype	
Contributor	SUM of Hours
	0
Contributor	0
Grand Total	**0**

EDP 7- Test Solution	
Contributor	SUM of Hours
	0
Contributor	0
Grand Total	**0**