Paper Bike Challenge 2022

ME310 Paper Bicycle Design Document

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Team **Nastro Anyone?** (2.4)
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1 Front Matter

1.1 Executive Summary

For the 2022 Stanford Paper Bike Challenge, eight teams designed a Vehicle, constructed solely from paper and paper-like materials, capable of navigating the narrow streets of medieval cities. The bike was required to support one rider and could be propelled by a separate individual as depicted in Figure 1. To meet the requirements for the paper vehicle, the bike *Nastro Anyone?* was built. The vehicle featured two wheels with two long arms to mimic the stability, control, and maneuverability of a wheelbarrow. Each bike was tested on a simulated narrow town at Roble Field on two similar tasks:

1. Navigate a specific delivery route through the town as fast as possible.

2. Visit as many distinct delivery locations as fast as possible.

In addition to the three person team for the specific paper bike, there were two macro teams each with four bike teams. Each Macro Team worked together and communicated to avoid traffic jams in the congested simulated 1.5 m wide streets. Scoring was determined based on each team's race time with deductions for inaccurate tokens and bonuses for aesthetics.

Figure 1: The Final *Nastro Anyone?* Paper Bike.

The paper bike *Nastro Anyone?* was designed to not only be comfortable for the rider and propeller but to optimize the vehicle's performance with respect to the primary functional requirements: **maneuverability, durability, speed, and safety.** This translated into the vehicle's ability to make sharp turns quickly, maintain structural integrity when subject to the intense forces of the paper bike race, and keep the rider in the vehicle during rapid accelerations and decelerations. The construction of the Paper vehicle *Nastro Anyone?* in Figure 1 included a 500 gram limit on the use of Non-Paper products.

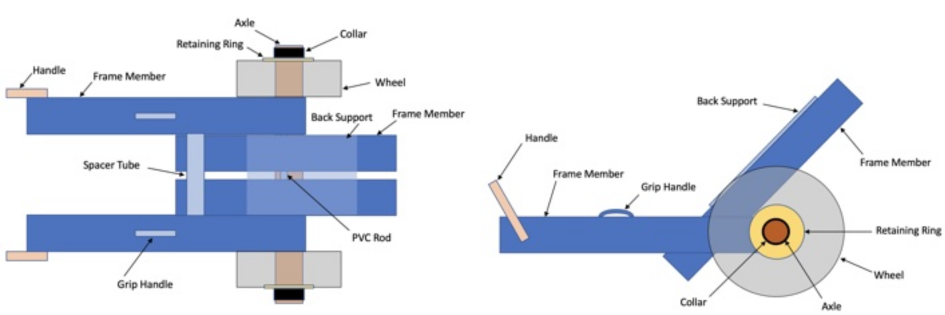

Figure 2: Top and Front Views of the *Nastro Anyone?* Paper Bike.

The key features of *Nastro Anyone?* may be observed in Figure 2. The bike has two wheels in order to facilitate facile propeller control. Since the propeller must lift the vehicle and carry a portion of the rider's weight while moving the rider's weight was kept directly above the Axle which ensured quick acceleration and lateral stability. Moreover, the rider sat leaning backwards with their legs above the horizontal axis. This made sure that during braking and turning, the rider doesn't fall off the bike. Additionally, grip handles were provided for the rider to hold during high speeds and turning. A pocket like cover, made of duct tape, was attached to the bike for collecting tokens at each point which was conveniently placed just between rider's legs. The aforementioned considerations led to the paper bike's eventual success as a reliable vehicle for navigating narrow city centers.

The paper vehicle *Nastro Anyone?* did not obtain significant damage during the bike race. The bike remained fully functional and was still able to perform as well as it could prior to the race. The team and bike were the runners-up in the overall bike rally.

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Glossary

Axle the long cardboard tube that supports and connects the two wheels. 3

Critical Functional Prototype (CFP) a model that aims to answer one or more critical questions relevant to the design. 14

Critical Question a question aimed to shed light on a specific design decision. 14

Deliverables our team meetings end with deliverables, a sort of homework assignment we must individually complete in preparation for the next team meeting. 12

Macro Team a combination of four Paper Bike Teams that communicated with each other to enhance collective performance with respect to the opposing macro team. 2

Non-Paper comprises all materials that are non-paper. Screws, duct tape, PVC tubing, etc. must weigh less than a combined 500 grams. 2

Paper all paper-based materials such as paper, cardboard, tissue paper, or paper tubing. 2

Roble Field a small outdoor field that is relatively flat on the Stanford Campus. 2

Team High Five the team's ritual, signifying the completion of a milestone, based off the Japanese "Tejime", which is a Japanese custom of ceremonial rhythmic hand clapping, typically accompanied by enthusiastic exclamation by the participants, performed at the end of a special event to bring the occasion to a peaceful, lively close. 14

Team Question our team meetings end with a Team Question, which is meant to provoke thoughts in each team member's head, hopefully priming them to ideate possible solutions to our current design problems, in preparation for the next team meeting. 12

Vehicle an interchangeable term to reference a paper bike. 2

Zip-Ties a nylon fastener in which a notched end is threaded through the opposite, securing end to create a permanent loop. 9, 22

2 Context

2.1 Need Statement

Historic city centers such as *il centro* in Tuscany present unparalleled narrow streets that impose a challenge to traditional delivery vehicles [3]. Not only are streets difficult for a single driver but present unique communication challenges to avoid road blockages. Team *Nastro Anyone?* set out to design and manufacture a paper vehicle propelled by one individual capable of navigating a single rider payload through medieval city centers. Stakes and ribbons on Roble Field mimicked a European town and featured narrow streets with sharp turns as illustrated in Figure 3. Success was not only contingent on a robust and thoughtful design but on intentional collaboration and communication with other paper vehicle teams. This design sprint presented a warm-up for larger scale corporate engineering projects.

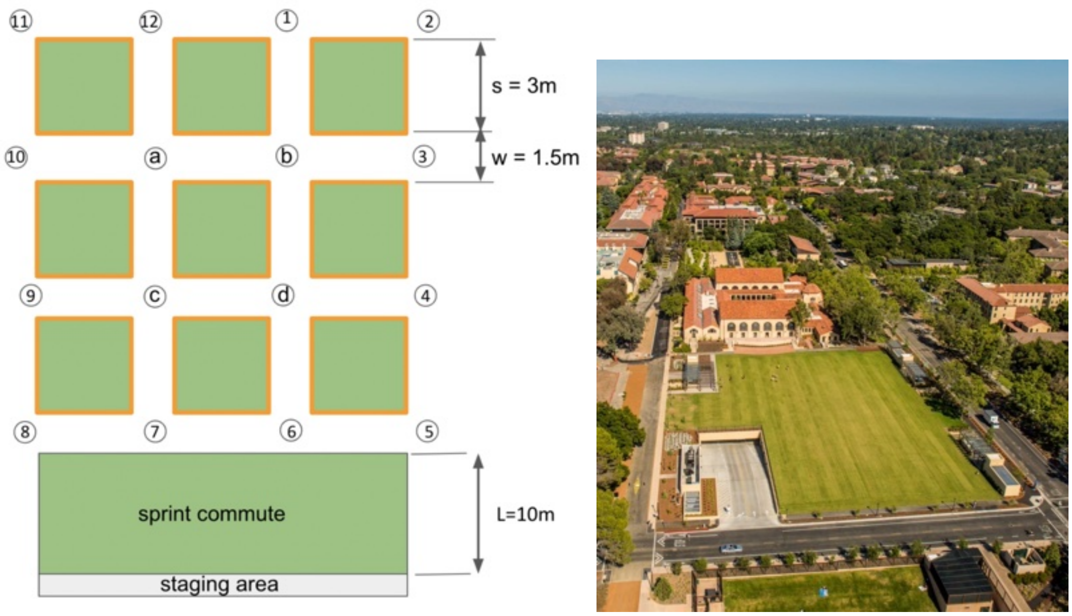


Figure 3: The Simulated City Center Layout on Roble Field.

2.2 Problem Statement

Paper Bike is a design challenge that signals the beginning of ME 310. In recent years, challenges have ranged from traditional games (i.e. capture the flag and polo) to interpretations of modern and trendy phenomenon (PokemonGO) [3].

The 2022 broad simulated challenge for each team was to navigate the established city center on Roble Field while completing a task as fast as possible. Each team was presented with a specific delivery plan with 4 destinations. Starting at the staging area depicted in Figure 3, a team must enter the city through the marked first delivery point and obtain a token. Subsequently, each team was tasked with navigating to the remaining three delivery points to obtain tokens prior to exiting through their start gate and racing to the staging area.

The eight teams were split into two macro teams, and the paper bike competition was split into three heats. The first two heats involved four teams. Two teams were from macro team 1 and two were from macro team 2. Each macro team could communicate to avoid crossing paths and being blocked to a gate. The third heat involved all eight teams racing to collect as many unique tokens from unique delivery points as possible.

3 Design Requirements

3.1 Functional Requirements

The functional requirements of the paper bike relate to how it should operate, both on its own and interacting with the rider and propeller. The primary functional requirement of the bike is to successfully maneuver the simulated city center with ease. A detailed compilation of functional requirements including: comfort, maneuverability, and durability is defined in Table 1.

3.1.1 Constraints

The following constraints were indicated by the challenge briefing:

- The rider must remain 15 cm above the ground at all times and must not make contact with the ground during the competition.
- The vehicle must be human powered.
- The bike must not impose danger onto the rider at any time.
- There may only be one individual propelling the bike at any time.
- The bike may not feature components that intentionally damage another team's paper bike.

3.1.2 Assumptions

The team made the following assumptions to narrow the scope of our design:

- Accidental collisions could occur between vehicles or the course infrastructure.
- The paper bike rally will occur in a dry environment: there is no rain and the grass has not been watered recently.
- Roble Field is relatively flat with minimal significant bumps.

3.1.3 Opportunities

The following opportunities were identified by the team as avenues to optimize the vehicle design:

- The vehicle does not need to contain safety features for the rider.
- The propeller could move the paper bike by pushing, pulling, or both.
- Concentrating the rider's mass over the axle would minimize moments and stresses on the chassis as well as limit the weight of the rider requiring support by the propeller.
- The rider can orient themselves in the vehicle however provides the best mechanical advantage, sitting, kneeling, or lying down.

3.2 Physical Requirements

The physical requirements of the paper bike relate to the the size, weight and material composition of the bike. The vehicle should be made almost entirely of paper products. For the purposes of this project, "paper products" include paper, corrugated cardboard, cardboard boxes, and cardboard tubes. The physical requirements are defined in Table 4.

3.2.1 Physical Constraints

- Only paper products can be used to construct the vehicle, with an exception for up to 500 grams of non-paper products.
- The vehicle can be mounted onto a beam in the ME 310 loft after construction.

3.2.2 Physical Assumptions

- Tape may be used in any quantity, unless it is used to construct structural components, in which case the weight counts towards the 500 gram non-paper material limit.
- A PBike from the 2021 PBike rally will be available for recycled use towards the vehicle construction.
- Most materials will be salvaged or scavenged. The design should be flexible to allow for variations in dimensions and materials depending on material availability.
- The team may swap the rider and/or the propeller between the rally heats.

3.2.3 Physical Opportunities

- Duct tape and spare parts (e.g. spare axles or wheels) can be interchanged on competition day in the case of vehicle failure.
- Screws can be used to secure components together.
- Materials such as graphite or thin metal sheets can be used between the axle and the wheel to reduce friction, while contributing little to the 500 gram non-paper material limit.
- The bike may be decorated and themed to increase visual interest.
- Cardboard with above-average durability can be found in bicycle boxes, which are easy to scavenge at local bike shops. This cardboard has been validated in previous paper bike competitions as durable enough to handle the stress of the competition.
- Tubes can be internally reinforced with cardboard, which increases radial strength.
- Zip-Ties may be implemented to tighten components together while adding little to the 500 g non paper allowance.

Table 1: Functional Requirements Detailing the Operational Standards for the Paper Bike.

Requirement	**Metric**	**Rationale**
The rider must not touch the ground during the duration of the relay.	The part of the rider that is closest to the ground must not be closer than **15 cm** at any point during the relay.	Predetermined race restriction. The rider in contact with the ground could pose a safety risk.
The vehicle must be maneuverable.	The PBike must be able to turn **90°** in under **3 seconds**.	In order to safely initiate a turn, the bike must decelerate first, which inherently causes a delay, so reducing that delay as much as possible is key to a faster bike.
The vehicle must be able to accelerate quickly.	The PBike should be capable of a propeller accelerating to **2.5 m/s** in **10 seconds**.	When forced to stop after encountering another bike, being able to quickly accelerate to get a token will enhance overall team speed.
The vehicle must be able to support the weight of the rider while in motion.	The PBike must be able to support an individual of at most **90 kg** with a safety factor of **1.5**.	If the cart can support a heavier load for a longer period of time, it should be able to support a lighter individual for a shorter distance on race day.
The vehicle must be stable when at rest.	The PBike should be able to stand alone without falling on either side with the required **(90 kg x safety factor)** weight of the rider.	Instability when not being operated could result in damage if the bike were to topple to one side.
The propeller should be comfortable when operating the vehicle.	The propeller must be able to operate the PBike with rider load for **5 minutes** continuously.	A lack of comfort would result in the need for rest stops mid challenge, which would impede the speed of the team.
The rider should be able to easily collect tokens.	The horizontal distance from the seat to the token should be less than **0.5** times the rider wingspan. The rider arm height should fall from **0.5 to 1 m**.	Positioning the rider at an optimal height and distance from tokens will enable the PBike team to grab tokens quickly. This will contribute to an overall faster performance.
The vehicle should be possible to construct within the bounds of the competition.	The PBike must be able to be fabricated within **1 week**. The PBike must be able to be fabricated out of materials available and obtained by the team.	Limited time and resources influence the design process.
The vehicle must be durable.	The PBike can be operated for **30 minutes** without substantial loosening or failure.	The PBike has to survive the intensity of the pre-rally testing and official heats on rally day.
The vehicle should be able to suddenly decelerate.	A rider should remain on vehicle when subject to **2.5 m/s** deceleration for **10 seconds**.	Rider safety is a priority, so keeping the rider aboard is paramount.
The vehicle should be able to withstand collisions.	The PBike should maintain functionality after **10 5 m/s** impacts with a metal rod or another Pbike.	The PBike will be subject to unintentional collisions that should not render the PBike broken.

Table 2: Physical Requirements Detailing the Structural Standards for the Paper Bike.

Requirement	Metric	Rationale
The vehicle must be made of paper and paper-like materials.	There must be less than **500 grams** of non-paper materials on the vehicle.	Predetermined race restriction.
The vehicle should be lightweight.	The PBike should not exceed **30 kg**.	Lighter bikes will be easier to accelerate and decelerate, thus, increasing speed as the propeller navigates other bikes and tight corners.
The vehicle should not harm the rider while in motion or stationary.	All exposed edges should either be flat or have a fillet radius of **5 mm**.	Rider safety is top priority during the race. Injury could slow the rider down or prevent them from completing the race.
The vehicle should accommodate a variety of rider sizes.	The PBike should accommodate riders of within a height range of **1.5 to 2 m**.	The PBike will have many riders. It is important each rider is safe, comfortable, and able to collect tokens with ease.
The vehicle should be thin to fit within the narrow streets.	PBike width must not exceed **1.5 m**	The PPBike must fit within the specified street width.

4 Design Development

4.1 Design Process

Our product development process was broken down into 5 main sections, ultimately following the product development process found in the textbook Product Design and Development [4]; neglecting the final phase of development according to the textbook because we were not mass producing our bike. Within the sections, we had a total of 7 team meetings to discuss progress and work on tougher problems together as a team, ultimately ending each meeting with a Team Question that we would need to individually think about for our individually assigned deliverables for the following meeting.

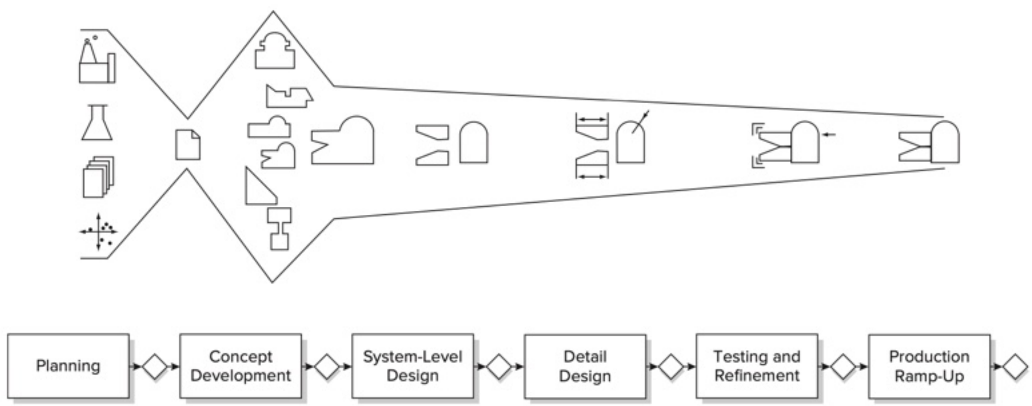


Figure 4: The Product Development Process as Outlined by Ulrich, Eppinger, and Yang [4]

4.2 Team Meeting 1

We began our first meeting discussing the core problem statement: design and create a vehicle that can carry a rider through a narrow roaded course. We then continued to benchmark previous years' bikes by continuing to analyze the final reports available in the loft and online. More specifically, we took a deep dive into Team Zamboni's Final Report from 2021, and eventually untethered that vehicle from the loft ceiling to further investigate how components were made and stuck together. We concluded our first meeting by establishing team goals and milestones, setting work expectations, deciding on a gameplan moving into the next meeting, especially with regards to cardboard tube acquisition, and assigning our first Deliverables: 2-4 bike sketches per person. Our Team Question for this meeting was "What everyday objects or vehicles exist in society today that are propelled with a human body, and can we draw inspiration from those?"

4.3 Team Meeting 2

We began our second meeting discussing the different bike sketches we all designed individually, having drawn inspiration from everyday pushed objects such as flat dollies, hand truck dollies, wheelbarrows, skateboards, Wheel chairs, wagons, luggage, and office chairs. We gathered all of our drawings together and discussed each major feature and each possible flaw. After that, because there was no clear winner of ideas when we discussed thoroughly, we stuck the ideas into a Decision Matrix to see if a more clear direction could be determined, with the base comparison bike model being Team Zamboni's from 2021. We quickly discussed which Decision Matrix metrics were most relevant, and our results are below.

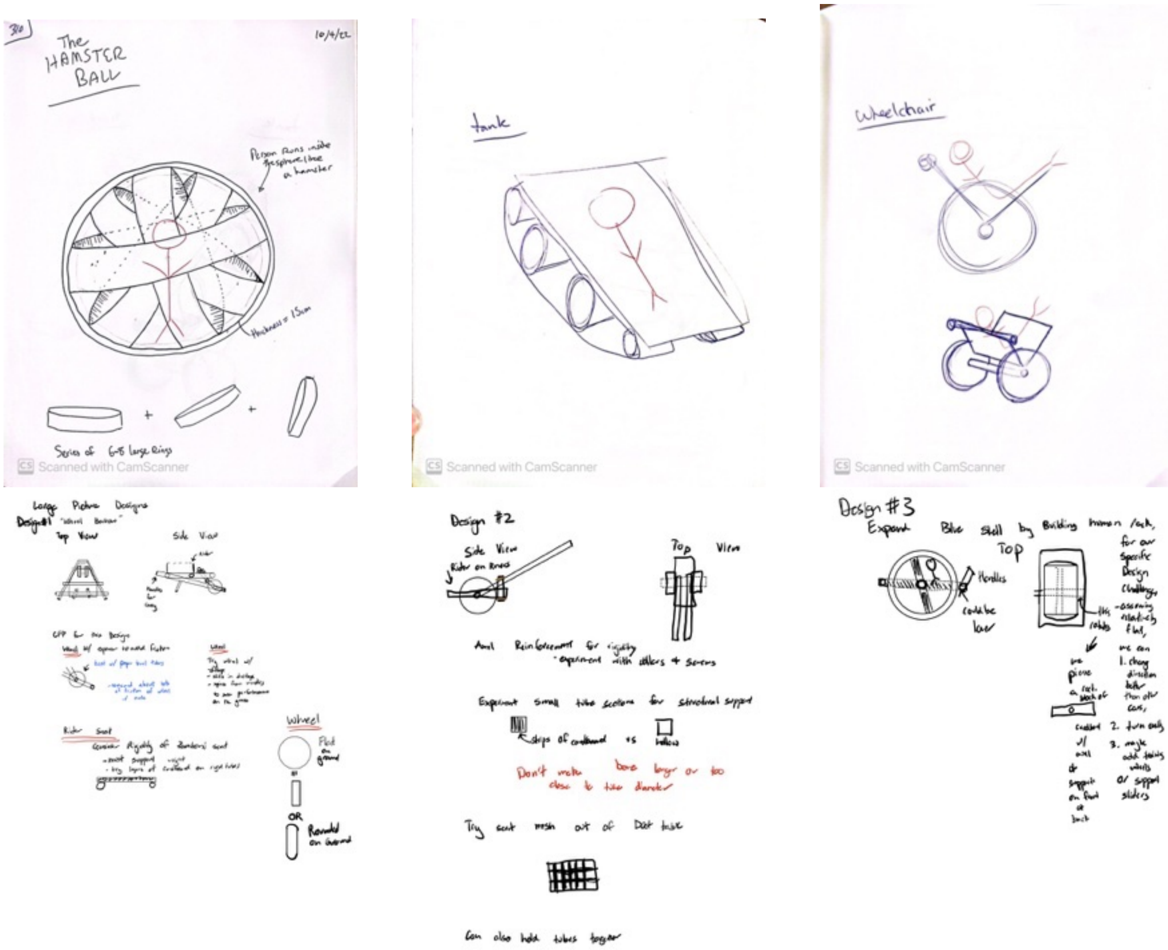


Figure 5: Our preliminary sketches showing our initial thought process

Ideas Metric	Zamboni	Hamster Ball	Tank	Wheel Chair	Hover Board	Dolley	Wheel barrow	Castor Wheel
Durability	0	0	+	+	-	+	+	-
Ease of Construction	0	-	-	+	-	0	+	-
Ease of Turning	0	+	-	+	-	+	+	+
Ability to Collect Tokens	0	-	0	0	+	+	+	0
Team Excitement	0	+	-	0	0	0	0	+
Stability	0	-	+	+	-	-	0	-
Speed	0	+	-	+	0	+	+	0
TOTAL	0	0	-2	+5	-3	+3	+5	-1

Figure 6: Our Decision Matrix

A Decision Matrix is an effective systematic tool to gauge overall performance after having detailed discussions of the designs in question. The Decision Matrix is not meant to be the be-all-and-end-all solution to our decision making process, but rather shed some light on a design direction in case of a stalemate of ideas, which was the case for our team. We compared the metrics of each design to the Zamboni design from 2021, indicating a "+", "-" , or "0" to show whether the team thought the design was better, worse, or equal in that metric relative to the Zamboni.

Overall, after our Decision Matrix results were discussed a little more, we found that a Wheel Barrow structure would be the optimal design. Thus, our first milestone was achieved, and we celebrated with a Team High Five. Thereafter, we discussed our possible Critical Functional Prototype (CFP) that we needed to test to validate the design. Ultimately, four CFPs were decided on, each which could test one or more Critical Questions, and we assigned our second deliverable, which was to individually ideate and thinks of ways to answer our next Team Question: "What materials do we need and what exactly do we need to prototype to answer the critical questions of the CFPs"

Table 3: Four CFPs and associated critical questions and rationales

CFP	**Critical Question**	**Rationale**
Wheel Base	How many wheels do we need (1 vs 2 vs 3)	The stability of the frame is influenced by number of wheels and placement
	Where should the wheels be located (close vs not close to centerline)	The rider position and the forces acting on the main axle are influenced by the wheel locations
	Do our current wheels need stronger traction	The driving performance is influenced by how much the wheels slip
Rider Frame Positioning	How should the rider be positioned on the frame	We need to maximize weight over the driving axle, lower the center of gravity, maintain comfort, and allow for easy token collection
Propellor Frame Positioning	What is the most comfortable way to operate the bike	Our propelling and maneuvering comes from the Bike Propellor, who needs to be able to quickly accelerate, decelerate, maintain speed, and turn
Bearing Surfaces	What bearing would introduce the least friction	A cardboard wheel rubbing against a cardboard axle or cardboard bearing plate creates unwanted friction, which could lead to lower wheel performance

4.4 Team Meeting 3

We began our third meeting discussing the possible prototypes we could make in order to test out each critical question from the CFPs. We came to a consensus on how we would validate our critical questions, then began to develop the CFPs. At first, we split off to tackle multiple CFPs at once, but soon realized it was easier to prototype if we worked together on a singular CFP at a time. At the end of the meeting, we nearly completed construction on all CFPs, and we were nearly ready to test each one at the next meeting. The Team Question for the day was “What is the best documentation procedure for our team, and can we start a document that houses all our progress photos we have been taking?”

4.5 Team Meeting 4

We began our fourth meeting discussing the updates to our team google drive folder, which included all relevant files such as our Decision Matrix, Idea Sketches, and Photo Documentation. We then continued to develop the CFPs, by adding finishing touches, testing them, identifying failure points, modifying, iterating, and re-testing until we were confident with the results. Below outlines the critical questions we aimed to answer and what we learned from those results. Ultimately, we came to final decision on what features to use for our final bike, and our Team Question for the day was “What materials and procedures do we need to fully construct our final bike during the next meeting”.

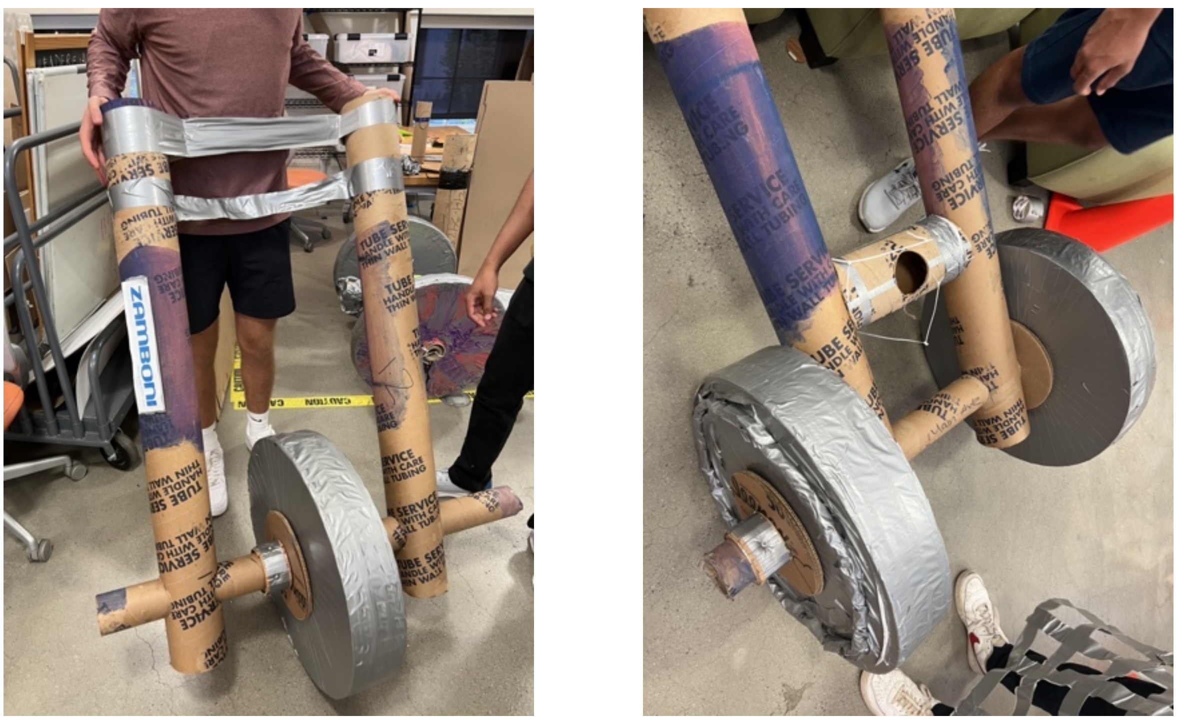


Figure 7: Testing the number of wheels

How many wheels do we need (1 vs 2 vs 3)? Two wheels offer the most stability with easiest turnability.

Figure 8: Testing the location of wheels

Where should the wheels be located (close vs not close to centerline)? The farther the wheels are from the bike centerline, the higher the moment the wheel axle experiences, but is easier to turn, and more comfortable for the rider.

[a]  [b] 

Figure 9: Testing wheel traction

Do our current wheels need stronger traction? Duct tape around the wheel has enough traction for riding across the Roble Lawn (a) without slipping, in effect meaning we could recycle last year's Zamboni's wheels (b) with some minor tape repairs.

Figure 10: Testing the rider position

How should the rider be positioned on the frame? A rider sitting on the center axle proved to maximize the weight over the axle while providing an optimal token collecting position. This meant we needed to develop an appropriate seating structure to hold the rider weight directly over the axle, so we tried making a mesh backing out of duct tape onto which the rider would rest (b). Ultimately, using a cardboard tube as the backing proved best (a). We also needed to develop a structure to hold the rider legs and arms without disrupting the propellor, so we tried making leg rests out of cardboard strips bent into a truss and cardboard tubes (c). Ultimately, tubes also proved more durable again (d).

[a]  [b] 

[c] 

Figure 11: Testing the propellor position

What is the most comfortable way to operate the bike? Pushing the bike like the way one pushes a wheelbarrow (b) instead of pushing like a hand-truck dolly (a) provided the best balance between speed and ergonomic design. Grips and handles were added to make the bike more ergonomic (c).

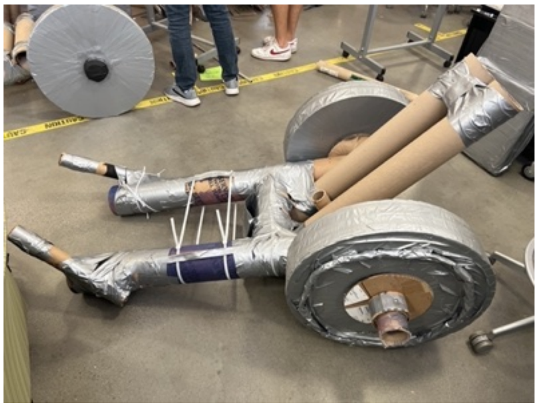
[a] [b] [c] [d]

Figure 12: Testing different bearing surfaces

What bearing would introduce the least friction? We found plastic lined spacers reduce the friction at the bearing (a) as well as between the wheels and the cardboard frame (b). We achieved this by gluing plastic sheet onto the cardboard spacers to prevent cardboard-cardboard contact (c)(d). While the effect of this was less obvious, we found that the spacers were now moving much less as the wheel turned, meaning the spacers were now decoupled from the wheel, meaning less friction existed between the spacers and the wheel.

4.6 Team Meeting 5

We began our fifth meeting discussing the gameplan moving forward to construct the final bike. We then recycled the cardboard tubes from both our CFPs and the remaining materials found in the loft in order to start final construction. Ultimately, we finished construction as a team, tested the bike on the lawns outside the loft, identified failures, made necessary adjustments according to our test results, and re-tested. Below is our final prototype bike at this stage. We ended the meeting confident that our bike could be slightly modified but essentially competition ready if the competition were to be held the following day. Our Team Question for the day was "If the competition was tomorrow, where would our current prototype fail?".

[a] 

[b] 

[c] 

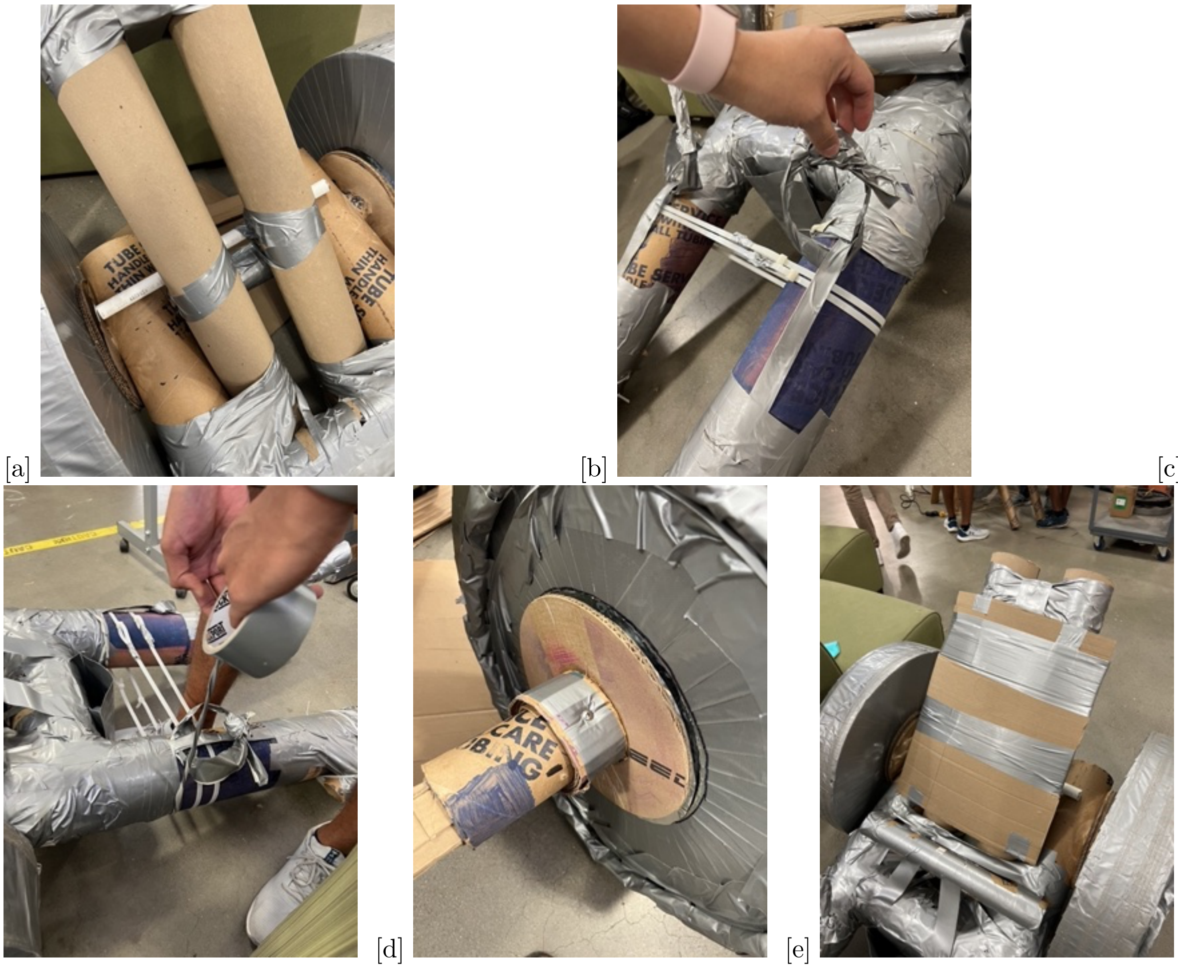
[d] 

Figure 13: Final bike design

Final structure design (a) with added features like structural Zip-Ties to hold the frame together(b), structural tape to hold the backing support together(c), and a duct tape pocket to hold the competition tokens (d).

4.7 Team Meeting 6

We began our sixth meeting discussing the potential bike failure points and what we needed to work on now with only 3 days until the competition. Mostly, that comprised of adding spacers between the wheels and the bike frame, repairing duct taped areas that were tearing, adding ergonomic grips to the propellor handles, stiffening the wheel axle, and developing extra parts to have ready during the competition in case of failure. Our Team Question for the day was “What do we need to watch out for when conducting our final full test runs?”



[a] [b] [c] [d] [e]

Figure 14: Final adjustments to the bike

Modifications to the bike ranging from adding a pvc pipe to take load off the main axle (a)(b), creating duct tape handles for the rider (c), reinforcing the duct tape handles by twisting duct tape into a roll then wrapping that around the duct tape tearing points (d), reinforce the wheel axle by adding cardboard strips and wood glue into the axle (e), adding a cardboard pad to the backing support structure to increase comfort for the rider (f).

4.8 Team Meeting 7

We began our seventh and final meeting discussing the current state of our fully tested bike, and adding the necessary final repairs and adjustments. We strategized potential routes with the rest of the Macro Team and concluded our final meeting by running another set of full scale test runs on Roble Field. Once we were satisfied with our bike, we performed a final Team High Five before the competition, and we left with our final Team Question: “How do we organize our extra materials and bike to be fully prepared at least two hours before competition tomorrow?”

[a]  [b] 

Figure 15: Finished Bike in the loft (a) and in action on Roble Field (b).

5 Design Description

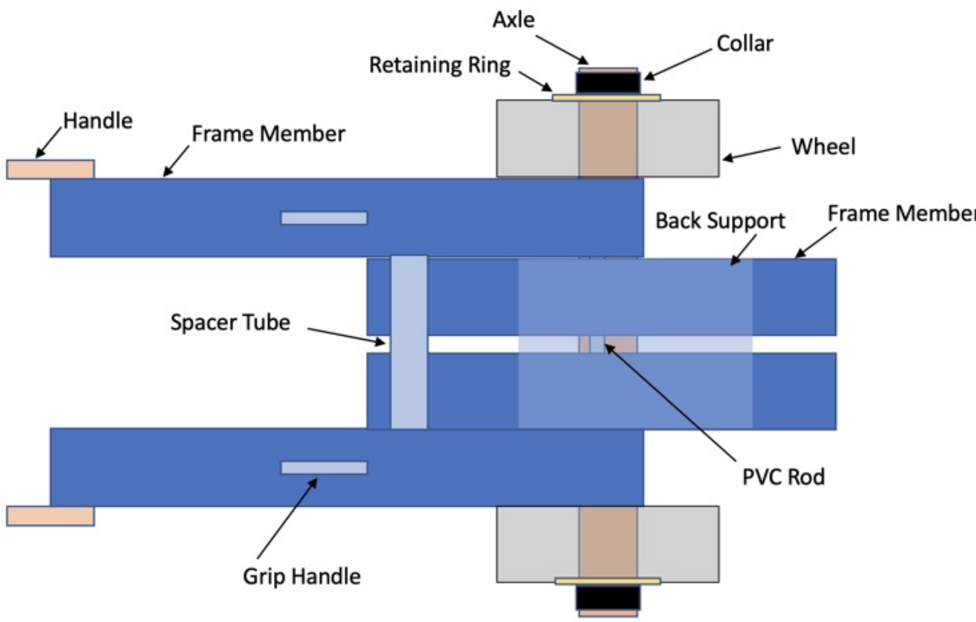


Figure 16: Top View Sketch

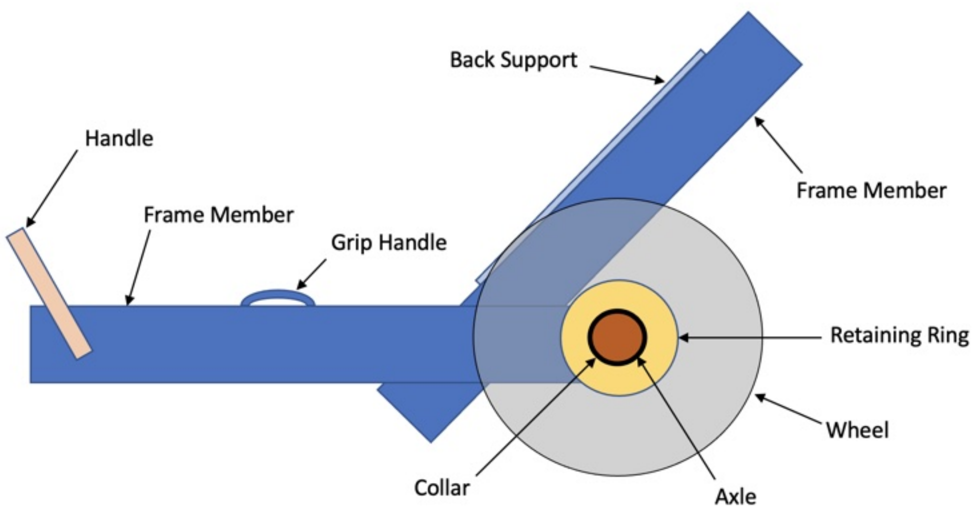


Figure 17: Front View Sketch

5.1 General Description of the bike:

The final design of the bike consists of four main frame members. Two members are attached to the axle, and the other two members are placed between the axle and spacer and between the first two frame members to add comfort for the rider via a back support. There are also two wheels and two handles. Two collars for the wheels and spacers (rings of cardboard in between the wheels and the main frame and collar) were used in order to secure the wheels. Cardboard sheets were used to provide extra comfort for the rider's back.

5.2 Specific parts

5.2.1 Wheels:

Team Zamboni's wheels were reused for this bike [2]. Those wheels were made by layering cardboard pieces together with the use of a "looped" duct tape securing method. This looping behaved similar to double sided tape. After attaching each layer, duct tape was implemented to wrap the entire wheel to provide a smooth appearance and avoid shearing between cardboard layers. Wheels of the bike were fourteen sheets wide, 24" (610mm) in diameter, 4.25" (108mm) thick.

5.2.2 Bearings:

After the wheels were built, through-holes were bored through the center, and the interior of the hole was lined with aluminum sheet metal. Our bearing surface, which was made of aluminum sheet metal, was designed to make direct contact with the axle. We utilized two collars that were attached to the axle with two wood screws on each side that ran all the way through the axle. Moreover, three cardboard retaining rings for the outboard constraint were added. In addition to maintaining the wheel's alignment with the bike's direction of travel, the retaining rings served as a secondary retention mechanism for the sheet metal bearing surfaces that were supplements to the interior of the wheel.

5.2.3 Frames:

The frame consists of four members, two of which are approximately 4 feet (1220 mm) long and two of which are 3 feet (915 mm) long. The first two pieces served as the major frames through which the axle traveled. One the opposite end of the first two pieces, handles were attached at an angle. The 3 foot frames were positioned tangentially between the pvc rod above the axle and the spacer tube (which was used to hold the 2 main frames at particular distance). Using duct tape and zip ties, the spacer tube was joined to the main frame. The 3 foot frames were attached to the spacer tube and pvc rod using duct tapes. PVC tubes were used in order to reduce the weight load on the axle and prevent any failure.

5.2.4 Fixed Axle:

The fixed axle is a cardboard tube which is approximately 3.33 feet (1016mm) long. Since this bike is two wheeled, all of the rider's weight rests primarily over the axle. Hence the cardboard tube was stuffed with thinner sheets of cardboard to reinforce the axle and prevent any bending or failure.

5.3 Non-Paper Components:

Below is a table showing a summary of all non-paper components used in the construction of the PBike and their total mass.

Table 4: Non-Paper components used in our PBike

Component	**Quantity**	**Mass(g)**
Wood Screws	6	18
Zip Ties	10	10
Sheet Metal	2	30
PVC rod	1	50
Bolts	2	30
Nuts	2	6

5.4 Recommendations for future work:

The primary reason for us choosing the 2 wheel design is to easily maneuver through narrow course that was setup. By choosing the two wheel setup we also decreased the overall profile of the vehicle but this compromises the overall stability of the bike since the propellor had all the control in adjusting the height and orientation of the bike. A third/fourth wheel would definitely add more balance to the bike and give better rider comfort. The wheels in this bike were made very broad in order to give better traction and improve balance but this increased the overall track width of the bike which made it quite difficult while turning through narrow corners in high speeds [1].

6 Resources

Table 5: Sources of Materials Obtained for Vehicle Manufacturing

Vendor	**Material Procured**	**Comments**
Tube Service Co.	Cardboard Tubes	Obtained via Team Zamboni Bike
Sports Basement	Cardboard Sheets	Obtained with Permission to gather from Dumpster
Team 2.2	Cardboard Tubes	Permission from Naveen and Vishal
2021 Team Zamboni [2]	Aluminum Sheet Metal	Recycled Wheels and Axle from 2021 Bike
Joann Fabrics	Flat Cardboard	Obtained with Permission to gather from Dumpster
ME 310 Loft	Screws	Used to Attach Wheel Securing Collars to the Axle

7 Reflections

7.1 Design Team Reflections

Team *Nastro Anyone?* was assembled by the ME310 teaching staff based on the "macro-teams" established for the Paper Sheath design. The individuals had not worked together for this design project and were assigned an effort to create to create diversity of thought and background provided by the different team members.

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I was born and raised in Dallas, Texas. My paternal family lives in France and my maternal family lives in New York. I attended Duke University in Durham, NC where I received a B.S.E. in Biomedical Engineering. I am interested in the bridge between form-fitting wearables and machine learning that offers potential to enhance human performance and prevent injury. I have interned at Scottish Rite for Children in a Motion Capture Lab (the same labs used to make videos games like NBA 2K/Fifa) and Humacyte (a biotech startup that creates vascular grafts with low infection risk).

Reflections
Looking back on the paper bike design challenge, my initial thoughts are that my team worked well together. I was glad our first discussions involved setting a group norm and culture. We learned communication preferences, expectations for checking communication platforms, and how to approach each other if there was conflict. Each team member was accountable and did the work and more that they were delegated. The beginning of the design process involved a lot of research into previous bikes which inspired some of the early brainstorming. If there was more time, I would have enjoyed brainstorming more before jumping into building. We had a strong existing bike to go from and this empowered the team to bypass brainstorming and evaluating additional features such as wheel size or tube diameter. When it came to finalizing a bike and sketching plans, we had an iterative approach. I think an initial design plan with more forethought could prove useful in the larger scope design project as iterations on a design may prove more costly than with the paper bike. I was content with the documentation of the paper bike challenge provided the short time frame. However, I would want to have more detailed meeting notes as well as a more organized google drive for a longer term project. I think with more tasks, a Trello Board or shared tasks list would benefit team members to see what has been accomplished by other members. I think the testing we performed on the paper bike was very intense provided the warnings of the teaching team. I did not hold back when accelerating the bike or suddenly braking. I turned sharply and actively attempted to make the rider fall off to see how secure the bike was. I think crash testing and other testing modalities could prove useful in a larger scope project. We focused our testing on the specific task presented to us in the form of the race. However, with the ambiguous design challenge prompt, I would want to put more thought into planned testing to address our user needs prior to starting a build.

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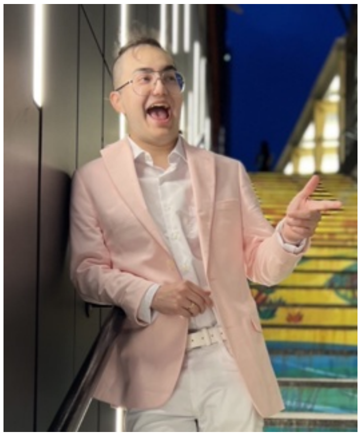
I was born in Srirangam, India but grew up in Chennai. I did my Undergrad in Mechanical Engineering at SSN College of Engineering (ANNA University). I previously worked as a research intern at Nanyang Technological University, Singapore where I studied and designed a wearable device with RFID embedded in it. I did my undergraduate final year project on Experimental Analysis and Evaluation of Drilling of Mg MMCs with B4C Reinforcement. I have also worked on projects in the field of Manufacturing. I am interested in working on research projects closely related to product design more specifically in industrial and interface design that can significantly improve people's life.

Reflections
I thought that designing, building, and testing a paper bike in a week was an almost impossible feat when I initially heard about the project. However, the crew as a whole was in agreement about the size of the task before of us. We were swift and efficient. Then, everyone had the freedom and drive to complete the assignment on their own schedule. We were quick on brainstorming ideas and testing them which helped us move in the right direction and eventually complete the bike without any hassle. Additionally, we didn't hesitate to criticize one another's ideas, which encouraged us to brainstorm more and cross-validate our concepts. I think one of the reason we were able to create an incredible paper bike in the short amount of time we had was because each of us brought their own special ideas to the table and contributed to the project. We didn't hold back when testing the bike, we drove the bike through rough patches in lawns which were much rougher than Roble field, we rigorously kept turning and braking instantaneously to check for failures. Since we delegated tasks effectively and worked at high pace were race ready very early. Our bike was performing very well many days before the race and this gave some room for slight improvement in performance of the bike and comfort for the rider and as well as propeller.



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Skills: Spanish, Chinese, Russian, Arabic, Japanese, Korean, French. Rapid prototyping

My parents are from Mexico, but I grew up in Arizona, that really hot state next to California. I studied in Boston for my B.S. in Mechanical Engineering at MIT, Class of 2021, and later worked as a course instructor and assistant for a year for 2.009, the capstone product design course at MIT, before coming here. I am currently also working for a small startup looking to create an at-home boba machine.

Reflections There have been a few MIT students who have gone through this course I'm sure, and they've probably mentioned how the capstone ME product design course over there also has a "build challenge" as part of the first project team assignment. But I do think I can offer a sort of unique perspective because I took that class in 2020 but then also actually was a TA for that class the year following (last year). I also at one point in my career really played with the idea of teaching ME or even PD at the university level. I have thought a lot about the build challenge there and here in ME 310 and about the overall differences and similarities I've noticed so far in the course; and I am heavily open to chat about my full thoughts on this course and MIT's course if anybody wants my perspective. But, to go back on topic, the MIT build challenge is ultimately also a less than 1 hour event on a singular day in October, but that one I remember as a TA spending a total of about 100,000 USD just for that one hour for that one day; and it is like that every year. The event is large, and extravagant, takes the labor of many many hired workers and TAs, and takes months to plan in advance because it is different every year. As such, it was extremely engaging when I was a student, and it was extremely difficult to set up when I was a TA, but the overall feeling I had is that that build challenge did not actually teach me much about anything really. Sure, I learned how to follow an instruction manual created by the TAs to screw in some bolts into a pre-made wooden frame, but I learned almost nothing about documentation, team dynamics, or overall how complex even the simplest of wicked problems can be. The build challenge here in ME 310, however, honestly did teach me a lot more than the one at MIT, despite having a significantly smaller budget. What MIT did achieve though is the interest of students in PD. However, having done ME 310's build challenge, it's now clear to me that there is a delicate balance in teaching about PD between garnering as much interest as possible, and actually teaching folks about the vast challenges in a wicked project team. Could ME 310's build challenge benefit from having a larger budget and making the challenge/event more engaging and interesting to students? Sure. But I was content with the knowledge I gained with this course, and striking that balance between interest and relevant teachings is quite hard.

References

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