# Final Prototype Evaluation

## User-Centered Product Design Capstone:

## Turn Signaling Handlebar Grip for Electric Scooter Safety

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## Introduction

Electric scooters have been a trending topic since their launch at The Ohio State University (OSU) campus in 2018 well into 2019. Their functionality and social effects have stirred conflict especially in terms of safety for riders, pedestrians, and drivers. The capstone scooter team conducted careful investigation of key stakeholders: officials of the city of Columbus, Smart Columbus, Traffic and Transportation Management at OSU, Lime, and experts at OSU in City and Regional Planning, Industrial Design, and Entrepreneurship. Through research and prototype iterations on various improved measures of safety, it became clear to the capstone scooter team to design a turn signal and integrate it into the existing scooters and be able to perform under current infrastructure. The final prototype of the turn signaling handlebar grip was designed for simple assembly and intuitive user operation.

Several key product specifications were evaluated to prove successful results of the final prototype: usability, design, durability, and visibility. Visibility of the pop-out mechanism with blinking turn signal was tested to ensure optimal safety from the perspective of drivers, pedestrians, and other riders/cyclists. Durability was analyzed in finite element analysis (FEA) to test the forces applied if the scooter handlebars were to fall to the ground, and materials were considered and applied for weatherproofing. The core design specifications were modeled in CAD to ensure proper fit to existing scooter handlebars and simple assembly. Finally, usability was tested on various individuals based on their ability to easily understand how to operate the product based on a three-step process and their feedback on ergonomic feel.

## Final Prototype Analysis

Regarding the specifications, the tests done for the final prototype provided the team with valuable user feedback and areas of improvement. During the Design Day Showcase, visibility of the turn signal was tested for users of various sizes, which can be seen in the following images. This testing was evaluated on whether the LED lights could be seen at multiple angles around the rider, and not obstructed by arms or shoulders. One of the most important locations for visibility is the back view to ensure drivers can clearly see the scooter rider's intended turn direction. For pedestrians, the front or angled side view is necessary to clearly see. If scooters are riding on pedestrian walkways (which is frowned upon, though still practiced), a more frontal view of the turn signal will alert pedestrians of scooters approaching towards them. The team acknowledges that the prototype tested during the showcase did not fulfill all visibility specifications due to timing and fabrication restrictions (e.g. re-3D-printing the handlebar to increase extended length).

Figure 1: User subject turn signal visibility for broad shoulders/large coat

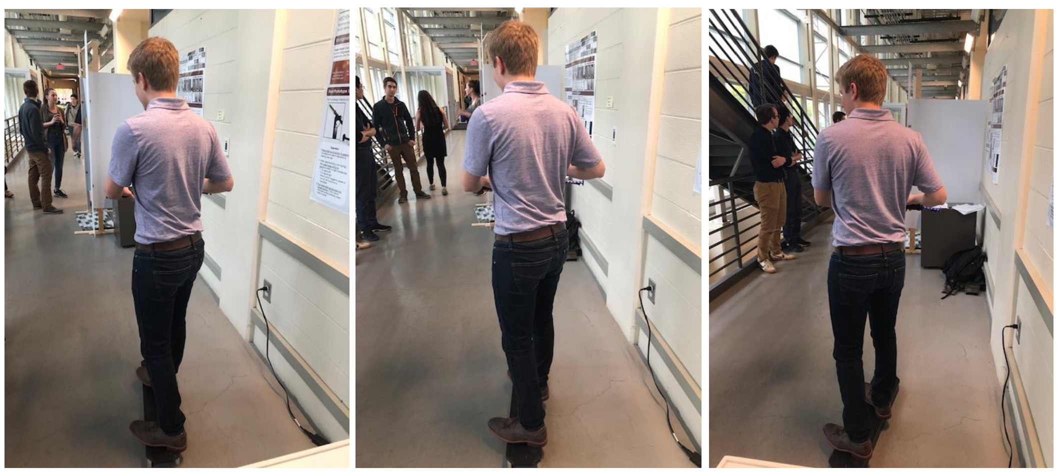

Figure 2: User subject turn signal visibility for short user with narrow shoulders

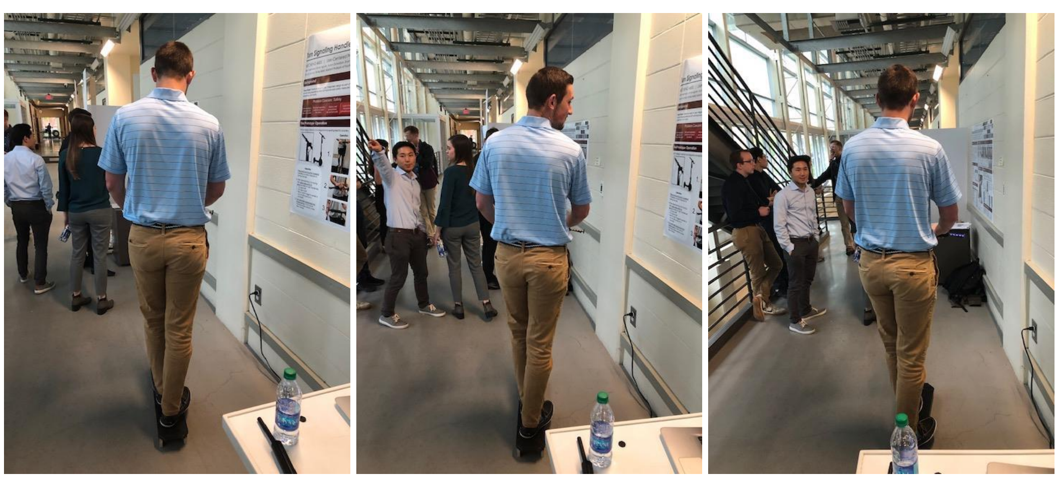

Figure 3: User subject turn signal visibility for tall user with narrow shoulders

Figures 1, 2, and 3 are samples of the images that were taken at the showcase to validate our visibility specifications. The team learned that it was difficult to see the turn signal for shorter users or users with broad waists or shoulders, since this area is where the turn signal is depending on height of the rider. Figure 1 helped the team evaluate the prototype under the condition of a broad-shouldered user, a rider wearing a large coat, or potentially carrying a wide backpack that may obstruct the signal visibility. The elbows of a shorter user, shown in Figure 2, illustrated the problem area of arm obstruction based on height. As depicted in Figure 3, the taller user avoided this issue because his elbows were further away from the turn signal, which allowed it to be visible. These varying obstructions validated to the team that the pop-out signal would need to be several inches longer than the final prototype tested during design day. It is important to note that the design of the final prototype was meant to extend six inches further than the handlebar. Due to the time constraints for the last prototype iteration regarding mechanical functionality, the mechanism only extended about three inches. This explains why Figures 1, 2 and 3 did not show ideal results, since the team's intention for the final product would extend far enough past the widest shoulder/elbow span that was evaluated. The CAD model properly depicts correct lengths for the final product.

To gain more useful information from evaluating visibility, it would be advantageous to have taken more photos and gotten user feedback from a person viewing the turn signal from the driver's seat of a vehicle. Another aspect of visibility is the color of the LED. Research showed that turn signals should typically be amber colored. The team decided that blue LED lighting would be enough to show proof of concept since the blue LED wiring was already soldered and wired to the electronic circuit. The team got positive feedback from users about the lighting and expressed that they would not mind whether the lights were blue or amber colored. In terms of visibility, the LED lights were not as bright from a distance. The team would easily be able to fix this issue by using the potentiometer to decrease the resistance in the circuit to create more vibrant lighting. To do this, the team also considered the battery supply necessary to power the turn signal lighting. The existing 9V battery was assumed to have a current capacity of about 500 mAh. Knowing that each 3 LED segment of the light strip draws 20 mA, with four of those segments on a handlebar assembly, then a turn signal only draws 80 mA. This means that the lights can be left on for more than 6 hours before the battery drains. If the turn signals were integrated into a Li-Ion battery pack with a capacity of 7800 mAh, the lights could stay on for more than 97 hours before the battery needs charging. Essentially, the LED lights need a very minimal amount of energy to function. The intent of this product would be to integrate it with the electronics of the original electric scooter so that the scooter can power the LED lighting without expending much energy.

**FEA Analysis**

Two total tests were performed on the inner tube for the FEA analysis. This analysis was done using Solidworks simulation tools. The first test was meant to simulate the scooter falling down with the turn signal extended. The point of contact would have been the very edge of the end cap, and this was simulated with a static force. The second test was meant to simulate the inner tube extending due to the spring force. Forces were put on the flanges that would contact the opposing flanges on the outer tube. Since the normal material used to make electric scooters is aerospace grade aluminum, three different types of aerospace grade aluminum were tested. The forces were determined based on the assumptions below:

Test 1 Assumptions:

- Total weight of the scooter is 26.9 lbs (12.2 kg)
- Bulk of the damage will be done by the scooter just falling over
- Approximate total handlebar weight (without turn signals) is 13% of total weight (3.5 lbs, 1.58 kg)
- Weight of handlebar assembly based on Solidworks material properties (for both the left and right side) = 0.44 lbs
- Total Weight used = 4 lbs (1.81 kg)
- Assumed force is equal to $F = mg$
- $F = (1.81\ kg) * \left(9.81\ \frac{m}{s^2}\right) = 18\ N\ (4.05\ lbf)$
- Other forces were based on doubling the initial force, then trying to find a force where the maximum stress is greater than the yield stress.

Table 1: Test 1 Results on the Inner Tube

| Force (N) | Material (Aerospace Grade Aluminum) | Yield Strength (MPa) | Maximum Stress (Von Mises) (MPa) | Displacement (mm) |
|---|---|---|---|---|
| 18 | 6061 Alloy | 55.15 | 9.232 | 0.04917 |
| | 2024 Alloy | 75.83 | | 0.04648 |
| | 7075-O (SS) | 95 | | 0.04712 |
| 36 | 6061 Alloy | 55.15 | 18.46 | 0.09834 |
| | 2024 Alloy | 75.83 | | 0.09295 |
| | 7075-O (SS) | 95 | | 0.09424 |
| 150 | 6061 Alloy | 55.15 | 76.93 | 0.4098 |
| | 2024 Alloy | 75.83 | | 0.3873 |
| | 7075-O (SS) | 95 | | 0.3927 |

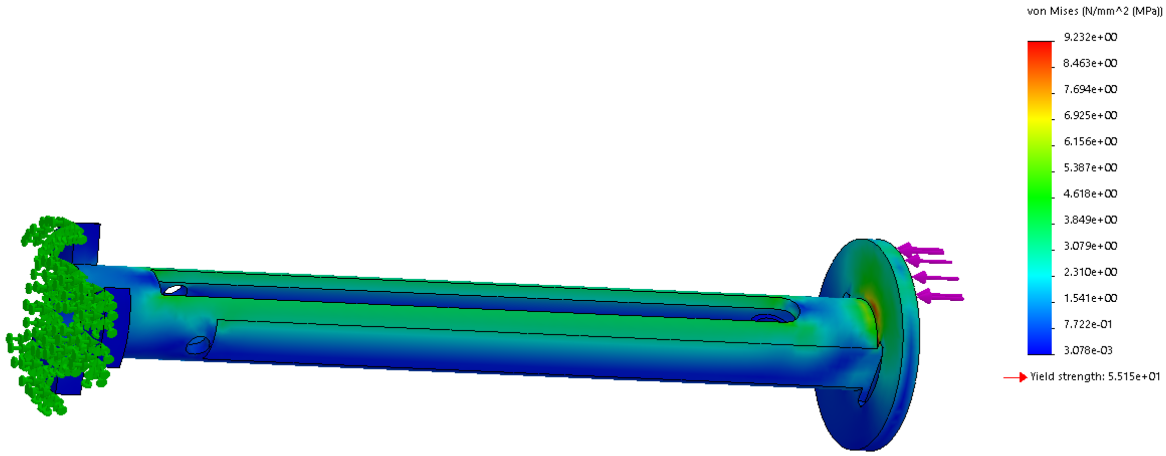


Figure 4: Von Mises Stress for Tip-Over Test (6061 Aluminum Alloy – 18 N)

The results from the first test are promising for the product. Based off the assumption that the inner tube would face 18 N of force if it fell, it would experience a very small displacement and the maximum stress would be well under the yield strength for the three different aluminums tested. Even if the force was doubled there is still a very small displacement and no fear that the inner tube would yield. It would take a force of about 150 N for the inner tube to experience yielding (based on 2024 alloy material). This is a very high force, and not one the inner tube would experience even if it were pushed over and not just fell over. This test reinforced the idea that the inner tube is durable and could survive normal scooter wear and tear.

Test 2 Assumptions:

- Spring Parameters:
    - Free Length = 6 in
    - Compressed Length = 1.45 in
    - $\Delta x = 4.55\ in$
    - Spring Constant k = 2, 4, 6 lb/in
- All of the force is transmitted to the contact points evenly
- $F = k\Delta x$

Table 2: Test 2 Results on the Inner Tube

| Spring Constant (N/m) | Force (N) | Material (Aerospace Grade Aluminum) | Yield Strength (MPa) | Maximum Stress (Von Mises) (MPa) | Displacement (mm) |
|---|---|---|---|---|---|
| 350 | 40.45 | 6061 Alloy | 55.15 | 21 | 0.02083 |
| | | 2024 Alloy | 75.83 | | 0.01969 |
| | | 7075-O (SS) | 95 | | 0.01997 |
| 700 | 80.90 | 6061 Alloy | 55.15 | 41.96 | 0.04164 |
| | | 2024 Alloy | 75.83 | | 0.03936 |
| | | 7075-O (SS) | 95 | | 0.03990 |
| 1050 | 121.35 | 6061 Alloy | 55.15 | 62.94 | 0.06246 |
| | | 2024 Alloy | 75.83 | | 0.05904 |
| | | 7075-O (SS) | 95 | | 0.05986 |

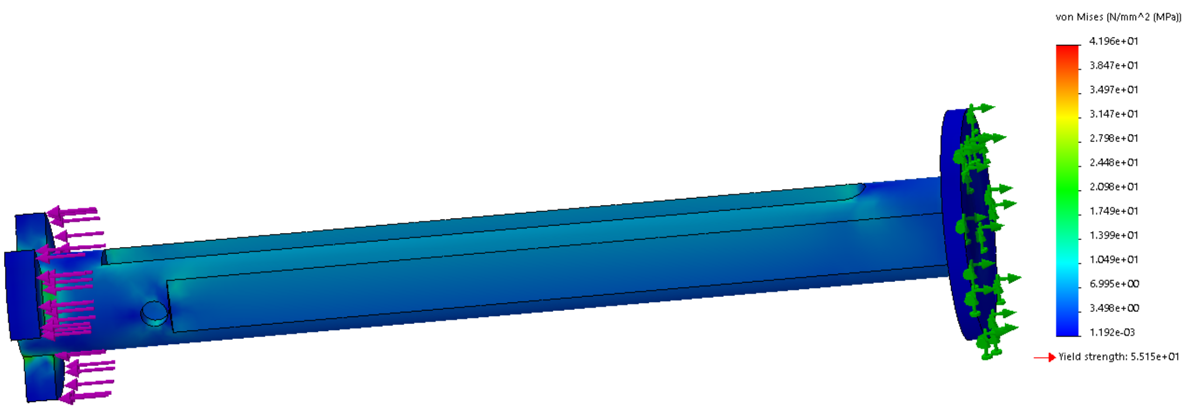


Figure 5: Von Mises Stress for Spring Force Test (6061 Alloy – 80.90 N)

The results for the second test display the maximum stress produced on the flanges based on different spring constants. The results from this test are not so promising for the product. If a spring with a spring constant of 1050 N/m (6 lb/in) was used, it would produce a force of 121.35 N and the flanges on the inner tube would yield (based on 6061 alloy). This is based on the assumption that the force would be the spring constant multiplied by the spring displacement. The flanges would not yield if a spring with a spring constant lower than 1050 N/m was used. lb/in) was used, it would produce a force of 121.35 N and the flanges on the inner tube would yield (based on 6061 alloy). This is based on the assumption that the force would be the spring constant multiplied by the spring displacement. The flanges would not yield if a spring with a spring constant lower than 1050 N/m was used.

**CAD Model Evaluation**

To illustrate how our turn signal will integrate into a Bird/Lime scooter, the team modeled this attachment using our CAD model as it was not feasible to cut off the handlebar of a real scooter. The model incorporates the appropriate sizing and spacing of our turn signals attachment location to have a complete integration into the Bird/Lime scooters.

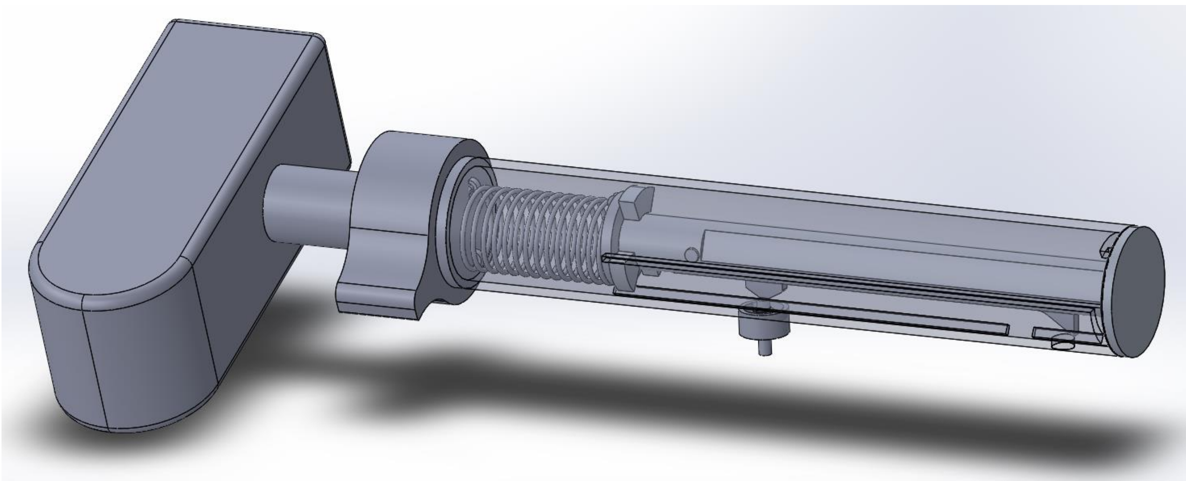

Figure 6: Final Assembly with integration into Bird/Lime handlebar

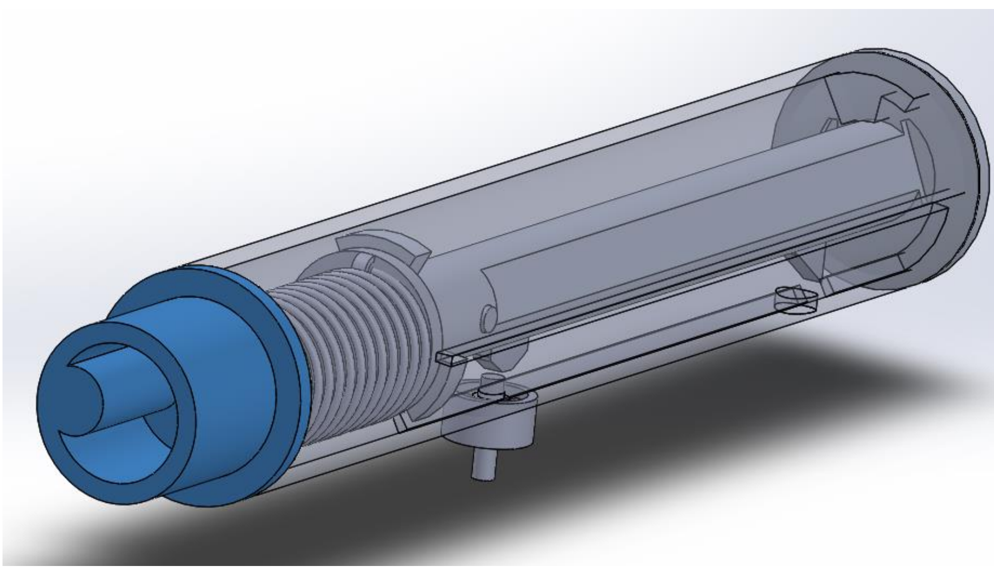

Figure 7: Handlebar connector

Figures 6 and 7 above show the integration of the turn signal into the Bird/Lime handlebar. As decided by the group, the handlebar was to be cut to three inches on each side to allow for the acceleration tab to maintain at its current location, which can be seen in Figure 6. Figure 7 illustrates the connecting part to the design of the current handlebars, which is highlighted in blue. This connector would be welded onto the handlebar for a secure connection where the handlebar and connector meet. It would also be welded to the end of the turn signal as it acts as an attachment point for the spring. The spring and spring connector can be seen in the exploded view of our full assembly (Appendix B: Figure 14). The purpose of the spring connector is to allow for the spring to contact the inner tube on a flat plane. The connection of this spring to the handlebar connector provides a firm connection of the spring so that it can be compressed by the inner tube.

**User-Centered Evaluation**

The usability specification for the turn signal prototype was especially significant when the team conducted their evaluations. Through every step of the design process the target audiences were considered: specifically, the riders and the scooter companies. The team had to ensure that they could design for seamless integration for the scooter companies, while keeping the handlebar feeling and operating most comfortably for the rider. The results of the user survey gave the team positive insight for our design and future improvements that would be implemented when connected with the scooters. The team was also given positive technical feedback regarding the integration aspect for scooter companies like Lime and Bird to easily assemble if our product was sold and supplied to them.

A key aspect of having different test subjects interact with the prototype was the feedback that they provided (see Appendix A for survey feedback). The participating user group consisted of about 75 percent of riders and 25 percent who have never ridden a scooter. One of the main strengths of the final prototype was the grip. Users found that the grip felt like an actual scooter grip and felt normal and comfortable in their hands. Another strength that was noted was the location of the extension button (feedback shown in Appendix A: Figures 9 and 10). Users said that they did not have to search for the button, and that their finger fell right on it. This was a crucial input for the team, as one of the main goals for the design was to be very intuitive and not require directions. These comments fortified the point that the prototype was designed with ease of use at the forefront.

One of the main weaknesses experienced was the location of the lighting switch button (Appendix A: Figures 11 and 12). Users remarked that it was too bulky, and that the location did not feel right. Subjects felt that if the button were slightly smaller and moved to the front of the handlebar (close to the orientation of the extension button) instead of towards the top, the switch would feel more natural. Another weakness of note was that the turn signal was not easy to push back in. Users experienced some friction and resistance while trying to push the turn signal back in. In future improvements there would be more clearance between the electric wires, spring, and outer tube, thus eliminating this friction and resistance.

**Future Improvements**

To continue developing this product, some changes need to be made to a couple parts of the overall design. Looking at the mechanical aspect of the product, the functionality needs to be more robust. The button that triggers the pop-out mechanism of the turn signal must work consistently. So far during prototyping, this button has only worked a handful of times. There could be several factors as to why this is. The lever itself that keeps the mechanism locked into place could be getting stuck somewhere in the outer tube. The button is meant to release this lever, but if it is just barely snagging on something, it will not release. There can also be an issue with the tiny spring that is compressed when the button is pushed and then pushes the button back to the original position once it is released. There is a possibility that the spring might be restricting the range that the button can be compressed. If the button cannot be compressed all the way, then it cannot release the lever mechanism. Overall, the whole button subsystem of the assembly needs to be optimized for ease of use, robustness, and durability.

The electrical system needs to be optimized as well. The wire routing was an issue for the prototype since it wasn't clear at first how many wires would be routed around the turn signal assembly and then to the circuit board. Due to this, the wires near the base of the assembly took up a significant amount of the available space around the inner tube. This restricted the release of the turn signal as it traversed through the narrow tube and proved to be frustrating to fix. To improve this, perhaps the wires could travel through the inside of the inner tube and so they would be hidden from getting snagged or being exposed to the elements.

The materials used for the product would need to be determined prior to manufacturing and production. The prototype was produced using a 3D printer with PLA filament. For mass production and durability purposes, this is not ideal. The FEA that was done for this prototype determined that aluminum would be the most durable material that can be used for the product. This means that the product will most likely have to be casted or machined. With casting, the product surface will most likely not be smooth. Since the mechanism requires smooth movement between components, casting will not work. The machining of the product the way it is designed currently would probably be cost-prohibitive and not ideal. The geometry needs to be improved to allow for easy manufacturing. The hollowness of some of the components as they are in the design was intended to make the product light and easy to 3D print. Prior to manufacturing, this will be changed so that the components can be machined using stock aluminum material.

## Appendix

### A. User Feedback Survey for Final Prototype

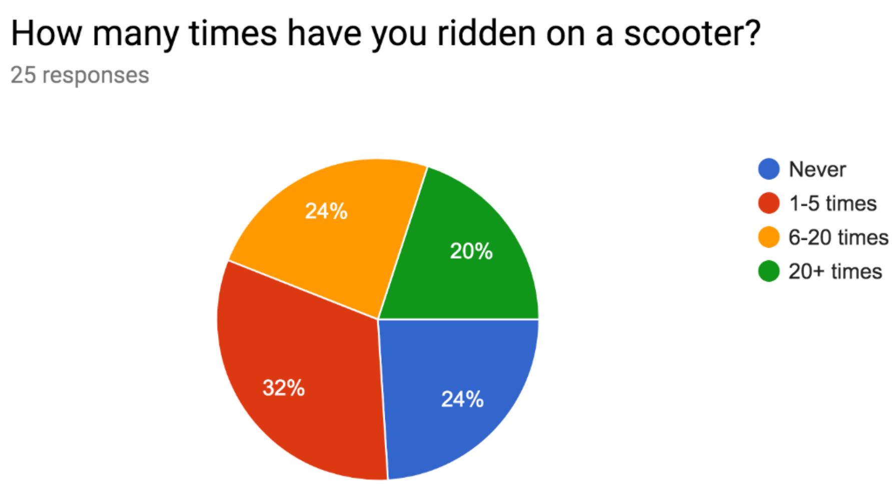


Figure 8

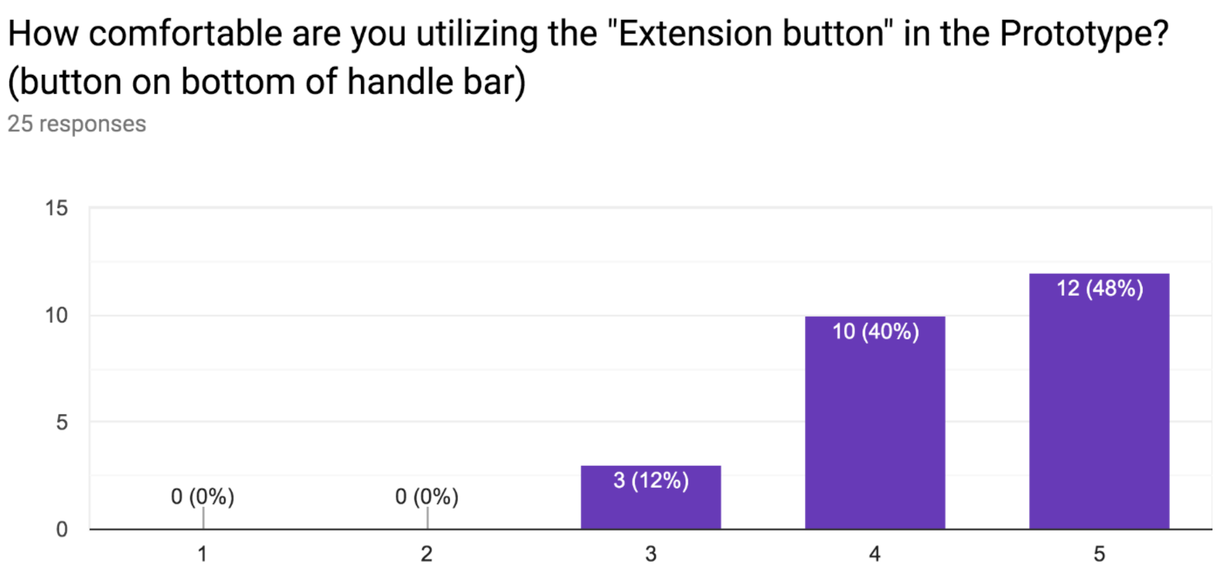


Figure 9

How confident would you feel using the "Extension button" if you were riding a moving scooter?

25 responses

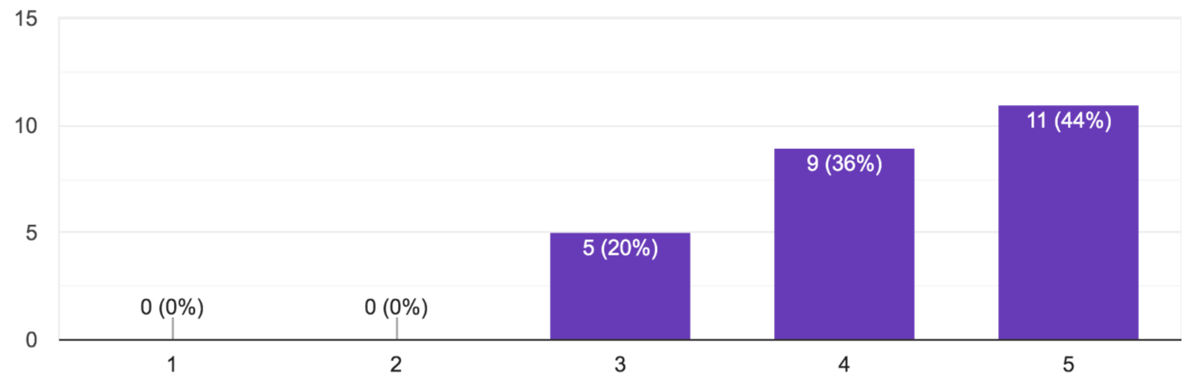


Figure 10

How comfortable are you utilizing the "Lighting switch" in the Prototype? (switch by accelerometer)

25 responses

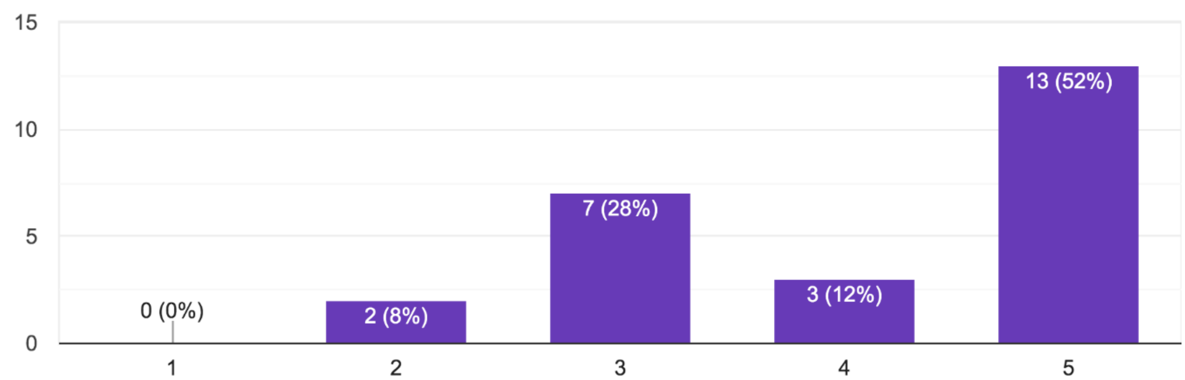


Figure 11

How confident would you feel using the "Lighting switch" if you were riding a moving scooter?

25 responses

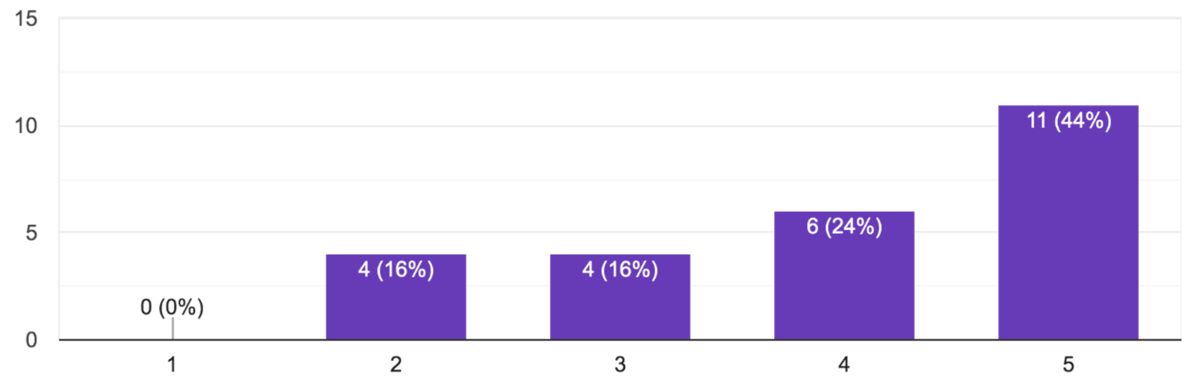


Figure 12

Overall, would you feel more safe if this turn signal were to be integrated onto an E-Scooter as a RIDER?

25 responses

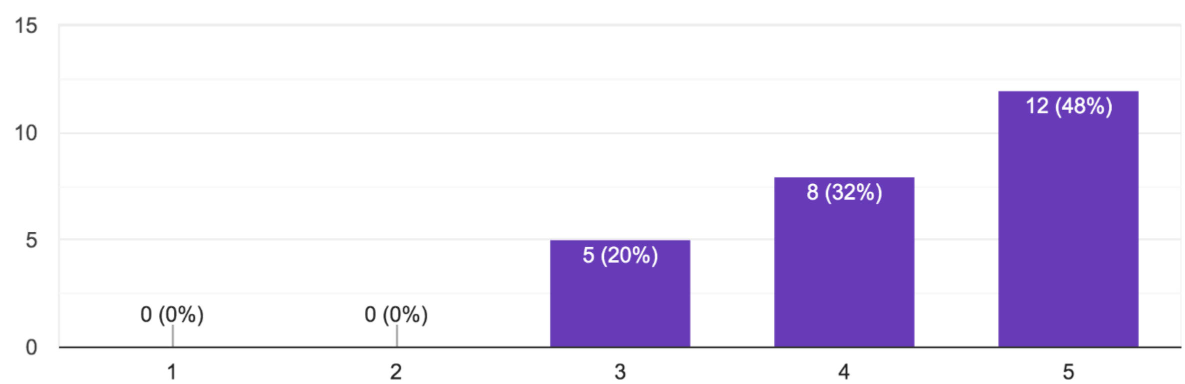


Figure 13

B. **Exploded View of Assembly**

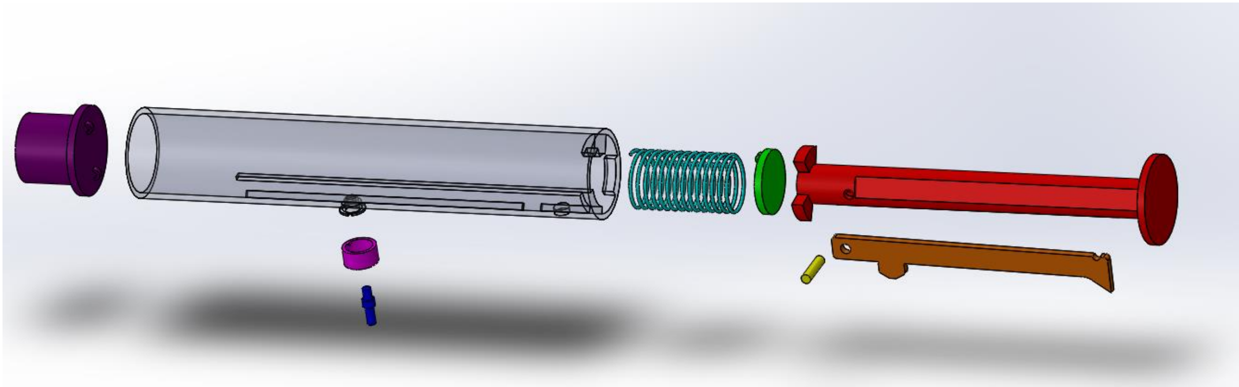

Figure 14: Exploded View of Assembly

Table 4: Exploded View Assembly Identification

| **Part** | **Color** |
|---|---|
| Inner Tube | Red |
| Lever Arm | Orange |
| Pin | Yellow |
| Spring Connector | Green |
| Spring | Light Blue |
| Button | Dark Blue |
| Button Cover | Pink |
| Handlebar Connector | Purple |
| Outer Tube | Clear |

| Criteria Description | Excellent Rating | Good Rating | Poor Rating | Points |
|---|---|---|---|---|
| Functionality/ Demonstration of use | Input about design was recorded from multiple test subjects of varying sizes. Multiple angles and situations were considered for visibility. Thorough analysis was completed about strengths/weaknesses/areas of further improvement for prototype. Proper documentation was recorded (visuals, etc).<br>Points: 8 | Input about design was recorded, but there is little variation in test subjects. Only 1 or 2 angles/situations were considered for visibility. Analysis of strengths/weaknesses/ areas of further improvement is completed but is lacking depth. Some documentation was recorded.<br>Points: 5 | Input about design was recorded from one or two group members. No angles or situations were considered for visibility. Analysis only focuses on strengths or weaknesses. No documentation was recorded.<br>Points: 2 | 8 |
| Product design problem defined | The team clearly defines the key problem being solved and how it requires user-centered engineering expertise.<br>Points: 5 | The team clearly defines the problem being solved, but explanation about user-centered engineering expertise is missing.<br>Points: 3 | Problem is defined but not clear, and explanation is missing.<br>Points: 1 | 5 |
| FEA Model | Appropriate materials are considered, analysis uses proper engineering judgement for intended use, and in-depth analysis of results.<br>Points: 6 | Analysis uses proper engineering judgement for intended use, not all details considered.<br>Points: 4 | Analysis not complete and does not properly represent intended use.<br>Points: 1 | 6 |
| CAD Model | Design clearly shows how the prototype device will integrate with the scooter. Exploded view shown. Proper details were considered when designing the scooter handlebar.<br>Points: 7 | Design shows integration with scooter, but it is not clear. Exploded view is missing components. Proper details and consideration are not considered overall CAD model.<br>Points: 4 | Design fails to show integration with scooter. CAD model is incomplete. Exploded View is missing.<br>Points: 1 | 7 |
| Professionalism | Team report exemplifies organization with few spelling/grammatical errors.<br>Points: 4 | Report is organized with several spelling/grammatical errors.<br>Points: 2 | Report is unorganized and has many spelling/grammatical errors.<br>Points: 0 | 4 |
| | | | Total Points: | 30 |