Prototyping AS 91611

Tools, Materials and Components

In order to develop my prototype for my Peg Cleaner project I used a large variety of tools, materials, and processes to produce a proof-of-concept and through to a working prototype, both materially and electronically. Some of these included:

Tools:

- Ultimaker 3D printer
- VLS Laser Cutter/Engraver
- CamCut PCB Miller
- AutoCAD
- Adobe Illustrator
- Adobe InDesign
- EasyEDA
- 2D Design

Materials:

- Acrylic
- PLA Filament
- Copper/fibreglass sheets

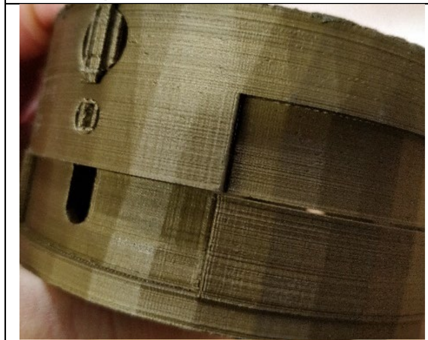
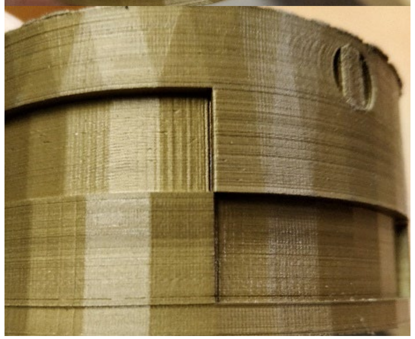
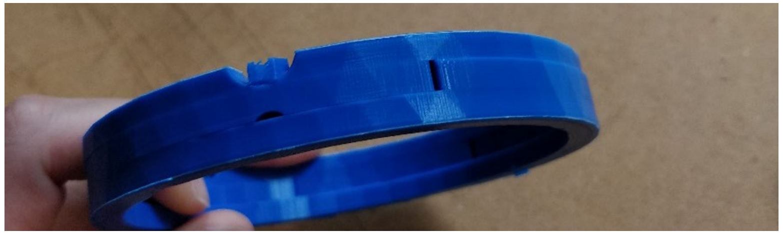
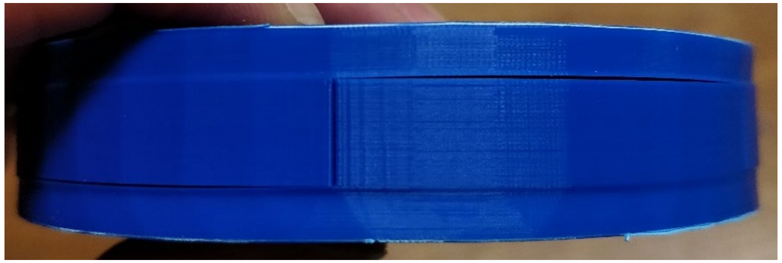
Processes:

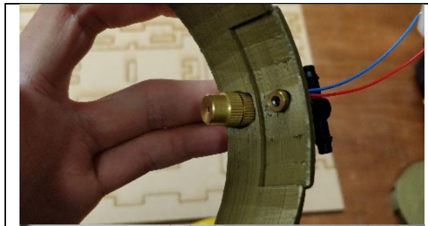
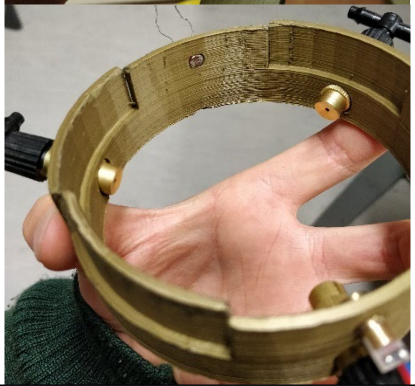
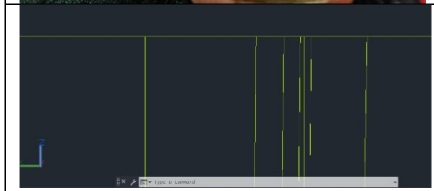
- 3D printing
- Laser cutting & laser engraving
- PCB milling
- Soldering

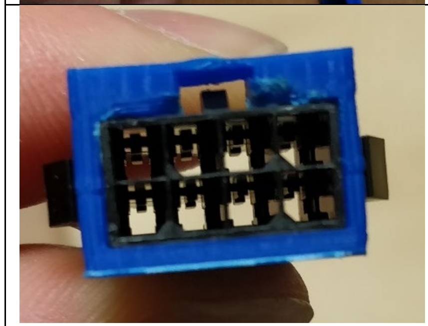
I decided to primarily use 3D printing to produce my models as it allowed me the flexibility in designs I needed, such as instead of laser cutting a 2D net of a box and gluing it together, I could simply design a 3D model of the box and print it, only needing to process the result if I used support material. If I wanted to laser cut acrylic to produce a shape such as the cylinder I had for the peg cleaner itself, I would have either had to redesign into a workable 2D shape or use a thermoplastic bending machine to attempt to produce something resembling a cylinder, and I would have never been able to produce the rounded spherical shape I had at the bottom of the 'bottle' to streamline the drainage system.

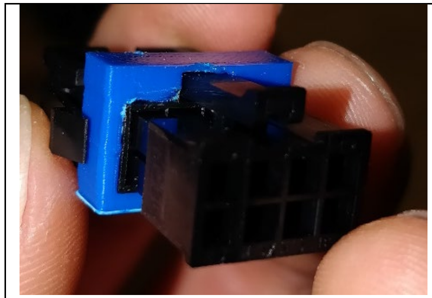
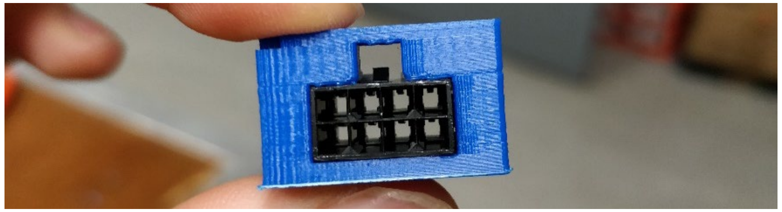
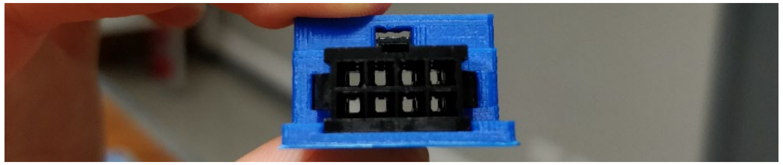
My initial plan to produce and fabricate my PCB was to use our previous Voltera prototyping machine to validate that the circuit was fully functional on a proper board and not just on the breadboard, after which I would have it fabricated by a prototyping company such as JLCPCB. Multiple aspects of the plan changed however, and I ended up not having the time to realistically send my completed PCB design off and wait for it to arrive, and also we moved away from the Voltera printed ink circuit boards back to a CNC miller. Therefore, my final PCB being used in my project was produced using the school's CNC miller.

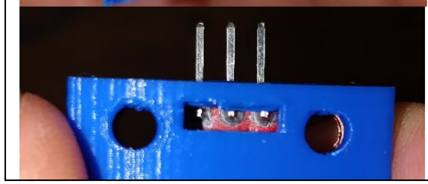
Testing and Stakeholder Feedback

Testing	Evaluation/Description	Result of testing
  	With my first test print to evaluate whether my interlocking design would work satisfactorily, I ran into issues as I did not include tolerance in my designs, which meant the models did not interlock as intended. This is likely as 3D printing is an additive process meaning that material is added rather than taken away, meaning there is a possibility for excess material, compared to the possibility for less material than expected with a subtractive process like laser cutting or CNC milling. Also, it is possible that the model has slightly warped or expanded as it does not cool instantly, all resulting in a pair of models which do not interlock.	As a result of this testing, I learnt that I needed to account for some tolerance in my designs prior to attempting to print them if I wanted to create interlocking pieces, and so I added 1mm of tolerance between the 'plates', and 0.5mm of tolerance between the edges. After re-testing this, I found that this went too far the other way and resulted in pieces that were too loose, and so I tried a tolerance of 0.5mm between plates and 0.25mm between the edges, which worked perfectly, and which met my stakeholder's standards.  *Figure 1: Far too much tolerance*  *Figure 2: Perfect amount of tolerance* *Commit:* https://github.com/JamesNZL/13CTE/commit/aa8a77da3e9661fec6106ba25978a57e9216726c#diff-478d489bfcf667342e1abaab833bd111caf388a7ed8cff49d9b7110c752adfb3

 	I then tested my measurements for my component mounting positions, which all fit well.	
	Testing taper angles to ensure a perfect fit between interlocking pieces, as in theory somewhere along the tapered edge would be the best possible tolerance level. To test this, I designed pieces with an extruded peg with its four edges tapered, and a female 'socket' with straight edges. In the image, the green lines from right to left represent taper values of -1 and -0.75 degrees which both overlap with the edge of the socket, and then -0.7, -0.65, -0.5 and 0 degrees of taper, all of which fall within the edge of the socket.	After 3D printing all the models and having my stakeholder test their performances, I found that the piece tapered at -0.65 degrees fit the best, and therefore I added a taper of -0.65 to all my interlocking faces. Testing: https://youtu.be/0a5CKYdv350 *Commit:* *https://github.com/JamesNZL/13CTE/commit/7d831fed5e6855c02678fc288ef6d3c090c2dea4*

  	I then tested my Cura 3D printing settings to see if I could improve them to get better results, particularly as my support material was extremely difficult to remove and often resulted in damage to my actual part. In this example of testing, I changed the support z distance and the support density in Cura, from 0.1mm to 0.2mm of z distance (i.e. the vertical spacing between the part and the start of the support material, a higher z distance means less adhesion), and a reduction of support density from 20% to 10%.	As can be seen in the images, the support material is now much less solid than that seen in the images above such as with the test print using gold filament, which meant these supports were extremely easy to remove, and did not negatively impact the quality of the final part.
	I then tested the measurements for my connector mount, in order to verify that it would all fit and mount correctly. I found that there was insufficient clearance in the top of the model, which required quite a bit of filing to finally result in a very tight fit.	https://github.com/JamesNZL/13CTE/commit/27d3916e76b9ce227ab2e8ded5c193118664894a As a result of this testing, I removed 1.25mm from all sides of the connector mount, and reprinted the part to see if that was sufficient. After re-testing, I found there was still adjustments needed for an optimal fit, and continued to adjust the clearances and tolerances in the model, such as in

		https://github.com/JamesNZL/13CTE/commit/66ca306ef55cf26e394b91cc1458b539f51610aa. Eventually, I refined the model to a point where the connectors mounted perfectly:  *Figure 3: View from 'exterior' of box*  *Figure 4: View from 'interior' of box*

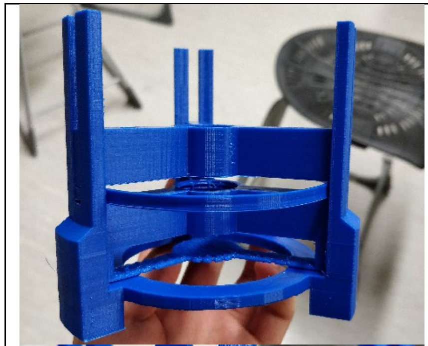
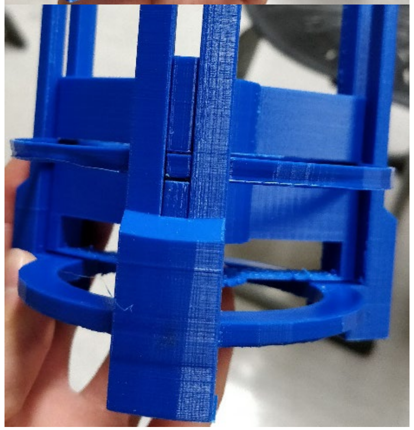
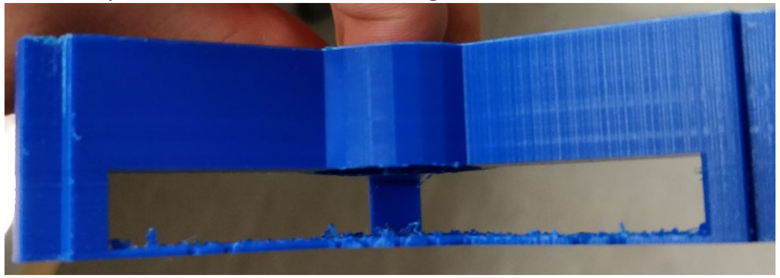
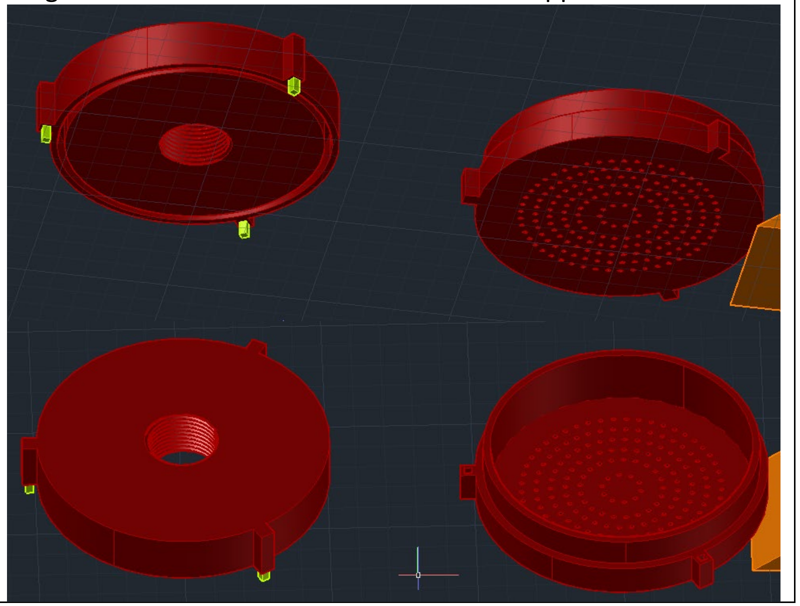


Alongside my testing of the clearances for my connector mount, I was also testing the measurements for the water level sensor to work as efficiently as possible, as I could easily fit both parts into the same print, meaning I could print both models at the end of the day and test them both the day after, instead of doing it one at a time.

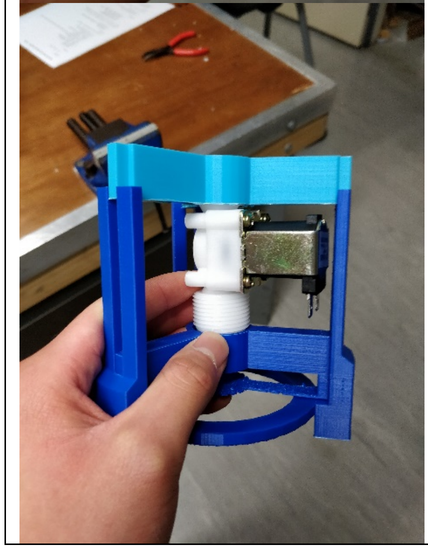
On my first version of my model for the water level sensor, I found that I had insufficient clearance for the bottom of the sensor, which required me to manually remove roughly 1.5mm of material with a knife before it fit tightly.

As a result of my testing, I removed 1.25mm from the bottom of the model: https://github.com/JamesNZL/13CTE/commit/e7651b49720eb194210a46844635a350b228c86a

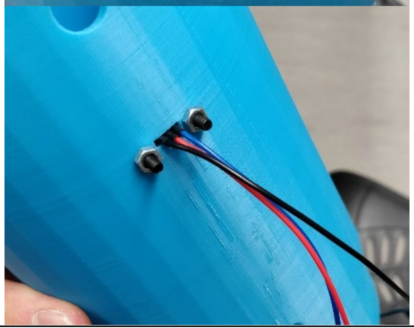
After re-testing this updated model, I found that the clearances were massively improved, and would be acceptable for my final print.

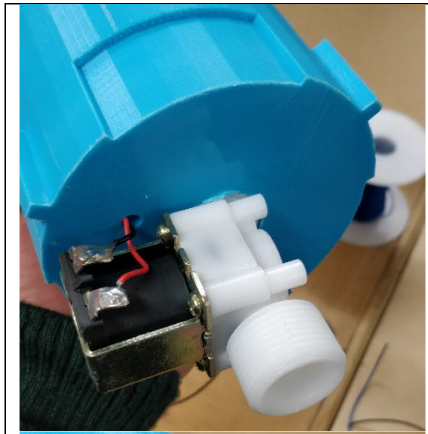
 	After I found performant values for tolerance in my interlocking lid pieces and after I applied the changes to my interlocking base components, I printed a skeleton just to verify that it was all acceptable, which it was.	As a result of testing these components however, I realised that my design for the watering rose would need to be redesigned, as for the model to print as a singular piece, it would need to be filled with support material, which would ultimately be far too difficult to remove as the only opening would be the 15mm hole at the top for the solenoid threading.  Because of this testing, I separated the rose into two components which interlock together, meaning that there is no longer a void which needs to be filled with support material. 

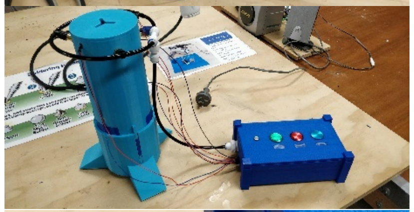
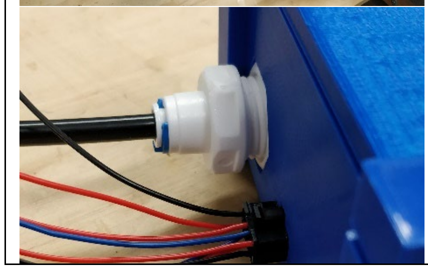
	Testing the alignment of the mounting holes for the Arduino, one of the holes is incorrectly spaced	Fixed by https://github.com/JamesNZL/13CTE/commit/4dc54e848215b89809f9dd6c7754f405596d120c
	Testing the threading for the modelled solenoid valve coupling	Perfect fit, no adjustments required



	Result of final box lid, with buttons and indicator LED mounted with holes for the acrylic button label inserts	
	Mounted female hose couplings	

	Cloudy button labels as a result of glue application	Given more time available, I would have liked to have tested this with a wider range of glue options and quantities, in order to have the best result. However, at this stage I was quite pressed for time as a result of the disruption caused this year meaning I had much less time available to physically be prototyping and testing, and after I found that using a glue stick would not be sufficient to reliably keep the acrylic labels in, I hastily used superglue, without ensuring an even application, resulting in the cloudy underside.
	Mounting of water level sensor in final printed prototype	

  	Mounting of drain solenoid valve in final prototype	

   	Completed layout of ‘plumbing’ system for water jets – the water all passes through the ‘control box’ from the garden spigot on its way to the water jets, where a solenoid valve controls whether the water is flowing or not. The hoses are all fitted with quick-disconnects at logical breakpoints as requested and decided by my stakeholder to enable easy storage.	

Fitness for Purpose of Prototype

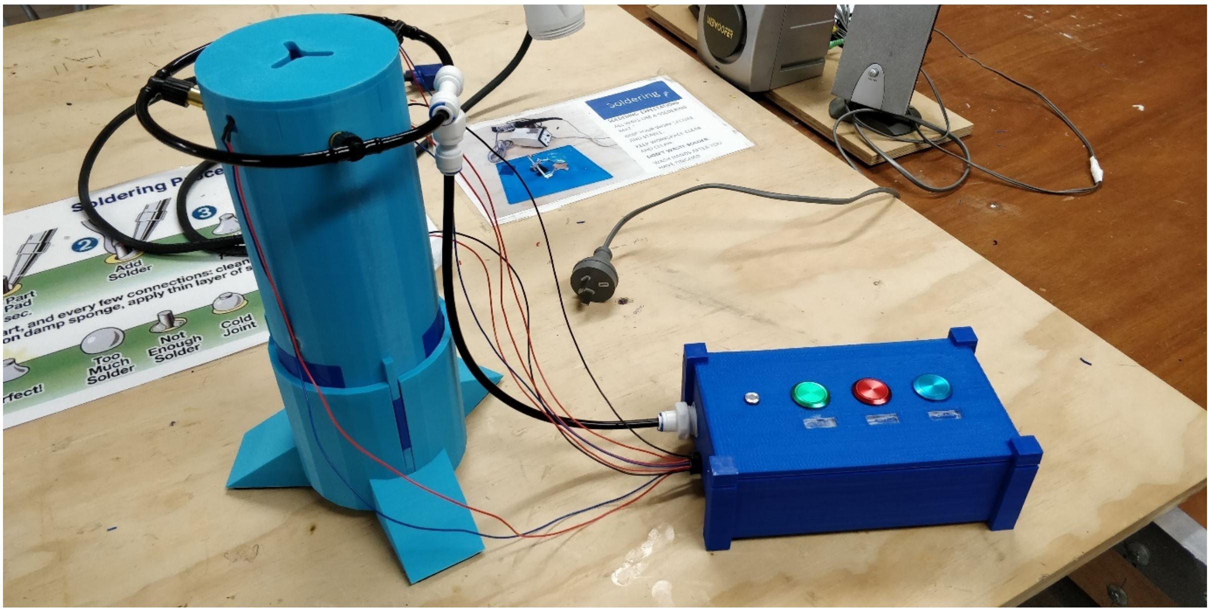


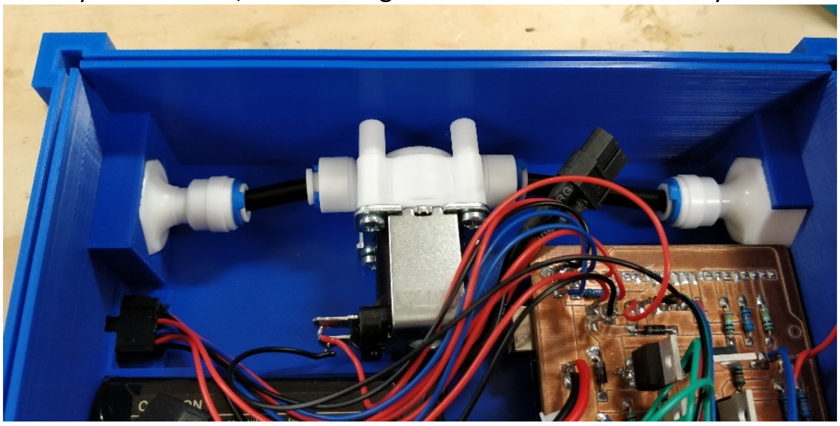
Figure 5: Final prototype

Evaluating the results of all my testing and prototyping, involving continual stakeholder consultation and feedback, the final prototype I developed was highly successful in meeting my stakeholder's brief and specifications, both physically and electronically. It is also successful in addressing the intended environment(s) where it will be used, being designed for an outdoors usage with features such as having non-slip rubber footing, to improve robustness and also prevent damage to the product itself if used on concrete. The user inputs are handled by durable industrial pushbuttons with an IP rating of IP65 for sufficient ingress protection, again to meet another of my stakeholder's specifications.

Evaluating directly against the attributes provided in the stakeholder's brief, I can again see that this prototype is very successful in being fit for purpose:

Attributes	**Evaluation**
Physical	
Lightweight. The product should be made out of 3D printed plastic or a similar lightweight and cheap material, with the added benefit of being easily manipulated and adjusted.	My prototype fully fulfils this provided attribute, consisting primarily of 3D printed models with some small laser cut furnishings, all lightweight and easily manufacturable, with extremely affordable costs for materials.
Blue, grey or black. The product should be made out of or finished in a blue, grey or black colouring.	My prototype is 3D printed with blue filament as per my stakeholder's request, though does use two different colours as the light blue filament was used up. After consulting with my stakeholder, he said that it was a non-issue as it was still a prototype, was still a blue coloured filament, and as they were two different components, where the water blaster is entirely light blue, and the control box is entirely dark blue (the dark blue piece on the water blaster is hidden when fully inserted into the base).

Professional. The product should be professional in appearance, with no messy wiring.	This attribute could and would be improved upon in future iterations, either by exploring a wireless method of transmitting information with a battery pack in the water blaster, or by looking at ways to better manage the wiring, such as with cable sleeving. After consulting with my stakeholder however, he said that he didn't mind, and that he particularly liked how easy it was to disconnect the two components due to the connector and quick disconnect in the hose.
Robust and durable. The product should be made with quality in mind, to maximise the lifespan of the product.	My prototype has been designed with multiple features to increase the lifespan of the product and to improve its durability and robustness, such as the rubber feet on the water blaster, securing wire connections/terminations in place with superglue to prevent shearing and fatigue, and using industrial grade components such as the pushbuttons and LED indicator to maximise the service life of my product.
Compact and storable. The product should be no larger than the rough dimensions of a 2L milk bottle to ensure storability and sleekness.	Although I was unable to fit it all entirely into a single physical component, after working together with my stakeholder to finalise a conceptual design I was able to design a two-part system to meet the purpose and the specifications, both of which meet the size requirements. My stakeholder was happy as although there are two separate components, he preferred to have two modular components over one large all-in-one solution.
Functional	
Automated. The product should automatically detect once a peg has been inserted and begin the cleaning process. It should also automatically drain contained water if necessary, and automatically power off if left unattended.	My prototype fully meets this functional attribute through its electronics and control system, using multiple sensors to guarantee performance. My prototype uses a laser tripwire with an LDR and a laser diode to detect when a peg has been inserted, triggering the solenoid in the control unit to allow water to flow through the jet blasters. It also has a water level sensor embedded in the side of the water blaster in order to detect a potential overflow, and automatically triggers the drain solenoid to avoid the possibility. Through its embedded software, it automatically begins/resets a 3 minute countdown after each user input, where if there have been no inputs after the 3 minutes, the device automatically turns itself off.
Effective. The product should be capable of completely addressing the issue and cleaning all debris off the peg.	My prototype uses sprinklers designed for watering gardens, with an adjustable screw-head that controls the size of the output, allowing me to control whether it produces a single powerful jet, or a fine mist. When configured properly, the jet stream produced is more than capable of completely cleaning a dirty tent peg, which both I and my stakeholder successfully tested.
Versatile. The product should be adaptable for a variety of locations and water supply systems.	My prototype can be connected to any water source provided it has suitable pressure and has a ½" male threading to fit into the receiving end of my control unit, allowing for a wide variety of water supply systems.
Stable. The product should feature a stable base with rubber or similar high-friction footing to maintain stability on sloped concrete.	As evaluated above in the point for '**robust and durable**', my prototype has rubber non-slip footing on both components for stability and protection, especially as the product is likely to be used in an outdoors environment, and potentially on concrete.

Social	
Eco-friendly. The product should be economical in its water and power consumption, and should contain all water used to be repurposed.	My prototype fully addresses this attribute by using extremely efficient garden sprinklers configured to produce a single, high pressure jet stream, with high pressure but low volume. Further, the prototype features a drain solenoid valve in the bottom of the water blaster to retain all water used until told to drain by the user through the drain button, unless the water blaster is about to overflow, in which case it will automatically drain just enough water to be at a safe level again.
Intuitive. The product should be intuitive to use, with logical and user-friendly layouts and inputs.	My prototype is extremely user-friendly and intuitive, with a connector and quick disconnect for all the connections between the two modular components, and labelled buttons and an indicator LED which will display different colours in different states (i.e. blinking, solid, etc.) in order to communicate information to the user.
User friendly. The product should be easily maintained, being easily connected to a water source and easily recharged.	As discussed above in '**versatile**', my prototype is easily connected to any water source provided the user has the correct male fitting to connect with my control unit. It is also easily maintained with a snap-on lid for the control box, allowing the user easy access to the electronics if needed. The prototype also checks the battery voltage on start-up to alert the user if the battery is getting low, or will automatically turn off if the battery level is critical. To recharge the battery, the user simply needs to open the box lid and disconnect the battery's connector, and recharge it as a normal LiPo battery.  *Figure 6: Control unit interior & battery connector*
Minimal set up. The product should not require any additional set up other than connecting a water source and ensuring the battery is charged.	My prototype fully meets this attribute, as its entire start-up process is: 1. Connect the two modules together, using the wired connector and hose fittings 2. Connect the control unit to the water source 3. Press the green on button

Iterative Development of Prototype

As discussed within the ‘Testing and Stakeholder Feedback’ section above, throughout my prototyping and development process I have been continually making changes and improvements to my design and making decisions in order to produce a better final result, and constantly consulting my stakeholder for feedback and input in order to verify that I was moving in the right direction as per their intent. Some of these changes were because I realised my initial modelled design would not work or would produce unsatisfactory results, such as the redesign I did for the watering rose, and others were for general improvements to the quality of the prototype, such as redesigning the brace around the drain solenoid valve in order to improve its structural integrity and strength. For the most part however, the final prototype closely resembled the conceptual design I developed alongside my stakeholder, and resulted in a product that fully meets their specifications and is fully fit for purpose.

Evaluation of Materials Selection

I decided early on in the development process to proceed with a design that was centred upon a 3D printed prototype, as it allowed for rapid prototyping and ease of design iteration and testing, as well as being affordable and repeatable. If I had chosen a different set of materials or techniques to produce my design, such as milling out a block of wood or piecing together sheets of laser cut acrylic, the lead time for prototyping would have been significantly longer and would have likely resulted in a prototype that was not even half-completed by the end of the year, and even more so with the even more limited time I had available to me to actually produce physical work in school this year due to the restrictions and disruptions due to COVID. By choosing to use 3D printing, I could easily iterate and develop my 3D model and design at home, and come in to school and start a skeletonised, reduced test print first thing in the morning, meaning I would usually have a completed test piece by our class period. This meant I could easily develop and iterate my design and continually have new things to show my stakeholder and to get feedback on, all of which contributed to the highly successful final prototype I produced.

If I had decided to use sheets of acrylic and laser cut them, I would have required a completely different design as it would have been far too difficult to produce a cylindrical shape, and would ultimately have resulted in a far messier final product with all the glue I would have needed to piece the product together.

Evaluation of Prototype against Specifications

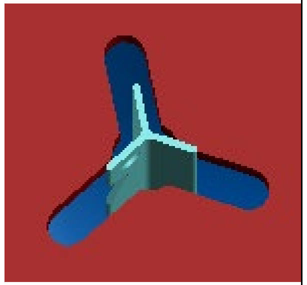
<table>
<tr><th>Specifications</th><th>Evaluation</th></tr>
<tr><td>Essential</td><td>This evaluation references all previously included evidence, and builds upon my evaluation of my stakeholder’s specified attributes.</td></tr>
<tr><td>1.1 The product must successfully address my stakeholder’s issue by completely cleaning all dirt and mud off a Sea to Summit Ground Control tent peg. This is to be met through using some type of water jets to ensure no dried dirt or mud is left behind.</td><td rowspan="5">My prototype fully and entirely fulfils these essential specifications of my stakeholder’s brief, having been designed specifically to address the brief with continual and comprehensive stakeholder consultation and feedback throughout the development and prototyping process.

As discussed above, my prototype uses an advanced control system with a variety of sensors and comprehensive embedded software in order to deliver the desired results, using solenoid valves controlled electronically in order to control the water jets that clean the tent pegs.

My product is fully automated, with a MOSFET control circuit that allows the Arduino to turn itself off, allowing me to have a 3 minute sleep timer, where after 3 minutes of user inactivity, the Arduino automatically turns itself off in order to conserve battery life. As previously discussed, other circuity includes a laser tripwire in order to facilitate an automated trigger for the water jets, and push buttons to control on/off and manual drain functionality.

My product is entirely watertight, with a single 3D-printed model acting as the body for the water level sensor, with the egress point being the input of my drain solenoid valve, which only allows water to pass through while the user is pressing the drain button or while the water level is above the water level sensor’s emergency trigger point.

My product is designed to be stable on all surfaces with a tri-footed footprint to maximise stability, with non-slip rubber footing to ensure grip and traction on all surfaces. Further, as the drain solenoid valve is effectively the only significant mass in the water blaster module, it is heavily bottom-weighted, further improving the stability of the product.</td></tr>
<tr><td>1.2 The product must be automated, requiring minimal user input. This will be achieved through a microcontroller such as an Arduino Uno, and electronic components and circuitry.</td></tr>
<tr><td>1.3 The product must have the capability to detect when a peg is inserted, automatically engaging the water jets. This is to be achieved by a laser tripwire system with a laser module and a photoresistor/LDR, to ensure maximum functionality in all conditions.</td></tr>
<tr><td>1.4 The product must be watertight to contain all used water and to protect all electronic components and circuitry. To meet this specification, I will explore production methods such as using 3D printing or laser cutting sheets of acrylic and gluing them together to ensure complete ingress and egress protection.</td></tr>
<tr><td>1.5 The product must be stable while in operation to ensure it does not tip over while in use. This must include a stable base with some type of rubber or similar footing to maintain stability on the sloped concrete at the location where the product is to be used and also to limit vibrations</td></tr>
</table>

which may damage the product and make it more likely to tip.	As previously discussed, the drain solenoid valve will only release the water contained in the water blaster while the user is pressing the drain button, or while the water level inside the water blaster is at a configured emergency level. Further, my selection for the water jets means that the water consumption of my product is minimal, with a high pressure but low volume water jet to clean the pegs. The prototype also has a watering rose built into the bottom of the drain, allowing for the device to be used directly as an imitation watering can. My prototype was also completed in time to meet the stakeholder's deadline, having been completed by the end of Term 3.
1.6 The product must be environmentally friendly. This is to include minimal water and power consumption and recycling all consumed water through watering plants and other uses. This is to be optimised by ensuring the drain has small sprinkler holes to facilitate watering directly from the product.	
1.7 The product must be robust and durable to maximise the lifespan of the product. This will be achieved through care during production and ensuring quality is always a priority.	
1.8 The product must be completed by the deadline set out by the stakeholder of the end of the school year.	
Important	
2.1 The product will have a system to turn itself on and off in order to conserve the longevity of the battery and reduce the frequency of recharging the battery.	As discussed above in my evaluation of the stakeholder's '**essential**' specifications, my product uses a MOSFET control circuit to allow the Arduino to turn itself off. This means that I was able to implement time-out and battery level monitoring systems in order to conserve battery life and protect the battery from discharging below its safe voltage threshold. The time-out system works by restarting a 3 minute timeout on each user input, such that once the inactivity period is equal to 3 minutes, the device automatically powers off. The prototype also includes a battery monitoring system, where each time the device powers on it will automatically calculate the voltage of the battery, and if it is within the 'low battery' range it will flash red on the indicator LED, or if it is 'critical', it will flash red then automatically power off in order to protect the LiPo cells.  My product is designed to be as versatile as possible, with an insert slot designed to accept as many types of pegs as is practical (shown right). It also only requires a ½" male
2.2 The product will be no larger than 270mm x 180mm to ensure compactness and storability. This is derived from stakeholder consultation and feedback, where the directive has been that the product should be no larger than the rough dimensions of a 2L milk bottle.	
2.3 The product will be highly versatile to ensure it suits as many use cases as possible. This will be achieved by ensuring the opening at the top of the product is designed to suit as many shapes and sizes of peg as possible, while still preventing unwanted ingress of objects and egress of water while in operation. Further, the product will be designed to work with a variety of water source systems.	

2.4 The product will be intuitive and easy to use, with labelled and well-designed user inputs, to ensure a smooth user experience.	threading for the water supply, meaning it will effectively accept any water source system provided it has enough water pressure and can be fitted with a ½” coupling. My prototype has labelled and colour-coded buttons for user inputs for an intuitive and user-friendly interface, with a dynamically controlled RGB indicator LED to communicate information and statuses to the user. My prototype is primarily designed and produced with 3D printed plastic, which has allowed me to rapidly prototype changes and iterations in order to improve my prototype and produce a better outcome that better meets the brief and is more fit for purpose.
2.5 The product will be economical in its water and power consumption. This will be achieved through ensuring an efficient use of water with high pressure but low volume water jets, and power efficient components that are automatically turned off if not in use.	
2.6 The product will be constructed out of a lightweight, cheap but versatile material such as 3D printed plastic. This will ensure a cost effective product that is easily developed and iterated.	
Desirable	
3.1 The product is to be user friendly, with easily removed battery and water source connectors. This will be achieved using universal connectors and well-designed layouts that are intuitive and easy to operate.	My prototype uses a variety of components designed to make it as user friendly as possible, including using quick-disconnect fittings for the plumbing system for quick assembly and disassembly, a MOLEX keyed connector to electrically connect the two modules together, and an XT60 battery connector to allow easy removal of the battery from the control box for recharging. It is also designed to be as simple as possible to set up and start-up, with the entire process consisting only three steps: 1. Connect the two modules together, using the wired connector and hose fittings 2. Connect the control unit to the water source 3. Press the green on button With the exception of the wires to connect the two modules together, I would agree with my stakeholder’s opinion that the final prototype is relatively professional in its design and appearance, with the majority of the control circuitry inside the control unit. With more time to iterate and develop the prototype I would have liked to look at exploring options for a wireless connection between the two modules or perhaps
3.2 The product is to require minimal set-up and assembly to ensure a smooth user experience, with the user only needing to connect a charged battery and connect the product to a water source. This will be met by ensuring the product is fully functional prior to delivery through comprehensive testing.	
3.3 The product is to have a professional appearance and design, with no messy wiring. To fulfil this specification, I will frequently contact my stakeholder for feedback and input on design decisions, and by ensuring components are tidily laid out in an enclosure where possible.	
3.4 The product is to be blue, grey or black in colour to fulfil my stakeholder’s requests. To best meet this specification,	

I will create a small scaled mock-up for each colour available to me to show my stakeholder how each colour will look, and obtain a final directive for which colour to proceed with.	moving from an Arduino board to just a standalone ATMEGA to miniaturise the control circuitry, or looking at getting cable sleeving to clean up the wiring.
Minor	
8.1 The product should be easily maintained by the user, with easy access to the battery for a smooth recharging process. It should also offer easy access to electronic components and circuitry to allow for easy troubleshooting.	As already discussed, the battery and the rest of the electronics is easily accessed just by taking off the snap-on lid of the control unit's enclosure, and is easily disconnected as it uses a standard XT60 LiPo battery connector. The product is highly portable and modular, being connected to each other only through two connectors, a MOLEX connector for the electronics and a ½" threading for the hosing. The rest of the prototype is also interlocking, with a base that is easily removed for easy storage.
8.2 The product should be portable, allowing the user to store it away inside their house and easily move it around. This will involve ensuring the product is lightweight and easily held.	

Evaluating my final prototype against the specifications provided to me by my stakeholder, I can see that my design and final outcome is highly successful in addressing the brief and is fully fit for purpose, and is entirely in line with the stakeholder's intent. This was also verified throughout the design, development and prototyping stages by continual stakeholder consultation, obtaining feedback on potential changes and design decisions to produce the best possible outcome.