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**Scholarship 2023**  
**Technology 93601**

**TOP SCHOLAR**

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Underwater Hockey Sticks



2023

With thanks to:

H team

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## 2 Abstract

Underwater Hockey (uwh) is a sport that was invented in England in 1954 by free divers to maintain fitness during the off-season. Today it is a global sport with a world championship every two years, although it is still a fairly niche sport around the world, it has gained popularity in NZ over the last couple of decades, with the implementation of a secondary school league and the initiation of clubs around the country. I began playing in 2020 and am very passionate about the sport, with my current height of performance being acceptance to the NZ Under 24 development squad for Age Group World Champs. As uwh is quite a small sport, there is not a lot of development or innovation happening in the equipment market. New Zealand is home to the most popular and successful uwh brand to date, but equipment is still significantly limited and there is much less range in products compared to more established sports. For this reason, I wanted to develop a new uwh stick that explores deeper in the possibilities of stick design and manufacturing while also taking into consideration sustainability and the perspective and views of the underwater hockey community. I have developed a commercially viable product that is comparable to the best uwh sticks currently available, as well as having various points of difference to explore what is possible within the market.

equipment. I also know that the primary market leaders in this sphere is a company based in New Zealand, and I have even previously personally met and played against the founder of this company / brand. I decided to contact him and ask for guidance in my project, as well as potentially reaching out to some other local companies to ask for help in different potential manufacturing processes. Having received a positive response from [REDACTED]

I have confirmed my chosen direction, and plan to proceed by beginning with extensive research in parameters, requirements, specifications, and attributes for my designs, such as materials, manufacturing processes and limitations surrounding design. After this, the main process of this project will be to develop various designs through concepting and development, followed by rigorous prototyping and testing, before eventually ending with one or potentially multiple end products, which may be able to be manufactured and retailed in real life by HydroU-WH, depending on the outcome.

### 3.2 My Stakeholder / Client

[REDACTED] is a former [REDACTED]

He is the founder and owner of [REDACTED], a New Zealand owned and operated underwater hockey brand & store, and manufacturer of some of the best underwater hockey sticks in the world, as well as a supplier of most other international uwh equipment stores. After settling on my project direction for the year, I knew straight away that I wanted to work with [REDACTED], as they are not only one of, if not the premier uwh equipment companies in the world, but are locally based and make products that I own and use. I reached out to [REDACTED] explaining my project and aims for the year and he agreed to offer his expertise and fill the client position for my project, as well as offering that a refined final product could be suitable for sale by [REDACTED]. As a locally owned and operated business and manufacturer, in a smaller market (compared to the markets of other sports such as football or rugby), he did inform me that he wouldn't be willing to discuss his exact design or

## 3 Background

### 3.1 My chosen direction

I have been playing underwater hockey for [REDACTED] and wanted to take on a project that I am passionate about, as well as one that I can work on with other members of the community to try and reach and outcome that is broadly fit for purpose and suitable for the use case. As an avid player of the sport, I realised that being such a small, yet internationally played game, there is a real lack of development and innovation in UWH

manufacturing processes simply to maintain the exclusivity of the contestable factors for his products. This was an understandable decision, and left me to explore my own contestable features, competitive factors, and innovative technological outcome throughout the product design and development process.

### 3.3 Existing Products

There are the [REDACTED] stick designers, manufacturers, and retailers in NZ and around a lot of the world. There is a history to uwH sticks, as it is not a very popular or widespread sport, for a long time there were no manufacturers of sticks, and each player would have to shape and make their own sticks from wood, and paint them black and white. In the more recent history of the sport, there has been considerable development in the community, both in terms of design as well as production, and my goal is to try and develop creative ideas and designs akin to those seen in the products available today, pushing the possibilities to the limit of official uwH stick regulations. While there are a number more stick manufacturers in modern times, [REDACTED] remain the premier brand used worldwide, and considering this along with them being my stakeholder, their products will be the standard to which I hold my outcome. Besides [REDACTED] there are a number of other creative designs which will not be disregarded

### 3.4 Typical Design

The basic layout of an underwater hockey stick needs to include a front edge, a back edge, a handle, as well as a feature that is not specifically outlined in the rules, but is practically essential; the hook. General conventions of uwH stick design involve the angles of the stick: When the handle is gripped by the player, the front and back edges will extend out from the hand at specific angles, and these angles are dependent on what the player wants from their stick. Typically, a greater forward angle on the front edge will result in a better flick (the underwater hockey equivalent of a pass, where the puck is flicked off of the pool floor using the sharp flicking wrist motion, causing the puck to roll up the front edge of the

stick and gain momentum, flying through the water). A backwards angle on the back edge of the stick typically results in a more secure hook when manipulating the puck with the back edge during play, and the interplay between these two primary factors has the majority of the impact on the mass, width, and balance of the stick as a whole. How each individual player wants to play the game can vastly effect what kind of stick is ideal for them - you might be looking for more size for consistency of control, as well as tackling and flicking power, or you might want less size for more speed and maneuverability, and some players may even own different sets of sticks for different positions. Considering these general conventions, I wanted to develop an all rounder stick, something that is largely applicable for any player or position, but primarily, I want to try and develop a product with new ideas that do not yet exist in the uwH scene - and by making the stick design a good all round model, it should be something that would be usable by anybody who wants to try a stick with the new feature/s developed, without having to compromise what they want out of a stick.

### 3.5 Attributes & Specifications

#### Attributes:

- Sustainability of design needs to be considered in product.
- It must be designed with stakeholders in mind.
- The product must be able to be held in a way that the stick has a defined 'playing area' where it extends from the hand. [The 'playing area' of the stick is that area not covered by the protected hand and forward of the thumb and index finger where they rest on the stick.]
- The stick must be considered safe: must be structurally sound, have no sharp edges, be unable to cause harm, etc.
- The product/s should be designed innovatively and attempt to incorporate a feature that does not yet exist.
- It should have a defined 'blade' aka 'playing area' and a defined handle.
- The product should incorporate researched techniques and elements such as ergonomics and hydrodynamics.

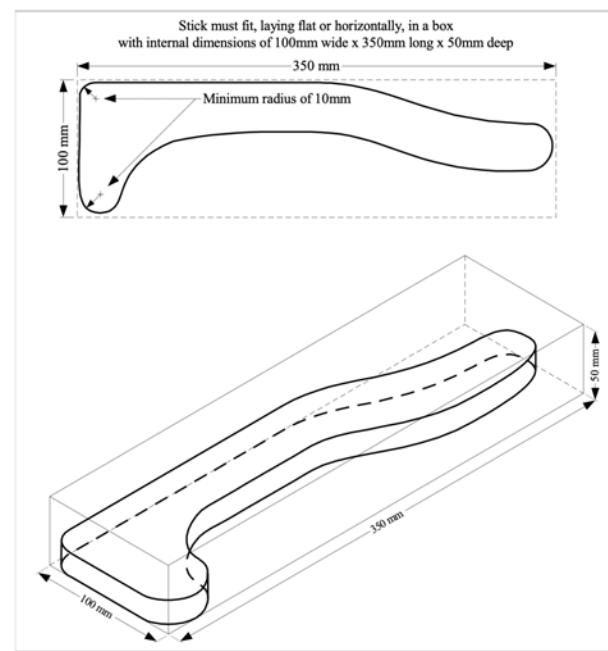
### Specifications:

- The product must fit inside a box with internal measurements of 100mm x 350mm x 50mm.
- Must have a minimum corner radius around the perimeter edge of the entire stick of 10mm
- Edges where surfaces intersect must be rounded.
- The stick must be uniformly black or white. [This is to distinguish what team each player is on]
- It must not surround the puck or any part of the hand, nor encapsulate the puck more than 50%, or lock it in place.
- It may not protrude of the heel of the hand by more than 25mm.
- Multiple materials can be used: wood, plastic, metal, glass, rubber, etc.
- You need to have some form of electronics in your project, or alternatively use complex processes to manufacture, providing your product with a point of difference from other available products.
- It must be assembled with simple tools or no tools.
- At least 2 parts of your design must be CNC machined.

within the minimum and maximum dimensions given. The illustration is only a guide. Knob(s) on stick is/are allowed. • The stick must not be capable of surrounding the puck or any part of hand, nor encapsulating the puck by more than 50%, or locking the puck to the stick. Image for reference:

FIGURE 3A

THE STICK



## 4.2 Product Environment

The environment of my product will be - while in use - underwater at most times. This means that they will spend periods of time in an underwater swimming pool environment, and will have to be designed to withstand the impacts that this can have on materials and products. They will not however be underwater for extremely extended periods of time, as the length of uwh games is typically 20 - 30 minutes, or if you are at a training session they may spend up to two hours in water concurrently: The exposure to water is not a constant one, and as such the effects of this environment will not be permanently applicable, but the product should most definitely be designed with these effects in mind and be built to withstand them to the greatest degree possible. Materials that are intended to last in an underwater swimming pool environment need to have certain features that allow them to withstand the conditions of this environment. The primary features necessary for this are:

**1. Chlorine resistance:** Swimming pools are

## 4 Research

### 4.1 International Rules

[https://drive.google.com/file/d/10zyxl\\_sitCVY9WM1Mg2v7zfERVqgRlzj/view?usp=share\\_link](https://drive.google.com/file/d/10zyxl_sitCVY9WM1Mg2v7zfERVqgRlzj/view?usp=share_link)

This is a link to a PDF of the CMAS (international uwh governing body) rules for playing area and equipment. It contains the exact wording of the rules surrounding stick design, but these rules can be boiled down to as follows.

- The stick must fit in a box 100mm x 350mm x 50mm.
- Minimum corner radius around the perimeter edge of the entire stick is as per figure 3A.
- Edges where surfaces intersect must be rounded.
- The stick must be uniformly black or white.
- The stick may be of any shape or design

treated with chlorine and other chemicals to keep them clean and free from bacteria. Materials used in the pool environment need to be resistant to the corrosive effects of chlorine. Materials such as some types of plastics, composites, and stainless steel are likely good options for chlorine resistance.

**2. Water resistance:** Materials that will be submerged in water for periods of time need to be resistant to water absorption. Water absorption can cause swelling, warping, or other damage to the material. Similar materials to those with chlorine resistance are resistant to water absorption.

**3. Slip resistance:** Materials that will be held and used for surfaces on the product need to be slip-resistant to prevent loss of grip of the player or puck. Plastic, rubber, and textured materials, are all viable options for slip-resistant materials.

**4. UV resistance:** Materials exposed to sunlight in the pool environment need to be resistant to UV damage, which can cause fading, cracking, or other damage. One again, the same types of materials in the first two features are also largely resistant to UV.

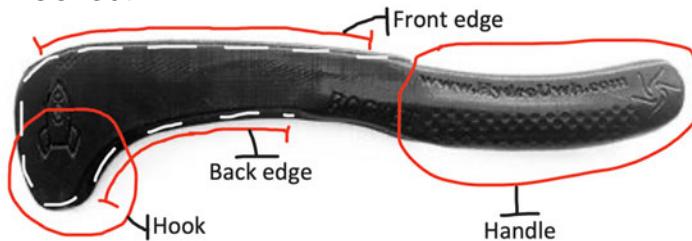
**5. Thermal stability:** Materials that will be exposed to a range of temperatures - but in this case primarily room temperature and cold - need to be able to withstand thermal changes without losing their strength or other properties. Metals and plastics often have good thermal stability.

**6. Low maintenance:** Materials used in swimming pool environments need to be easy to maintain and should not require efforts such as polishing or repairs at almost any time. Previous materials are largely durable in the relevant pool environment. Overall, the specific features required for a material to last in an underwater swimming pool environment will depend on the specific conditions of that environment, such as the chemical balance of the water, as well as the use and design/composition of the product. For my purposes, the primary factors to take into consideration will be durability, water resistance, and slip resistance. The sticks get significant use in training and games, and as such need to be as durable and have as good grip as possible, both with the puck and the user. The best ways to meet these requirements will be to use intentional design

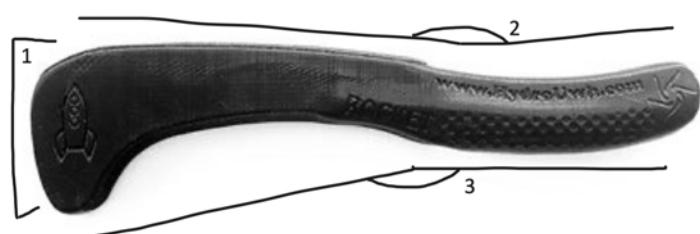
conventions to increase strength/durability, as well as grip, as well as choice of materials to once again benefit the same factors. Other than this, there are no specific constraints required for the intended environment, as outside of use they will reside in gear bags, and are by the nature of the environmental requirements will be more than suitable for this environment as well.

## 4.3 Design Conventions

Diagram of most popular HydroUWH stick 'rocket'.



Dashed white line indicates the legal playing-edges of the stick.



1 - Blade width, 2 - Front Edge angle, 3 - Back edge angle.

### 4.3.1 Playing Area

**Front Edge Angle:** A larger front edge angle will result in a stronger, faster and more consistent flick, but will inhibit vertical use making it more difficult to block flicks using a technique called 'slap down'. Often too steep of a front edge angle can reduce the back angle to keep the stick balanced, and this can in turn reduce tackling effectiveness. The generally accepted maximum front edge angle is 30 degrees. A smaller front edge angle will decrease flicking efficiency as it requires a slower and longer wrist motion, and the benefits of a larger angle typically outweigh those of a smaller front angle.



**Back Edge Angle:** This is a primary defining factor in how well the stick will tackle; as such a stick with a steeper back angle and a smaller hook will tackle as well as a stick with no back angle and a large hook. Having a deeper back edge angle or a steeper hook, can make it a lot harder to be tackled or for you to lose possession of the puck, with the puck having a greater amount of surrounding and protection from tackling.



**Blade Width:** A sticks balance largely depends on the width of the stick and particularly the blade - handle width is already constrained by hand size. It also considerably impacts puck flicking and retaining capabilities, while still needing to remain balanced, thus also finding the balance between the various benefits of angle as outlined above. Larger width gives you more mass and more impact on tackle, helps to keep the stick flat, improving aim and pass control, provides more surface area for catching and moving the puck, and have a centre of gravity towards the end of the stick increasing flick power, but the stick can be slower and more unwieldy to use. Lesser width gives you less mass thus more speed, more ability to use the stick effectively on its side, making use of the larger side surfaces of the playing area / blade, but have less stability and power. Once again this is largely dependent on your play style, but it very possible to achieve a balanced blade width with the merits of both options, and blade cutouts to reduce mass and increase speed while have a larger blade are also a prevalent option.



**Front Edge Style:** Sticks can either have a straight or curved front stick, and these both have their own relative merits, although they have less impact on play style than other factors. Curved front edges reduce mass and taper the front angle away so you can have

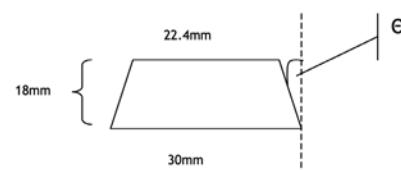
width to facilitate strong flicking without compromising as much speed and maneuverability, however it does decrease flick consistency due to an inconsistent angle. Straight front edged sticks primarily increase the consistency of the flick, as the puck will be travelling at the same angle no matter where it begins from on the blade.



**Stick Depth:** Slimmer sticks will move faster through the water, however too thin will result in control issues, being unable to properly direct the puck. Thicker sticks will reduce speed but increase impact, having more mass and allowing stronger motions and tackles. Conventional stick depth ranges from only 14mm at the thinnest to the thickest at 20mm, with the comfortable midrange being 16-16mm.



**Bevels:** Beveled edges help to slightly lift the puck off of the floor and enable easier passing, but the more bevel introduced, the more difficult puck control becomes. The path is the use the least amount of bevel that allows you for a strong and consistent flick. Typical bevels range from 8-12 degrees.



**Hook:** This is a very important aspect of the stick, used for tackling and curling away the puck. Generally, flatter hooks allow for better back edge flicks, while deeper hooks allow for more security and control of the puck while in the hook. The puck tends to sit in the most curved point of the hook, and having a completely smooth and consistent hook will mean the puck has nowhere to sit and will become difficult to control in the hook, but the deeper hook will reduce options for puck maneuverability. Range of motion and degrees of contact are also important factors to consider in hook depth and curvature.

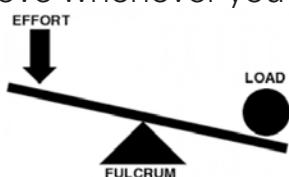


**Length:** This primarily impacts balance of the stick, and has a far less pronounced effect on the speed or movement, mainly adding or removing mass, which can increase reach, and more importantly fine tune the balance point of the stick.



**Balance:** This is a highly important and highly variable factor to consider in stick design, and can have a very significant impact in the sticks capabilities, as having an unstable balance point will render the stick more or less useless.

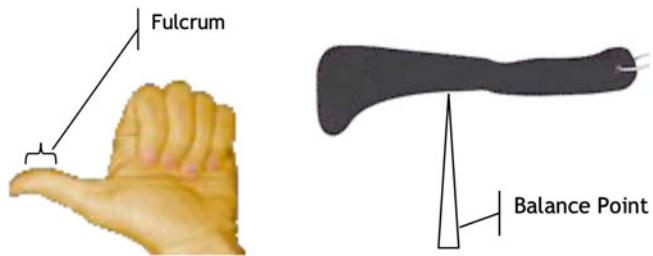
The balance point of the stick is the centre of gravity and the point around which the stick will move whenever you alter directions.



A balance point too far to the blade will feel clumsy and unwieldy, rotating too much around the playing end of the stick and reducing leverage, although may be partially mitigated by additional reach, and a balance point too far to the handle will feel light, unstable and oversensitive, and will have reduced power in the flick.

An important factor to consider in the balance of an uwh stick is the grip; the way in which the stick is gripped involves holding the stick with your fist, while the thumb is extended akin to a horizontal thumbs up (pictured first on the left), and the pad of your thumb in this position acts as a fulcrum (a pivot point at which a lever turns - pictured second on the left) around which you apply force to the stick. The closer your sticks balance point to your thumbs fulcrum, the more mobile the sticks movements will feel, allowing faster, cleaner and easier movements and manipulations of the puck. Typically the centre of gravity is balanced to around a couple centimetres off of the thumbs fulcrum point to allow

more leverage for flicking and tackling with power.



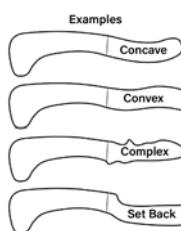
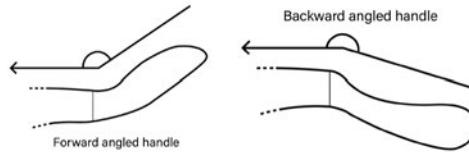
#### 4.3.2 Handle

**Grip Style:** The type of grip you use on your stick dictates the ideal design and conventions of your handle. Typical gripping style ranges on a spectrum between power (upper left photos) and control (lower left photos). Whichever your primary grip styles tends towards should be the main way in which your stick is designed to be gripped. A more powerful grip means the thumb reaching down the stick for balance and power, which results in consistent flicks, powerful tackles, and general strength behind the puck - this is the most effective and widely used grip in the sport. It is also suitable for most shapes of handles and highly versatile. A more control-focused grip means having the thumb opposite the forefinger on the stick, and gripping in this way can allow for more dexterous movement, but reduces power considerably and significantly weakens flicks. It is not as versatile and is much better suited to a curved handle design. It is entirely possible to range and shift between these styles, and an ideal handle is one that is universal and able to accommodate any desired grip style within reason.



**Handle Front Edge:** The front edge of your handle is important in terms of grip comfortability and grips that are actually comfortable and plausible. It also gives relative definition to the angle of the front edge of your stick, as the angle at which your handle's front edge extends from the playing area will define the angle at which your playing area is held. The front edge of the handle can be straight, concave, convex, complex, set back, and incorporate oth-

er features such as finger notches, etc. The best middle ground option for a versatile stick is a balanced degree of concavity, which allows for a comfortable grip in every style, accentuates in the impact of index and pinky finger allowing for more finesse in movements. Avoiding setting back the handle or incorporating finger notches is also pertinent, as these reduce the benefits of having your thumb as a fulcrum, weakening it by forcing a bend, as well as you will have your fingers locked in place and be unable to vary your grip style.



**Handle Back Edge:** The handle's back edge is additionally heavily influenced by the design of the front edge but there is a much simpler rule of design for the general shape / curve, and that is to create a comfortable and stable gripping surface for the palm of your hand, which is only ever done with a convex shape to avoid breaking your thumb when tackled, and you mostly have to figure out the right degree of curve so as to be comfortable but not lock your hand into one position. Thus because the back edge curve is already defined, the primary consideration of the back edge of a handle is thumb placement.

- One of the most common, popular, and versatile options is to add a thumb groove, usually located under the fulcrum point to assist in transferring power into tackles and flicks. These can be as subtle or exaggerated as desired to differing results.



- Another option is a thumb kink, having the blade angled sharply forwards relative to the handle, allowing the thumb to be placed strongly against the back edge of the blade, which helps brace the stick and transfer power, but locks the grip and reduces versatility and makes numerous skills impossible.

- Alternately you can use a knob, which is a raised section of the back edge that the thumb can press against, and bracing your thumb in this way can help transfer power into your movements, but will also smash into your thumb when being tackled.



- You can also have nothing, keeping the back edge as a smooth seamless curve, which essentially offers no benefits but no downsides.



**Handle Width:** Handle width can greatly impact playing style, changing the dynamic of the stick through both the overall balance as well as the grip capability. A wider handle allows for better grip and better power transmission, having better contact through the base of the thumb meaning greater spread of impact. A thinner handle allows for easier rotation of the stick with smaller movements allowing for greater precision in puck control and increased range of motion, but reduced gripping power and strength. Handle width also affects the angle of the front and back playing edges, allowing thinner handles to get better angles out of narrowing blades. Handle thickness can also vary along the length, and this can have similarly various effects on the success of puck skills and flicks, but all changes make small differences, and typically handles have a slight increase in width towards the end.



### Permutations:

**Undercutting** - Taking a few mm of the bottom of the handle reduces the overall size of your handle, and gets your playing area closer to the pool floor, reducing the offset of the protective rubber glove worn on the playing hand.

**Raised handles** - Helps to get the playing area closer to the bottom without reducing handle thickness, but makes using the stick inverted that much more difficult.

Angled handles - the handle follows the taper of the blade, helping it stay raised from the bottom while maintaining a consistent top surface, and is a similar and similarly viable option to undercutting.

All of these design conventions and features of underwater hockey stick design carry their own weight and impact in the design of an uwh stick. As they frequently impact similar or the same aspects and features of the product, they must be carefully considered relative to each other, and balanced in the design so as to end up with a balanced stick. As I am aiming for a summative design in terms of form, to make the stick as versatile and effective for the widest range of players possible, the innovation and experimentation will come with original and unique design conventions, as well as material use.

#### 4.3.3 Relevant Concepts

**Physical Ergonomics:** “Physical ergonomics is concerned with human anatomy, and some of the anthropometric, physiological and bio mechanical characteristics as they relate to physical activity. Physical ergonomic principles have been widely used in the design of both consumer and industrial products for optimizing performance and prevents injuries.” Wickens; Gordon; Liu (1997), An Introduction to Human Factors Engineering. Ergonomics relate to the comfort and suitability of a product for use by human anatomy, and as such the ergonomically based part of this product will be the handle. As prior discussed, there are a number of design features and factors that influence the comfort and suitability of an uwh stick handle, and these must be balanced or incorporated with principles of ergonomics so as to develop the best possible design. This will mean focusing on the handle design to achieve comfort, strength and versatility in gripping, designing it to fit the natural shape of the human hand in a comfortable and secure position without causing any discomfort or difficulty.

Typical concepts of ergonomic design - specific to handle design - that I will need to consider in my design process are:

- Comfort: Must fit the shape of the hand

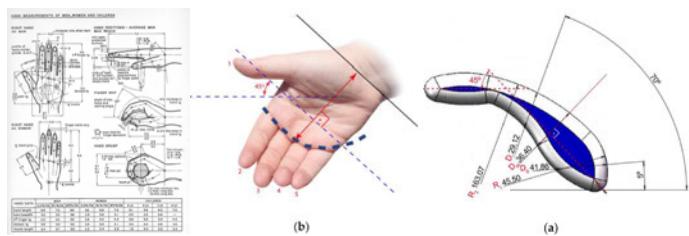
with contours to provide support for the fingers and palm

- Size: The handle needs to be a suitable size for most people, or I potentially need to develop different size options to cater to a larger variety of people.

- Material: It will need to be made from something with a comfortable and secure gripping surface and texture.

- Weight: This means the stick will need to be balanced to increase comfort and ease of use.

- Adaptability: It must be adaptable to a wide variety of different users, with different hand size, shape, strength, as well as those with different preferences for gripping style.



**Hydrodynamics:** “In physics, physical chemistry and engineering, fluid dynamics is a sub-discipline of fluid mechanics that describes the flow of fluids, liquids and gases. It has several sub-disciplines, including aerodynamics (the study of air and other gases in motion) and hydrodynamics (the study of liquids in motion).” Hydrodynamics are relevant to this product because they will define the way it will move through the water, specifically drag and resistance. Developing a design with elements and principles of hydrodynamics will be important to help the efficiency if the sticks movement through the water, and thus its efficacy in its primary purpose of efficient design for use in underwater hockey. The primary factors that must be considered in terms of hydrodynamics are:

- Shape: The products shape is a key factor in hydrodynamics. The stick should be designed to minimize drag and turbulence, which can slow down the player’s movement and reduce control over the puck. A streamlined, tapered shape with a smooth surface can help reduce drag and improve efficiency, but this must be balanced with material choice to retain texture and grip.

- Surface roughness: This can also have an

effect on the hydrodynamics of the product: A rough surface can create more turbulence and increase drag, while a smooth surface can reduce turbulence and improve efficiency. Thus, the stick's surface will should to be smooth and free of bumps or irregularities wherever possible.

- Material: Using a light, stiff material for the product can help reduce the weight of the stick and improve the player's speed and control. Some classically and typically popular materials include wood, plastic and on occasion, fibreglass or carbon fibre.

- Blade design: The design of the blade aka playing area is also important for hydrodynamics. A thin and sharp blade, with a smooth surface will reduce drag and improve maneuverability. Ideally the shape of the blade would be optimized for the player's preferred playing style, for example quick manoeuvres or strong shots, but with my product I intend to try and balance the capabilities and downsides of the stick as much as possible, including in terms of hydrodynamics.

- Player bio-mechanics: The design must also take into account the bio-mechanics of players. The length and shape of the stick should be optimized for the averaged size, strength, and balanced playing style. A stick that branches to any extreme will negatively affect the products hydrodynamics and performance.

weight and will make the stick sink naturally in the water, it will also provide greater impact, better resistance to impact, stronger flicks, and likely be structurally stronger, albeit will be heavier. Less density on the other hand will decrease the mass and thus the weight.

- Flexibility: This is the tendency of a material to flex or temporarily warp along its length when placed under force. Sticks with greater flexibility are prone to flexing during powerful impacts and can be unpredictable or lose the puck at important moments, however they do add some spring force to flicks.

- Compaction: The compaction of a material describes its ability to accept localised impacts. Materials with low compaction will often cause the puck to bounce off of them very easily when impacted. Softer materials have a higher degree of compaction and under impact the puck will indent into the material, absorbing an amount of the impacts force, while improving contact with the stick and thus control.

- Texture: This related directly to the amount of control exerted over the puck by a movement of the stick. It creates the sticks 'grip'; a smooth and glassy surface would slide along the side of a puck, while an edge with too much variety will have no consistency to its grip, with the ideal propose of texture being to increase surface area and variation.

**Material Qualities:** The material/s used to make the stick plays a very large part in a number of different aspects of your play when using the stick. Every type of material and every variant within those types will give you a different result with the exact same shape. There are numerous advantages and disadvantages for every material you could plausibly use, but the qualities of materials that need to be factored into your design are the same:

- Density: This is the amount of mass contained within the volume of the stick. More density brings more mass and thus more

## 4.4 Materials

**Wood:** This is the traditional material used to make underwater hockey sticks by each individual, and the primary consideration in terms of species of wood was the degree of hardness, ranging from soft woods such as pine, to harder woods like oak, with the most wide-

ly popular being somewhere in-between leaning towards higher density, although wood is used less and less with the modern emergence of more versatile materials. Some of the most popular historical choices of woods are:

1. Ash - This has been a highly popular choice for hockey sticks due to its flexibility and durability. It has a medium to high density, which makes it suitable for use in underwater hockey. One of the drawbacks of using ash is that it can be prone to splitting, especially if not properly dried or treated.

2. Birch - Another dense and durable wood that can be a good choice for underwater hockey sticks. It has a straight grain pattern, which can make it less prone to splitting than other woods. However, birch can also be heavy, which may make it less popular among players who prefer lighter sticks.

3. Maple - A popular choice for hockey sticks again due to strength and durability. It has a high density, which makes it a good option for sticks. One of the drawbacks of using maple is that it can be brittle and prone to breaking if not properly maintained.

4. Spruce - This is a lightweight wood that can be a good choice for players who prefer a lighter stick. It has a low to medium density, which makes it less durable than some of the other woods on this list. However, spruce can still be a good option for players who value speed and maneuverability over durability.

**Plastics:** These are a modern advancement in the uwh product scene, with most players today using plastic sticks for the benefit of their relatively low cost, durability, and strength. My client has experimented with different plastics and narrowed down to the most effective plastic for his manufacturing process - Polyurethane, as many other plastics are not versatile or durable enough while remaining cost effective enough for use in underwater hockey. Polyurethane is a type of polymer plastic that is highly versatile and can be produced to have a range of different properties, such as flexibility, hardness, durability, etc. This plastic is very fitting in applications requiring high durability and abrasion resistance, with very good chemical resistance and generally being able to withstand wear and tear.

This makes it a very suitable material for underwater hockey as it will not degrade from swimming pool chemicals, or receive significant damage from impact from tackles or abrasion against other sticks or the pool floor. It is also highly mouldable making it a feasible option for production, albeit it is prone to degradation over time if exposed to UV light or high temperatures, although this is not an issue for this purpose.

Additionally, There is an alternate option depending on manufacturing style, such as Polyethylene which is used in injection moulding, however this is much more expensive and less plausible for my project, more likely would be the use of Polylactic Acid (PLA) which is the bio-plastic used most commonly in 3D printing filament.

**Rubber:** This is a material seen in some of the more advanced underwater hockey sticks sold by HydroUWH, and it is implemented as an outer coating over the hard plastic core of the stick. This is a highly effective design and something I may look in replicating or developing in my product. The primary properties of rubber are elasticity, compaction, grip and resistance to abrasion and tearing:

1. Flexibility: Rubber is a pliable material, allowing the blade to compact and grip on contact with the puck. This flexibility helps players effectively manoeuvre the puck in the underwater environment.

2. Grip and Control: Rubber coating provides an excellent grip on the puck due to their natural tackiness. This ensures better control and precision during games.

3. Durability: The rubber used in underwater hockey sticks is typically firmer, resilient and able to withstand the abrasive pool surfaces. This durability ensures that the stick's blade can endure the rigors of the game and resist wear and tear. Resistance to Water: Rubber is naturally water-resistant, which is vital for underwater hockey sticks.

**Polyurethane Foam:** This is a polymer composed of organic material - which is good for sustainability - that can be manufactured into a solid foam. It is commonly used as a thermal insulator, and is produced in rigid boards. My teacher suggests use of polyure-

thane foam as a material to produce prototypes quickly and easily in the conceiving stage. Because of the foams properties, being very light but still dense, it is firm and solid to create prototypes, but still easy to sculpt due to how easy it is to sand and reduce material.

## 4.5 CNC Machining

**Laser Cutting:** “Laser cutting is a technology that uses a laser to vaporize materials, resulting in a cut edge. While typically used for industrial manufacturing applications, it is now used by schools, small businesses, architecture, and hobbyists. Laser cutting works by directing the output of a high-power laser most commonly through optics. The laser optics and computer numerical control is used to direct the laser beam to the material.”

Laser cutting is a potential option for this project as it can quickly and accurately cut shapes into layers, which I could use to create a base shape or prototype for my design. I have a decent amount of experience with laser cutting having used it to make a cardboard prototype of a prior product, as well in a structural feature, eventually achieving good results.

**3D Printing:** “3D printing or additive manufacturing is the construction of a three-dimensional object from a CAD model or a digital 3D model. It can be done in a variety of processes in which material is deposited, joined or solidified under computer control, with material being added together (such as plastics, liquids or powder grains being fused), typically layer by layer.”

3D printing is a very good potential option for my product, as it is a very easy way to make highly accurate physical 3D models out of digital 3D models, and this is very suitable for my project thanks to the efficiency, ease of use, and accuracy of 3D printing. I could even use 3d printing to make the actual sticks themselves, or reverse models for mould making. I have a lot of experience 3D printing, having my own 3D printer and using it frequently, as well as using the printers at school on various occasions.

**CNC Router:** “A computer numerical con-

trol (CNC) router is a cutting machine which typically mounts a hand-held router as a spindle which is used for cutting various materials such as; wood, composites, aluminum, steel, plastics, glass, and foams. CNC routers can perform the tasks of many carpentry shop machines and can also cut joinery.”

A CNC router is a good potential option for the manufacturing of my product, as it is a very accurate and precise method of cutting material to shape, as well as being relatively easy to transition from CAD to CAM in Fusion360, making it convenient for my purposes. I have used a CNC router at the school at considerable length for multiple prior products and as such am very capable of using them quite efficiently to good results.

## 4.5 Legal & Ethical Considerations

1. Compliance with regulations: My design and manufacturing of underwater hockey sticks should comply with applicable legal regulations and standards, such as safety, environmental, and health regulations.
2. Intellectual property: My design and manufacturing of underwater hockey sticks should not infringe on any intellectual property rights, such as patents or trademarks.
3. Fair labour practices: I need to ensure that fair labour practices are in place, such as fair wages, safe working conditions, and no use of child labour or forced labour.
4. Environmental impact: I must consider the environmental impact of the product and minimize any negative effects. This includes reducing the use of hazardous materials, minimizing waste, and promoting sustainability throughout the product life-cycle.
5. Product safety: I have a responsibility to ensure that the product is safe for use and does not pose any risk of harm to users. This includes conducting appropriate testing and quality control measures to ensure the product meets safety standards.
6. Transparency and disclosure: I should be transparent about my manufacturing processes, materials used, and potential environmental and social impacts of the product. This includes disclosing any potential

risks associated with the product and being transparent about any efforts made to minimize those risks.

7. Product liability: I will be liable for any harm caused by the product. My design and manufacturing of the product should consider potential risks associated with the product and include appropriate safety measures to minimize those risks.

Another relevant application of legality and ethics is the specific intellectual property of my stakeholder / client HydroUWH: As a smaller scale business operating out of NZ, they are very liable to being ripped off and undercut by manufacturers with cheaper production costs. As such, they do not want to share explicit details on their methods both in terms of design and manufacturing, and this is something that I have been asked to take into consideration.

## 4.6 Product Life-cycle

A product's environmental life-cycle refers to the impact that the product has on the environment throughout its entire life-cycle, from the extraction of raw materials used in its production to its disposal or recycling at the end of its useful life. This primarily relates to the environmental impact and sustainability of the product.

1 - Raw material extraction: The process of extracting raw materials for the production of a product, such as mining for metals or harvesting trees for wood, can have significant environmental impacts. This includes deforestation, habitat destruction, and soil and water pollution.

2 - Manufacturing: The manufacturing process can result in greenhouse gas emissions, air and water pollution, and waste generation.

3 - Distribution and transportation: The transportation of products from manufacturing facilities to warehouses and retail locations can result in carbon emissions from vehicles and airplanes.

4 - Use: The use of a product can result in energy consumption, greenhouse gas emissions, and other environmental impacts, depending on the type of product.

5 - End-of-life: The disposal or recycling of a product at the end of its useful life can also have significant environmental impacts.

Landfills can result in soil and water pollution, while recycling can reduce the need for raw materials extraction and manufacturing.

Understanding the environmental life-cycle of a product is important for companies and consumers to make informed decisions about the products they produce, purchase, and use. By analysing the environmental impacts of my product throughout its life-cycle, I can identify opportunities to reduce environmental footprint and develop a more sustainable product.

### ***Material Considerations:***

**Woods:** Sourcing of the wood and the impact of deforestation on the environment. Sustainable wood sourcing practices, such as using wood from certified forests or reclaimed wood to help reduce the environmental impact of wood-based products.

**Plastics:** Use of non-renewable resources in their production, the generation of plastic waste, and the negative impacts of plastic waste on the environment. Practices can be utilised such as using recycled plastics or biodegradable plastics, reducing the volume of single-use plastics, and implementing recycling programs to minimize the environmental impact of plastic products.

**Rubbers:** Environmental impacts of rubber production and disposal. Sustainable practices include using recycled rubber or natural rubber from sustainable sources, reducing the use of rubber in products where possible, and implementing recycling programs to minimize the environmental impact of rubber-based products.

### ***Sustainable Options:***

- Use recycled plastic or bio-plastics made from renewable resources.
  - Opt for plastic-free alternatives or design products that can be easily recycled at the end of their life.
  - Implement closed-loop recycling systems to reuse plastic waste and reduce the amount of plastic sent to landfill.
  - Use recycled rubber or natural rubber from sustainably managed rubber plantations.
  - Minimize waste and energy consumption during rubber processing
- Consider using rubber alternatives like sil-

icone or biodegradable rubber to reduce the environmental impact of rubber production and disposal.

Overall, the primary product life-cycle considerations for the design, manufacturing and use of underwater hockey sticks are:

1. Raw Material Sourcing: The environmental impact of raw material extraction and transportation should be considered. The materials used in the production of the underwater hockey stick should be responsibly sourced, environmentally friendly, and preferably locally sourced.

2. Manufacturing: The production process should be optimized to minimize waste, reduce energy consumption, and prevent pollution. Efficient production processes such as computer-aided design (CAD) and computer-aided manufacturing (CAM) could be employed to reduce waste.

3. Durability: Underwater hockey sticks should be designed to last long and be able to withstand the harsh underwater environment. Durability reduces the need for frequent replacements and helps to minimize the overall environmental impact of the product.

4. Packaging: The packaging of the product should be minimal and made from recyclable materials. The packaging should be designed to reduce the product's environmental footprint, minimize waste, and facilitate recycling.

5. Transportation: The transportation of the product from the manufacturer to the retailer or customer should be optimized to reduce carbon emissions. Transporting the product in bulk, using efficient modes of transportation such as rail or sea, and choosing carriers with a low carbon footprint can help to reduce emissions.

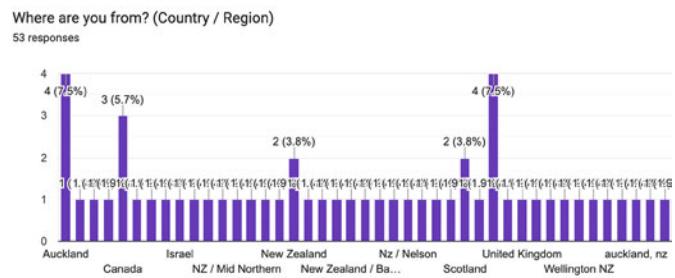
6. Use: Underwater hockey sticks should be designed to be ergonomically comfortable and easy to use. This reduces the likelihood of damage and increases the lifespan of the product.

7. End of Life: Underwater hockey sticks should be designed to be easily disassembled and recycled at the end of their life. This includes separating different materials used in the product, making sure that the materials used in the product can be recycled and disposed of safely, and developing

systems for take-back and recycling.

## 4.7 Consumer / Player-base Survey

For research into the player base, I created a survey with the outline of my project, and a number of the more experimental conventions that I want to explore, asking what people would want to try, along with their thoughts on the concepts, and any ideas they had for concepts. I posted this in numerous online forums for uwh, including my club, the regional, national and international Facebook groups, and asked for their location to get an idea of where my feedback was coming from:



I received around 65 responses total in the end, with around 40 coming from various locations around NZ, primarily Auckland and Wellington, but including Christchurch, Taupo, Bay of Plenty and Nelson. I received a number of responses - about 10 - as well from the UK, with a couple specifying England, and numerous specifying Scotland. There were a few responses each from both Australia and Canada, as well as some responses from further countries such as Poland, Israel, America, Hungary, Netherlands, and Romania.

The survey asked where participants were from, what sort of concepts participants would be interested in trying in a stick design, as well as any related thoughts, opinions or experiences. For the first question, the options with the highest rates of interest were a malleable / shock-absorbing handle, edges or knobs for puck grip, and a modular stick. Everything else received a decent amount of interest, with the lowest rate of interest being in a magnetic blade, as this would not be effective when playing with a lead puck as around 99% of games are, with the only time steel pucks are used being for the rare occasion

of a significantly different pool floor surface. I also received a lot of suggestions and opinions, the most prevalent being:

- Grip on the puck is very important to the players surveyed, for general play as well as effectivity of flicks and skills
  - Strength needs to be balanced with speed through water
  - Anything too innovative or drastic is liable to be disallowed by tournament organisers or referees
  - Suggestions around existing designs eg. horizontal blade cutouts, internal reinforcement.
  - Suggestions for new designs eg. metal framing for strength, differing handle sizes.
- I also received a large number of interesting but illegal or unrelated ideas which I will unfortunately not have the time to explore in this project.

Overall I think there is some very good feedback presented here, a lot of good opinions and ideas, and I will take all of this into account and refer back to these responses when necessary throughout this project. I also want to make a refined list of ideas and do a second survey including visual aides later in the project.

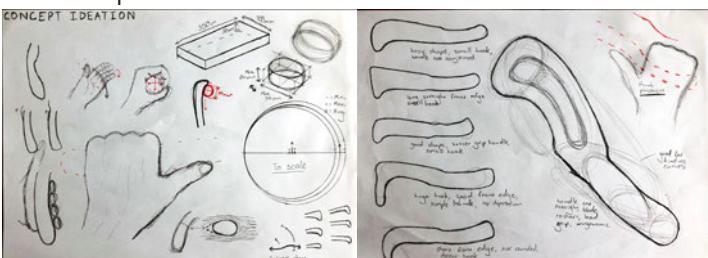
- Water repellent coating.
- Modular stick / handle to swap different types of blades between games or mid-game.
- Magnetic blade
- Removable / replaceable outer case - e.g. metal/plastic base, rubber/silicone outer shell.

Not all of these ideas are likely to be feasible or even legal - as stick suitability is also up to the jurisdiction of gear checkers, and ultimately individual tournament organisers - but this process definitely helped me in getting big creative ideas of the possible directions to be taken, and I think there are some interesting directions to consider, that could potentially be implemented to great success in the uwch community.

The initial idea for the base stick design remains the same after my research: designing an innovative but all-round suitable and effective stick - something that surprises people with how much they like using it - that has been designed very intently with extensive consideration, development, evaluation and refinement.

## 5.2 Design Ideation

This was my initial concept ideation, considering size constraints, handle ergonomics, hydrodynamics, blade shape & edges, progressing to looking at initial shapes and the pros and cons of these forms, as well as experimenting with bubble sketching to get accurate curves. During this initial sketching I was thinking about the official rules of underwater hockey design and formulating basic ideas before moving into specific concepts.



As previously mentioned, I am aiming to develop essentially a base design, which is as widely suitable to the underwater hockey player base as possible, from which I will be able to experiment with the more significant developments in the manufacturing stage. This means though that I am aiming

## 5 Concepting

### 5.1 Initial Ideas

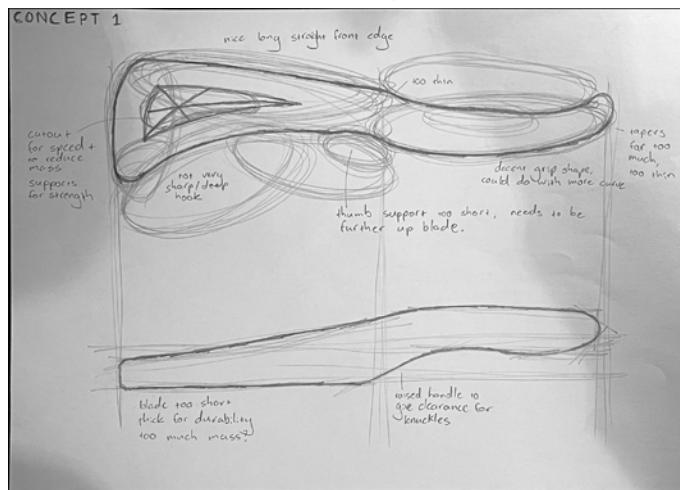
My research helped a lot with informing my design process and style, but it has also helped me develop a lot of creative concept and innovation design and manufacturing ideas.

- Stick with a moving component - adjustable handle angle, rotating blade, etc.
- Malleable / Gel, shock absorbing handle - akin to memory foam but firmer with a solid centre.
- Horizontal blade and / or handle cut-outs.
- Concave front edge - & concave blade end.
- Puck slot in blade - encompassing less than 50% of the puck.
- Puck slot or prop in hook.
- Puck gripping edges / knobs on the bottom of the blade.

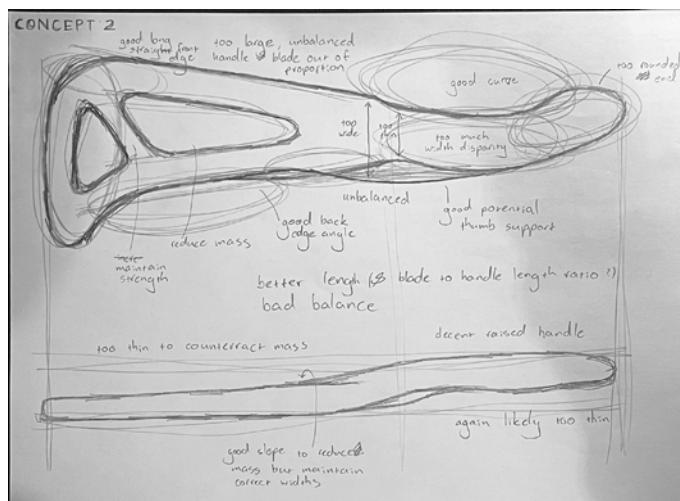
for the most all round proficient and balanced stick possible, so the next step is to move into specific concept designs.

### 5.3 Concept Drawings

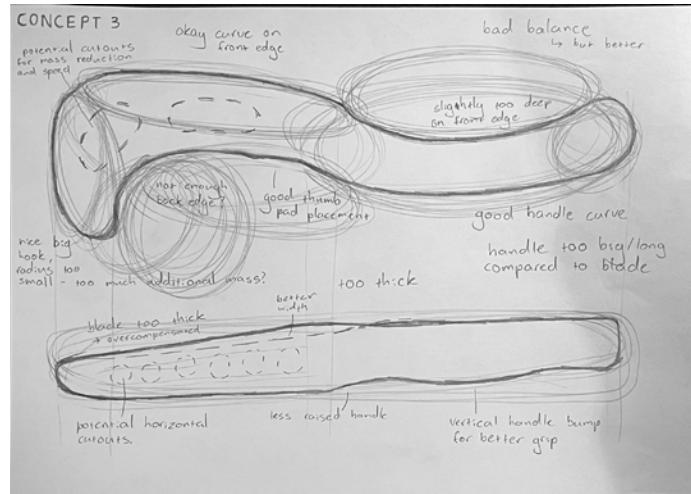
I decided to keep using bubble sketching as it was very good for getting clean curves and overall ergonomic and flowing shape for my concepts. I also decided to focus on the top and side profiles of the stick for my designs, as these will be the primarily factors in the stick, and other features can be refined in further development.



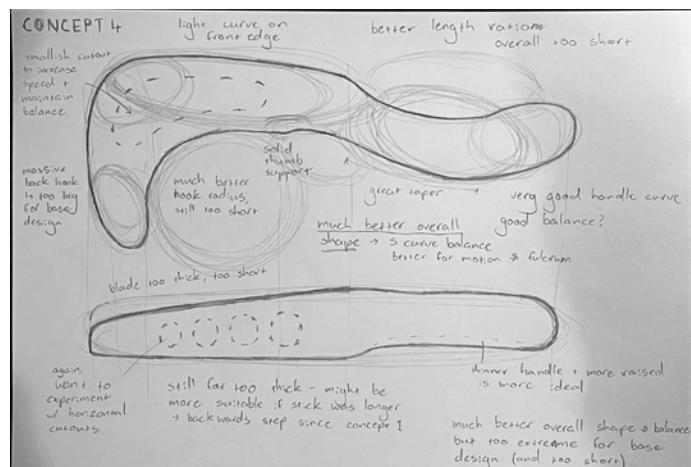
Concept 1 - This stick was decent, albeit definitely too small, with too extreme a taper, making it unbalanced and having bad placement and integration in some of the design features. However, the blade shape is quite good potentially.



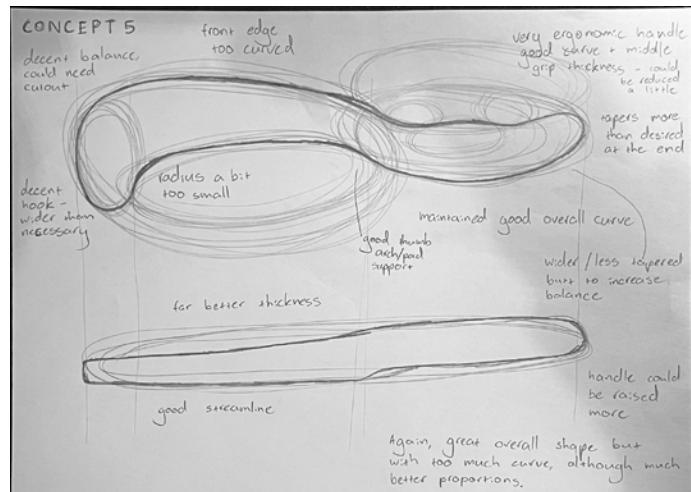
Concept 2 - I overcompensated in blade size and ended up with an unbalanced stick, the blade being far too large, the stick tapering and handle being very unergonomic after I attempted to modify the sketch. I also drew the stick very thin to counteract the size which would severely impact durability.



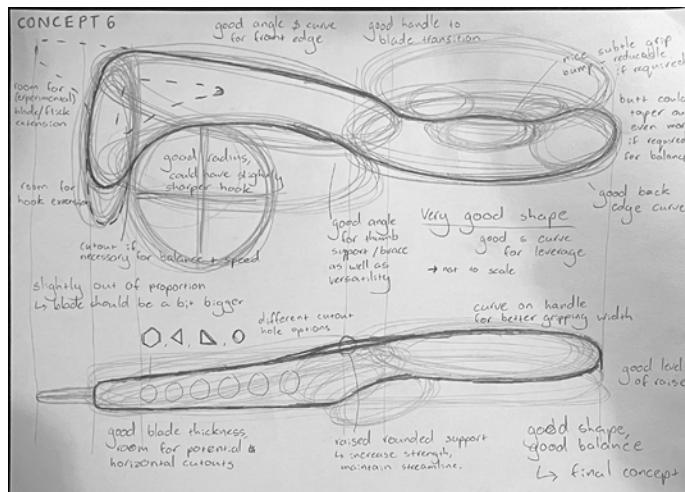
Concept 3 - This was a big step in the right direction, with a more natural and flowing design, creating more of an overall S curve which is much better for leverage and maneuverability, although the blade was too short in proportion to the handle, and the side profile ended up far too thick.



Concept 4 - This stick again improved on the overall shape from the last, with a good handle curve and blade shape, but overall was again too small and had too extreme of a hook, which is not ideal for the base model of stick. Again the side profile was too thick and lacked any real positive factors.



Concept 5 - This design built on the S curve and flow of the last couple of designs, finding better proportion between blade and handle, as well as improving the handles ergonomics through thumb support and grip width, but the blade came out far too rounded with an overdone outward taper, unbalancing it with the lack of an outward taper on the handle.



Concept 6 - Design iteration 6 managed to bring together all the best features explored in the previous concepts, with an ergonomic, versatile and supportive handle, that tapers outwards for overall balance, a straight and outward angled front edge, a sharp hook for better puck leverage, great overall shape and curvature. The stick itself is not to scale but the blade is also drawn slightly out of proportion from the handle, but provides an overall very balanced design, with all the necessary conventions and desired benefits that should be provided by a stick. The handle is also well tapered to help with the handle to blade balance, and has a rounded handle for better grip, along with a hydrodynamic raised portion to increase strength but maintain streamline. These designs were informed by my research into the design conventions of underwater hockey sticks, as well as my specific research into relevant factors, and helped me to consider a number of factors that help to create a highly balanced stick design that checks all of the primary principles of an effective underwater hockey stick.

## 5.4 Client feedback

I talked to my client about this concept, and he advised to be careful with the curvature (or undercut) of the blade ramping up to the handle, as this has significant repercussions if the stick needs to be used upside down, otherwise he warned about some issues in construction if using holes in multiple axis of a stick, as well as considering the different strength and variables in different materials and acquiesced that the base model being basic in terms of material as well as design, and modifying the design as necessary would be the best way to go. Overall he said that it looks like a nice simple and well rounded design.

Hi

Ok some feedback, firstly on the sketch.

Nice simple design I think.

On the design itself, 2 main things. First, it's easy enough to put holes in one axis, ie in plan view, or in elevation sideways through the blade, but as soon as you decide to have holes in 2 axis at once the actual construction gets instantly way more complicated. Something to be aware of.

Second, you have a pretty significant undercut and angle on the handle in elevation. The more you undercut like that, it might give you better characteristics with the stick as it's usually played, but as soon as you flip it over and play the puck it has very negative characteristics, ie a big gap the puck can easily slide through. So undercuts usually have to be pretty subtle to keep the stick useful both ways.

Second and a half, when you're dealing with holes etc, and I can see you're adding bits to the design to strengthen it, you need to know what material you're using so you know if you need to strengthen it like that and how thin you can go with surrounds of voids etc. Is the design going to drive the material? In which case if you have lots of voids it's going to be so strong you won't need to worry about bits to strengthen the handle. Or are you going to decide on the material and then strengthen where you can to make up for any weak spots. You know?

Thirdly on your core/sleeve idea, yeah that's a good concept and I've been down the design track with it a fair way, there are lots of tricky bits to it that aren't immediately apparent but I reckon that would be a fun direction. You can have sleeves with different bevels and even different left/right handed sleeves in concept.

The tricky bit is to use a soft material which would be the ideal for handling but still manage to make it durable.

Hope you're having fun!

My client raises a number of good points here, I am glad he thinks that the design is overall suitable, being nice and simple. I have tried to counteract inaccuracy of my physical design notes through my digital annotations. I don't intend to put holes in two axis necessarily, so this is a miscommunication through my design plans, but I have since considered this possibility, and will keep in mind his advice if I do explore this. The undercut is quite significant as he mentions, and this is something that I will try to dial back in my prototyping so as to make the stick suitable even when infrequently used inverted, balancing the weight and mass in different areas if it becomes necessary. In terms of holes, these will likely be added to later iterations of the base design when beginning experimentation, and this is when the materials will be decided upon so I will be able to consider the design based

around the holes and materials at the time. He has also considered the same concept of a core and sleeve design, which could be helpful if I choose to explore this idea, as he will be able to provide insight although I will keep in mind his notes about the difficulties of this concept.

Overall this advice was very helpful and I will bear it in mind moving forward into prototyping and development.

## 6 Concept / Mock-up Prototyping

### 6.1 Foam Mock-Ups

#### 6.1.1 First Mock-Up

For my first stage of prototyping, I want to use my concept sketches to inform initial form prototyping using polyurethane foam to make quick and effective prototypes.

I transferred my final concept sketch to a piece of cardboard for prototyping reference, starting by cutting out the top profile on the scroll-saw, followed by first sanding the side profile on the orbital sander, as well as rounded edges and handle details, and finished off by sanding finer details by hand.



This prototype came out quite well, with a good straight long front edge on the blade, and a comfortable and ergonomic handle grip, but was not precisely the desired shape and curve from the concept. I tried

out holding the stick with various grips and seeing how a replica puck fitted to the hook. To improve this model for the second prototype I want to increase the S curve between the handle and the blade, as well as the rounding at the very end of the hook, and the height and curve of the handle to increase the suitability of the grip.

#### 6.1.2 Second Mock-Up

I started out the same, cutting out the top profile on the scroll-saw and sanding down to the side profile on the orbital sander, I continued by sanding edge definition and general shaping with the orbital sander, and finished off the second prototype again hand sanding to finalise the shaping and details of the stick.



This is the finished model of the prototype, as well as some close ups of the handle shaping, which I took a lot more care in this time: I went for smoother curves overall, with a slightly deeper back edge curve, and a less prominent front edge grip curve. I also made the handle bigger and more raised, with a greater taper to balance the stick out more, along with a rounded edge on the bottom curve of the handle to help with grip purchase.

Overall I think that these changes to the handle were a big improvement, but an overcorrection, as it is important to keep the design of the handle neutral so as to be usable by the widest audience possible. To this extent, I definitely want to keep changes regarding refined curvature, particularly

upper and lower edges, however this handle was also too extreme in how raised and set back the handle is from the blade, as well as increased width; the handle-raise makes the stick too tall and the addition of an undercut makes it largely unusable upside down, as well as the thickness being an over-adjustment. In terms of the handle, I want to strike a balance between the results of these first two prototypes, taking the curvatures and ergonomics from the second handle, and scaling them down to the more modest and restrained proportions of the first handle.

In terms of the rest of the stick, I again think that I have developed the overall shape and form very well with the second prototype, but have over adjusted and created too extreme overall proportions: The blade and handle are both longer and bigger, which I want to scale back to the size of the first prototype to maintain a balanced and maneuverable size. I developed more refined hook strength but again made it too big in the new prototype, as well as creating edge bevels, but making the blade too thin. I also attempted to bring more curve into the form, but ended up having the handle too set back.

Overall for the next prototype, I want to balance the design between the first two prototypes, achieving middle-ground size and proportions, while maintaining the refined shape, form, angles and curves developed in the second prototype, along with slightly improving the overall curve of the stick to match that depicted in the final concept sketch.



## 6.2 Comparisons w/ Real Stick



## 6.3 Final Concept Mock-up

### 6.3.1 Initial Construction

For my third and hopefully final prototype, I want to take a slightly more planned approach, and create the desired balanced cross between the first two prototypes out of wood using measurements and dimensions from the prior prototypes for accuracy, so that I am able to physically test it in water, before moving on to digital modelling.

I started off with a block of wood that I sketched the top profile onto using my final concept as a reference, as well as the insights gained from feedback and more importantly the first two prototypes, then cut this out on the band-saw. I tried to keep the strong hook and reasonably narrow blade, keeping it angled forward and improving the handle angle and overall curvature of the stick. After this I moved to the orbital sander to sand the edges to size and smoothness. This left the top profile nicely fleshed out, so I moved on to sketching the side profile onto the stick, primarily using my two prototypes - as well as my actual underwater hockey stick - as references, as well as going a bit larger in general so that I had room to adjust down. I then roughly cut out the side profile, again cutting a bit larger than indicated to leave room for error and to sand down as required, and repeated the step of taking this to the orbital sander to smooth

and refine the side profile. With this done, I went back to the orbital sander to refine the general shape, and especially the rounding and refined shape of the handle, as handle comfort, ergonomics and suitability is something that I saw raised fairly frequently in my player-base research, something I hear complaints about in person, as well as something that I have noticed myself, so it is something that I want to be a primary focus of my base model. I finished the prototype for now, a bit larger and not completely refined in terms of final form, by hand sanding - moving through various grits to get a nice smooth finish while using a low grit on the playing edges to increase texture. I then took this to a training and some uwh games for testing.



### 6.3.2 Initial Testing

- UWH Concept Stick 1.0 - Test 1  
<https://youtu.be/serMHvkMJf0>
- UWH Concept Stick 1.0 - Test 2  
<https://youtu.be/iVLaGjW9PTQ>



I was very easily able to figure out the necessary changes after use, and while the stick worked well overall, I very quickly found that the side profile was too large, and slowed it down significantly in the water, the handle was again too wide as well as too boxy, although it did have a generally comfortable grip. This thickness reduced the efficacy of the flick, although again the stick managed a very strong flick despite this fact, which reflects my decision to use a long, straight and forward angled front edge. Additionally the playing edges of the stick were too straight, stopping the puck from making full contact with the stick

and reducing effectiveness and puck grip. Overall, I found the stick was a good shape, had the start of a very suitable handle, and had a very good hook that did not detract from the rest of the stick in terms of balance, strength or form, albeit was too thick and not hydro dynamic enough, reducing speed and flick strength, as well as having flat playing edges which reduced contact with the puck, decreasing control and flick strength. The main changes that I want to implement with the stick will be thickness; I will sand down the top of the stick significantly to reduce drag - which I will additionally reduce by increasing rounding on the top edge - and weight, although I will have to be aware of how this affects strength, along with this I will be adjusting the handle further, increasing the rounding, adjusting the angles of the grip, and using the rounding strategically to ergonomic benefit in different parts of the grip where there are different amount of curvature in the palm when gripping.

### 6.3.3 Refined Construction

To make the refining changes based on my testing and evaluation, I went back to the orbital sander as well as disc sander to begin sanding down the top surface of the prototype, followed by refining the shape of the blade and particularly handle, before finalising once again by hand sanding with various grit sandpaper.

The side profile was looking a lot better after a significant amount of work, with a reduced blade width and significantly reduced handle width. I put a lot of effort into refining the handle into an ergonomic, comfortable, and suitable grip: Curved and rounded back edge to fit firmly into palm, convex front edge grip detail to increase handle width for longer fingers as well as to create varied surface angles to facilitate varied grips, curved and thickened handle end to allow for more subtle pinky finger control during skills, as well as additional power during flicks, etc. The blade also finished well, with nicely angled front and back edges, increasing towards the handle where the stick is more raised due to the hand and thickness of the glove aka where the stick will need to be most angled down to maintain contact, as well as more rounded edges

to reduce drag and increase speed through water. Overall, I am very happy with this development of the final prototype and hopeful that it will live up to my expectations in the next testing.



#### 6.3.4 Development Testing

- UWH Concept Stick 2.0 - POV flick test  
<https://youtu.be/-5ltZpqy5Wk>
- UWH Concept Stick 2.0 - POV hook test  
<https://youtu.be/KDougu2PyHg>
- UWH Concept Stick 2.0 - Skills test  
<https://youtu.be/C651TaMW6GY>



This testing was sub-par unfortunately, simply because I forgot my glove, and so throughout the testing I was having to try keep my hand up to avoid scraping my knuckles repeatedly on the tiles. Because of this, it is not very easy to see the improvement since the last iteration of this concept. Despite this oversight, I was able to tell that the stick moved much faster and more smoothly through the water than previously, although I still think this could be improved somewhat and I will do this by sanding the upper front edge more to increase the stick's hydro dynamics. Despite the lack of a glove, the flick seems

fairly consistent with the original tests, which hypothetically means that it should be better with the addition of a glove. An issue I ran into was losing the puck on turns, but this was not an issue prior and as such was definitely a result of missing a glove. I will definitely have to do another test at the next available opportunity so get a better idea of exactly how these changes have affected the prototype, but until then I will work on sanding a little bit more refinement into the rounding of the top edge, and potentially refining the grip a little more if necessary - there are also some details that I have not been able to implement with the sanding machines that I have been using, such as a thumb indent on the back edge, as well as a slight indent in the back of the convex curve on the bottom of the handle to help with additional fingertip grip.

#### *Retesting:*

- UWH Concept Stick 2.1 - POV flick test  
<https://youtu.be/QGG2ykq2OYs>
- UWH Concept Stick 2.1 - POV hook test  
<https://youtu.be/qfo0PSyaqws>
- UWH Concept Stick 2.1 - Skills frontview  
<https://youtu.be/OVyamzSIJqc>
- UWH Concept Stick 2.1 - Skills sideview  
<https://youtu.be/e58sd3Kz2Es>
- UWH Concept Stick 2.1 - Skills & Flicking  
<https://youtu.be/xJn-77nKmHs>
- UWH Concept Stick 2.1 - Comparison  
<https://youtu.be/tZaBRx9fL4M>



I did a significant amount more testing the second time around, trying to get a more realistic feeling of the features and style of the stick. Overall I think that it performed very well, matching my actual stick more or less in every category, and outperforming it in a lot of skills as well as significantly improving the comfort and suitability of the handle grip, before even looking into materials. I think that the two main significant improvements that this design offers, are the handle design, which through taking an intentional approach to comfort and ergonomics creates a balanced but much more comfortable and grip-able handle for people with a range of hand sizes, which as pri-

or mentioned is something that I have seen sought after for a period of time, as well as the larger but still balanced hook:



This allows much more control and security of the puck on the back edge, without compromising maneuverability, mass unbalance, or speed.

There were however definitely some downsides I noticed which although not significant they are certainly worth addressing: The blade of my concept is still not as tapered towards the end as it could be which does decrease speed and maneuverability somewhat, with the more prevalent issue I noticed being the tendency of the puck to flip over the stick of the stick occasionally when positioned in the hook - and this is a general hazard no matter the stick - but I could definitely avoid it happening as much through implementing more of an angle on the back edge of the blade, specifically in the hook, to help maintain contact with the stick when the stick is angled, as well as keep the contact point between the puck and stick slighting higher up to stop the puck from flipping over the top when the stick makes contact below the fulcrum point of the puck. These are fairly simple changes to make to the prototype, so I will make an attempt to sand more a taper towards the end of the blade to increase hydro dynamics, as well as add an angle to the back edge of the blade to decrease likelihood of losing the puck during turns.

### 6.3.5 Refinement

I used various grit sandpaper to add the changes outlined above.



Far left - Sanding the stick. Middle left - More tapered blade end. Middle right - Top view of back edge / hook angle. Far right - Angled edge hook.

**Evaluating:** After some more testing, I found that angling the hook actually had more of an adverse effect than a positive one, and so I used a sanding machine to revert this change by straightening out the back edge on the hook.



Having reached my a largely refined design for the concept prototype, and having moved into focusing on digital modelling of the design, I decided to experiment with applying texture to the playing edges of the stick, through puncturing and essentially mashing up the edges with the back of a hammer, a leather punch, and cutting small grooves with a chisel. I also decided to paint the stick black so I am able to use the concept prototype during actual games and see if I can get any more insights from this.



I am very happy with my final concept prototype, and think that it very well suits the requirements, as well as meeting all of the design specifications and attributes applicable at this stage of the project.

### 6.3.6 Client Feedback

I emailed my client asking for feedback and advice on my final prototype design, and he responded as follows:

Hey there,

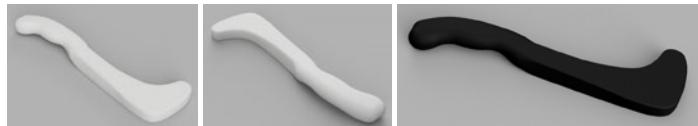
Looking like a stick! Nice work. A stick, the way we need it with angled bevels etc is a very difficult shape, with a mix of precise angles and freeform handle. If you are comfortable designing in foam/wood physically then i would suggest you do all the design iterations that way and 3d scan afterwards to get it in the computer. Then you can use the scaling, mirroring etc functions in fusion as needed which are far simpler tools to use, and use the functionality to 3d print in different sizes, or even 3d print a base shape and make changes to that by sanding and adding material etc and re-scanning to get it digital again.... if you can get an easy method of 3d scan you are going to be way faster iterating that way than banging on for weeks training yourself up to model it in fusion, because it could take weeks or months. The end result in fusion wont be the same as what you've made unless you're really really skilled.

That's my best advice really, do it the way you are most comfortable, otherwise it'll be like trying to recreate a paper charcoal sketch in MS paint using your foot on the mouse. If that makes sense. Best use of your time and all that.

The only real feedback that he gave on my final concept prototype was that it was looking like a stick and that it looked like nice work, which is good to hear. He then evidently offered some advice on the next step of the process for me which is converting this design into digital form, which I have made two attempts at already, with solid body and form body modelling, and the next attempt I intend to be using 3D scanning, but all in all it seems like my client is impressed with the prototyping and thinks that the base model design is coming along well.



This worked fairly well, as I was able to get a solid general shape, but this method did not afford me the detail and intricacy I want to achieve, creating imperfections and inaccuracies in precise details, although it definitely turned out well as a first development.



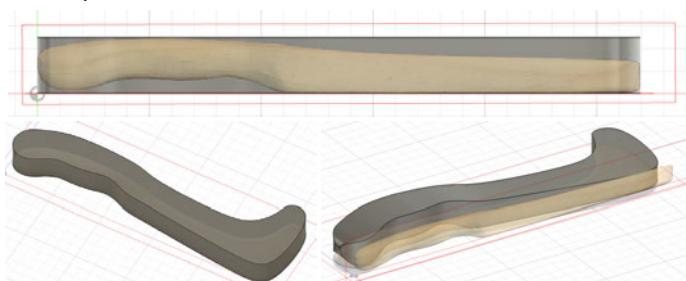
This also gave me a good idea of how the stick will need to look in terms of colour, and information on some of the specific shaping that I want to aim for with the 3D model.

## 7 Design Development

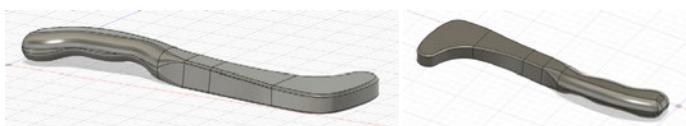
### 7.1 Initial Modelling

My design development plans are to move into 3D modelling of the base design, to specify dimensions and complexities of the design, as well as for future use during manufacturing and experimentation. I am going to use the prototype design derived from the final concept as a reference for the modelling in Fusion 360.

For my first attempt modelling the organic shape of the stick, I used the same approach as when prototyping and started out modelling the top profile of the stick using a reference image from the final prototype, before adding another reference image from the prototype and using that to model the side profile.

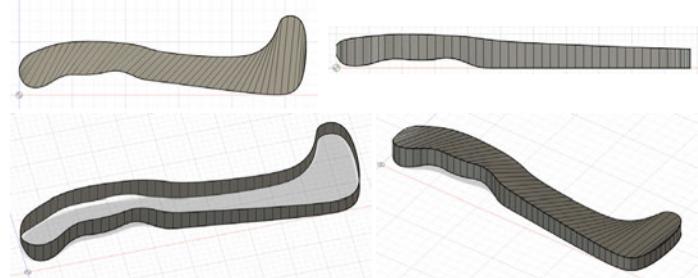


I proceeded with this approach, using my knowledge of Fusion360 to get as close of a digital replica as possible using the solid body modelling tools.

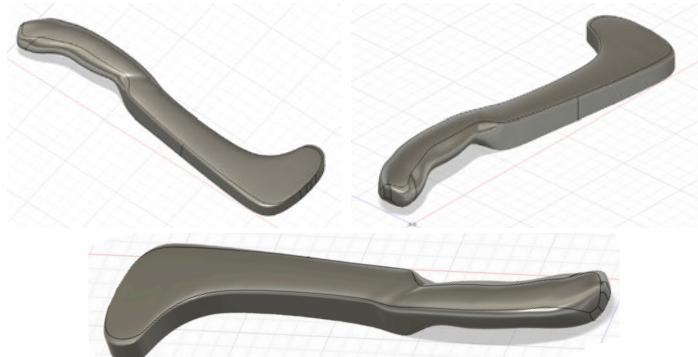


### 7.2 Form Body Modelling

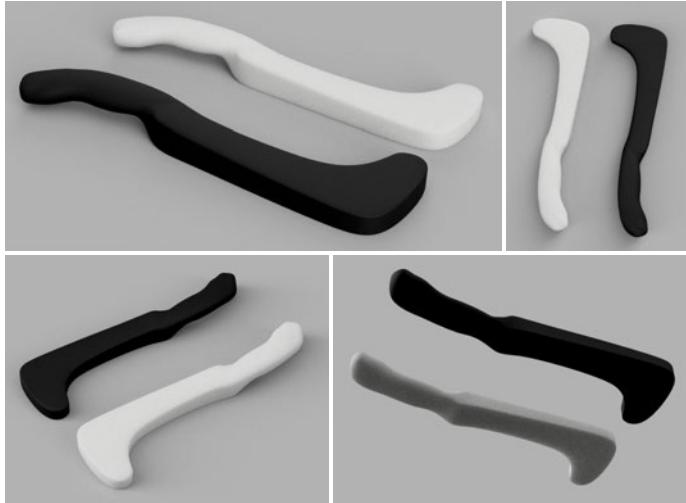
To try and increase the suitability of the model, I am going to move into the form modelling capabilities of Fusion360 and see how good of a design I can get compared to the solid body model. I got some basic instruction from my teacher on form modelling, as well as experimenting around and learning the ropes a little, before beginning on this model.



I took a similar approach to the first model, doing the top profile followed by the side profile, before delving into the more complex and intricate capabilities of form modelling.



I think that this approach worked to good effect, and it is possible that there is room for further development and improvement of the model, especially in specific details, if I am able to increase my proficiency in form modelling, this being my first experience with it. This design approach definitely yielded a lot more opportunity for detail and intricacy, which I attempted to take advantage of, but additionally have a higher bar in terms of program proficiency. Despite this, I think this model is more true to the prototype, getting more organic curvature and angles, again with some issue in precise details akin to the first model.



I think that this model is definitely an improvement on the first attempt, but again certainly still holds imperfections and inaccuracies.

During this process I was thinking about the relative difficulty of getting precise and specific details especially with organic shapes, between real life and the digital space. This lead me to think of using the refined final prototype to take a 3D scan and import into Fusion360 for further adjustment, meaning I can keep all of the development I have already done with my prototyping and progress into further development and detailing more easily afforded by 3D modelling. This is again not a process that I am familiar with, but something that I know is easy enough to do effectively at home, so this is the approach I want to attempt for my next iteration of the model.

### 7.3 3D Scanning

I looked into the process of 3D scanning, and found this video very insightful:

3D Scanning with your phone  
<https://www.youtube.com/watch?v=axd-Plc6FqQU>



Something went wrong with my first attempt, as I ended up with a model of the room I attempted the scan in, instead of a scan of the prototype, so I will have to attempt this again, and potentially use a different application.



I had a few attempts using the same application, but after more fails, I decided to heed some of my client's advice:

Best case now, from my perspective is once you are close enough to be ballpark to your physical model, which it looks like you are, then chuck the physical and work with the digital. Print the thing out so you can hold it and get a feel and make adjustments from there. I've made a few sticks having to iterate like that and it's a pretty useful sequence.

Better to have the "real" most up to date design in the computer and the physical one be a superceded stepping stone than trying to recreate the physical and feeling like you never quite got it, because it's impossible to get it perfectly in my opinion. Better psychologically but also it is better for editing later and adjusting size etc too.

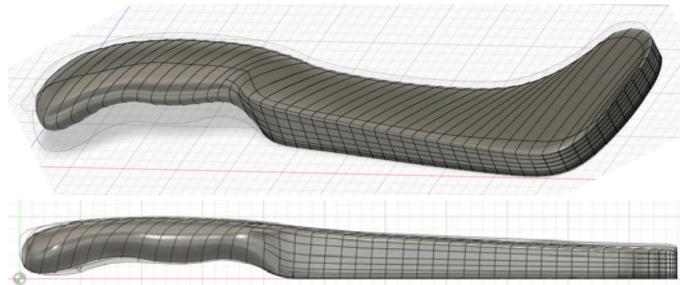
I followed this advice by moving on from the final concept model and moving to use it as a visual reference, along with all of the insights that I have found from making it - additionally I can still use it to test any future changes I implement in the design during the development if possible.

### 7.4 Form Body Development

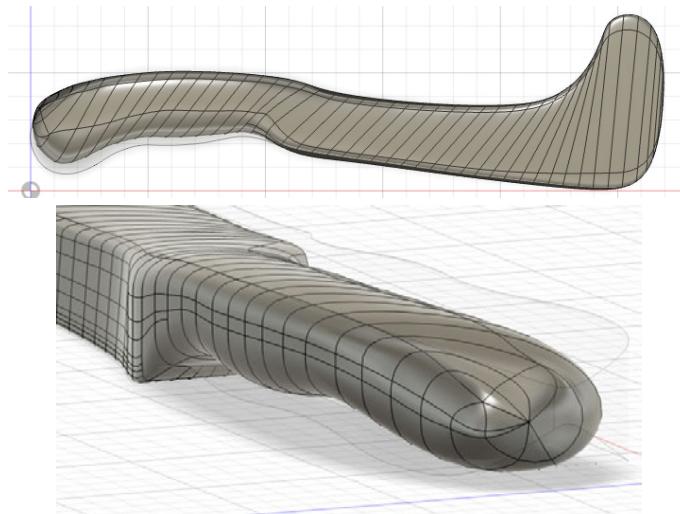
I went back to my form model in fusion and began working on more development to the existing model.

I started by creating a more uniform surface to even out the shape and smoothness of the design. I adjusted the handle to create more even handle grip indentations, slightly reducing the thickness towards the end of

the handle to allow for better grip with the smaller pinky finger, as well as increasing the taper of the blade towards the end; mimicking successful existing designs, allowing the blade to be lighter and more functional when used upside down.



This involved creating a more uniform surface to even out the shape and smoothness of the design, adjusting the handle to create more even handle grip indents, slightly reducing the thickness towards the end of the handle to allow for better grip with the smaller pinky finger, as well as increasing the taper of the blade towards the end; mimicking successful existing designs, allowing the blade to be lighter and more functional when used upside down.



I continued by cleaning up the end of the blade and the handle for a smoother curvature.



I think this is a significant improvement in the digital model of the base stick design, and I have contacted my client for any advice or feedback, as well as asking for preemptive suggestions for direction going

forward, with what avenues of experimental design to pursue.

## 7.5 Development Continued

I continued the development of the stick by continuing to refine the features and design.

*Blade end view:*

you can see the contours of the blade profile, as well as the gradual rise into the curvature of the handle.

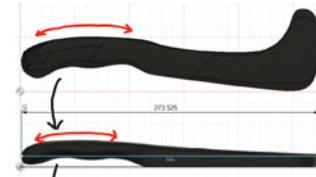


*Handle end view:*

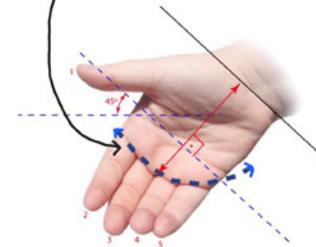
you can see the complex but significantly cleaned handle end, as well as some of the connecting curvature between the handle and blade, as well as the shape of the handle: angled downward so that when used in play, the stick extends out of the hand at a suitable angle to match the angle the stick will be held at.

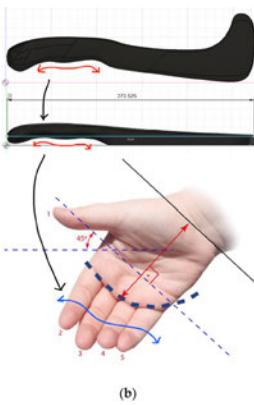


*Stick profile from the front edge:* showing the gentle undercut in the height between the blade and handle to reduce weight and mass while retaining upside-down usability, as well as total stick length, and the ergonomic handle profile that I have continued to tweak based off of feedback from players who I have asked to hold the physical concept prototype, to create a handle as comfortable and stable as possible, for the widest range of players and hand sizes possible. The idea of the handle is to create a shape that fits naturally into the palm of the players hand.



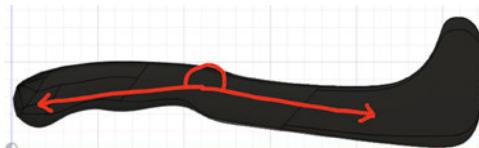
The handle is curved on the side and top profiles to fit comfortably into the rounding of the palm when gripping.





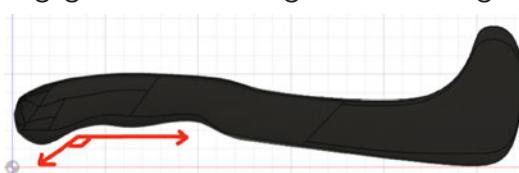
The shape of the finger-side of the handle is designed to balance out the placement of the fingers, creating a larger circumference for the longer centre fingers to wrap around comfortably and securely.

(b)

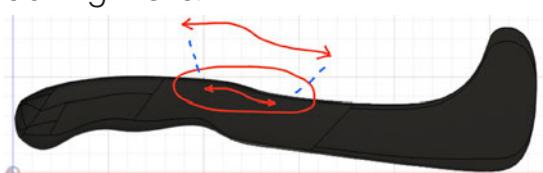


The difference in angle between the

blade and the stick ensures that when held forward facing, the blade will extend from the hand in a forward angle which is beneficial for maneuvering the puck as it helps keep it on the front edge, as well as providing greater leverage for flicking.

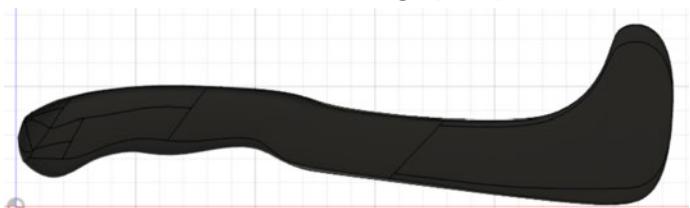


Having the handle continue in the outward parabolic curve allows for greater grip versatility, as it means you can shift your hand down the handle to change angles and grip type for different situations, as well allowing the pinky finger to lever the handle downward for additional momentum during flicks.



The connecting curve between

the back edge of the handle and blade forms a subtle ramp to allow bracing the thumb for maximum support and strength when using a power grip, while still allowing the versatility of being able to swap to a more control orientated grip style.

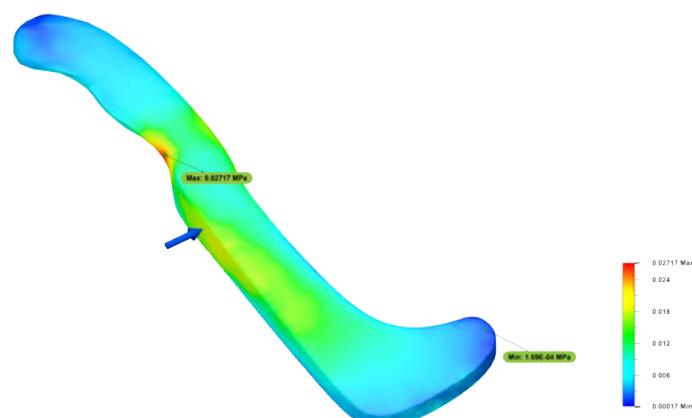
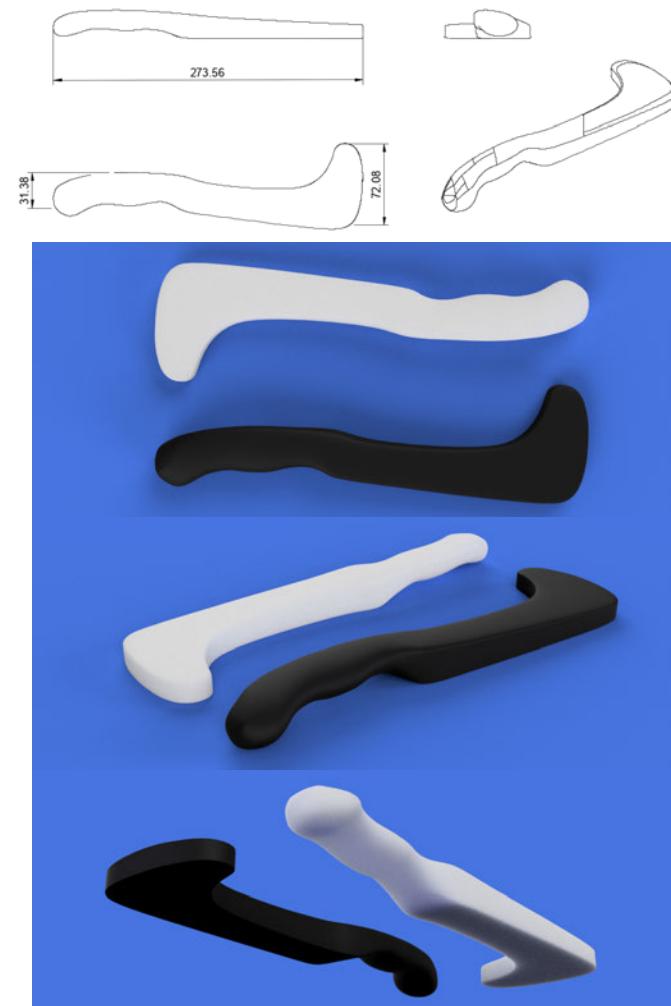


Top profile of the stick - Shows the overall shape design in terms of general use cases; the handle shape for gripping, the front

edge for skills and flicking, the hook and back edge for turns and skills, etc.

The general ideas around the overall stick shape - as seen from the top profile - is to have a long, straight and forward angled flicking edge, to have a strong and secure hook, and to have a comfortable and secure handle.

Further adjustments to the base model of the stick were evening out the curve on the front end of the grip, refining the ends of the model as much as possible, and stretching the handle for a little bit more length, to increase suitability for all different hand sizes, as well as to adjust the balance of the stick slightly:



I also did a force simulation showing the structural stress of an impact on the front edge of the stick. This clearly shows that the front edge at the fulcrum point is under the most stress, so when using the prototypes I will look out for indications of stress or damage particularly at this point, and it may need to be strengthened in the future depending on the material and manufacturing choices.

## 7.6 Design Evaluation

I think that this is a largely effective and suitable design for a base UWH stick, with room for development in terms of design, materials and manufacturing once I have refined my experimental directions to go in. There is a lot of careful consideration and intention design in every feature of the stick, as can be seen through the stages of the design process right from the extensive research, to the prototyping, testing and developing. Overall I think that this will be a very effective and usable stick for a wide range of players, and a very suitable base upon which to develop further conceptual ideas and processes. It also meets all of the attributes and specifications, as well as international rules for uwh stick design.

# 8 Base Design Prototyping

## 8.1 3D Printing Theory

3D printing, also known as additive manufacturing, is a process of creating physical objects by adding material layer by layer based on a three-dimensional digital model. It is a transformative technology that has gained popularity in various industries, including manufacturing, healthcare, architecture, and more.

### *3D printing process:*

1. Digital Model Creation: The first step in 3D printing is creating a digital model of the object you want to print. This is typically done using computer-aided design (CAD) software or by scanning an existing object using a 3D scanner. The digital mod-

el defines the shape, dimensions, and other specifications of the object.

2. Slicing: Once the digital model is ready, specialized software called a slicer takes the model and slices it into thin, horizontal layers, typically ranging from 0.05 to 0.3 millimetres thick. Each layer is a 2D cross-section of the object.

3. Printer Setup: The sliced file is transferred to the 3D printer, which consists of several components. The printer includes a build platform or bed where the object will be printed, a print head or extruder that deposits the material, and control systems to regulate the printing process. The printer may also have heating elements, cooling systems, and other features depending on the printing technology used.

4. Material Deposition: The 3D printing process begins by depositing the chosen printing material onto the build platform. The printing material can vary depending on the printer technology, but common materials include plastics, metals, ceramics, resins, and even food-grade substances. The material is usually in the form of a filament, liquid resin, or powdered form.

5. Layer-by-Layer Printing: The printer starts to build the object by following the sliced layers from the bottom up. The print head or extruder moves along the x, y, and z axes, precisely depositing or solidifying the material according to the instructions in each layer. The material is typically melted, cured, or bonded together to create a solidified layer.

6. Support Structures (if needed): In some cases, support structures are printed alongside the object to provide stability during the printing process. These support structures can be removed or dissolved once the print is complete.

7. Post-Processing: Once the printing is finished, the object is allowed to cool or cure, depending on the printing technology and material used. Post-processing steps may include removing support structures, sanding or polishing the surface, painting, or applying other finishes to achieve the desired appearance and functionality.

3D printing offers numerous benefits, including rapid prototyping, customization, complex geometries, and reduced material

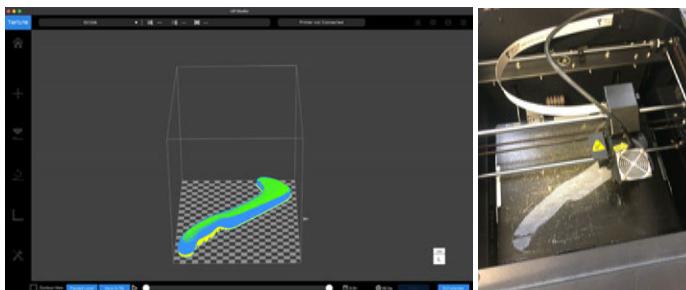
waste. It has revolutionized various industries by enabling the production of intricate parts, functional prototypes, and even end-use products. With advancements in technology and materials, 3D printing continues to evolve, pushing the boundaries of what is possible in manufacturing and design.

## 8.2 Initial Prototyping

### 8.2.1 First Attempt

For the first stage of my process, I want to 3D print my base stick model to get a physical feel for its suitability, and look at where I want to go next in the process, with any additional design features as well as the manufacturing route I am going to take.

I exported the STL file from Fusion 360 and put it into Tiertime Up Studio to arrange and slice the model before printing with the default maximum speed settings.



Unfortunately this first attempt failed due to a filament jam with the thread of plastic having been accidentally looped underneath another by a previous user.

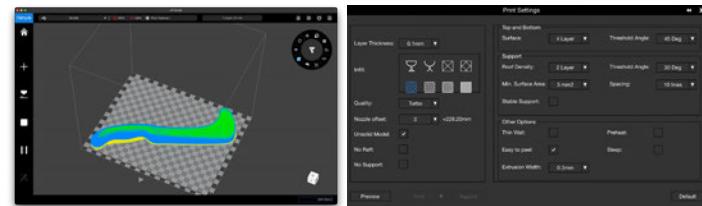


Despite this failure, I was still able to use the partially printed model to test the ease of raft / support removal, particularly on the curved handle. I found this to be surprisingly effective with the right tools, and left a very nice bottom surface as seen above right (handle segment at top of image, removed waste at bottom of image).

### 8.2.2 Second Attempt

For the second attempt, I adjusted the print settings, going into the advanced panel to get more adjustability and customisation

with my print settings. I knew I would be putting the print on for a longer period of time so I elected to select a smaller layer thickness for greater detail, a higher percentage of infill for greater structural integrity, and I also tweaked the support and raft layer settings to try and make them easier to remove.



The second print attempt was successful, although there was definitely some visible warping around the edges and especially towards the top of the blade which is not ideal.

I used a variety of tools to remove the supports from the handle; small and large pliers, wire cutters, and a paint scraper, before securing the print in a vise and switching to a chisel for the flat area of the bottom of the blade.

The supports were all removed with difficulty but without any significant damage to leave a very nice physical version of my digital model, albeit with unfortunate warping towards the end of the blade.



### 8.2.3 Prototype Comparison to Concept Mock-up





This 3D print of the development model is a very close match to the final concept mock-up, and as such I think it will be a very good basis from which to further develop and refine my base stick design, and eventually the additional advanced features of the product.

### 8.2.4 Testing & Feedback

#### Player feedback:

I took the 3d printed model of my stick design model to a club uwh training night to get feedback, and overall I got a lot of positive feedback: The most common immediate response was that the handle was very comfortable (generally and especially in comparison to other sticks), and although I did hear from one person they did not like the handle, they reevaluated their decision when trying the stick wearing as glove, as I modelled it with a thinner handle to be more suitable while wearing a glove - in comparison to the final concept prototype, which was very suitable for bare handling, but too bulky when wearing the thick rubber glove required during play. Along with general club members, a number of current and prior New Zealand UWH men's and women's elite team members at the club expressed their appreciation for the design of the stick, in terms of the blade shape, flicking ability, hook size / shape, and especially in terms of the handle suitability and comfort. It was additionally described as a combination of two of the most popular sticks in the professional uwh scene, the 'T [REDACTED]' and the [REDACTED]' both sold by my client [REDACTED]

which I personally see as a good sign.

The primary concerns and suggestions given for improvement were fairly varied but small adjustments: Blade too thin - partially due to warping from the 3d printer, but also something I suspect was caused by scale difference when modelling in fusion from photos of the final prototype, the material was too smooth and slippery - this is again constrained due to the 3d printer filament I have available and something I intend to

change and develop during the manufacturing design process, lack of weight - this once again is due to the material / method of production and is something that will change significantly in the future. I did also hear a brief concern about the angles of the stick in relation to wrist injury, but this was dismissed after I explained my intentions in the design and closer inspection was taken. I also heard from one person that they didn't love the hook shape, although that it was simply personal preference and this is to be expected as it would be impossible to design a stick that would cater to the specific desires of every player.

I also made some insights from trying out the stick myself as well as comparing the 3d printed model to the wooden prototype, particularly finding the handle to be very comfortable, the flick to be very good despite the unsuitable material, the hook to be very effective - albeit too thin as mentioned before.

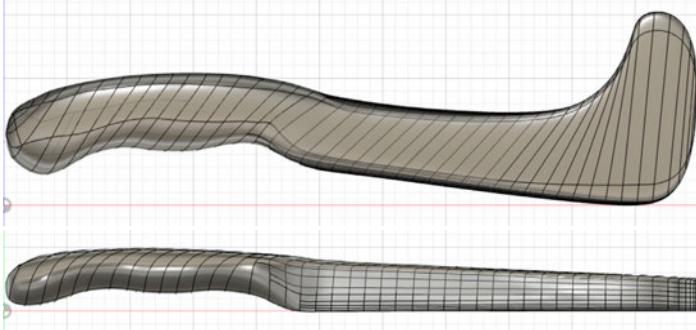
## 8.3 Additional Design Development

Based on my testing and the feedback I received, I want to make some design changes. These changes will be some adjustments to the rounding of the back edge of the handle for comfort and aesthetics, thickening the blade and potentially the handle to improve grip and puck control, and an increase to the front and back edge bevel for reducing puck drag and improving maneuverability - as well as in the long term potentially changing the material and production method of the product.

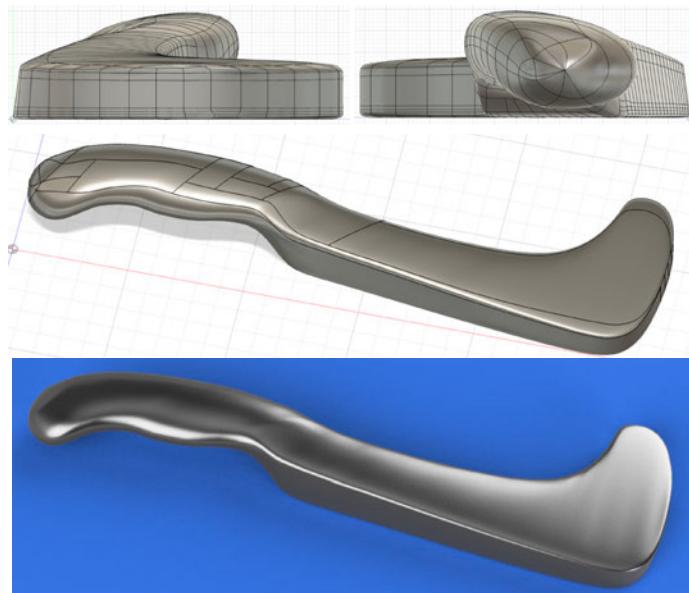
I started off by adjusting the rounding on the back edge of the handle where it connects to the blade, so as to create a slightly more comfortable and palm-fitting handle, as well as the increase support for the thumb when holding the stick.

I also increased the thickness of the blade, to create a slightly larger surface area for grip and general contact of the puck, as well as to add some more mass and power to the stick to balance it out more to be suitable for a wider range of players, as it will still remain easy to move through the water, while also allowing better use when inverted. These changes will also largely cancel each

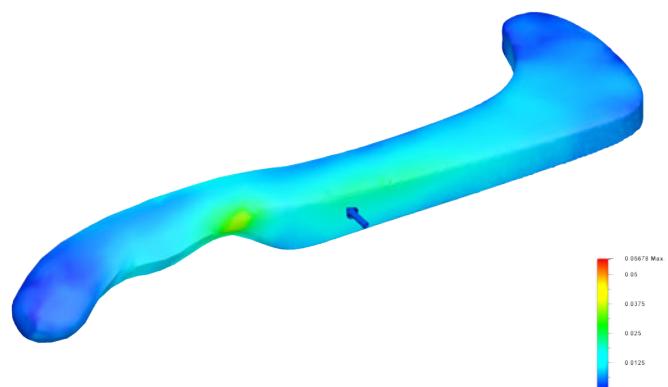
other out in the mass of the stick, helping to keep the balance centered at the fulcrum point of the thumb.



This was followed by adjusting the bevel / slope of the front and back edges of the blade, increasing each by 5 degrees to greater reap the benefits of reducing puck contact with the pool floor while swimming, maneuvering, performing skills, and flicking. I also reduced the number of vertices of the edges of the blade, to create a more uniform surface for the sake of maintaining an accurate model, although I will be developing texture patterns in the future of the product.



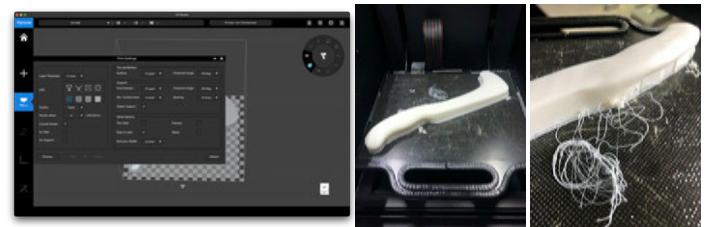
Developed Base Model Design V2



This is a repeat of the previously shown force simulation on the new developed model, showing significant decrease in stress at front edge connection point between blade and handle. Because of strengthening the back edge of the handle, the impact force is significantly more spread out along the length of the handle and more-so the blade, as this is where the impact is landing.

## 8.4 Prototyping Continued

I implemented revised settings to print the new base model design for testing and the print finished successfully - it was put on with another print simultaneously, and the other print failed, but mine was unaffected and succeeded first attempt.



I was able to more effectively remove the supports this time, thanks to learning from the first model, without need for a chisel. Holding the stick with a playing glove after sanding the stick to remove excess plastic buildup; I found it a very ergonomic and comfortable design. The refinements were very suitable as to the desired effect, creating a more comfortable and secure fit to palm as well as improved thumb support.



**Evaluation:** V2 model (far right) in comparison to V1, final concept prototype, and real hockey stick. The V2 is more comparable to the sticks I currently own in terms of thickness as well as front and back edge bevel, which is a good indicator of the suitability of this refinement, but this will be hopefully confirmed after using in a real game or training. So far these refinements to the base design seem very promising and I think that

I am approaching a final base design. I also found a number of unintentional improvements caused by this stage of refinements - thickening the blade reduced the slightly overbearing undercut seen in earlier stages of the development, while increasing the front edge bevel created a subtle scoop along the bottom of the blades front edge, which will help keeping the stick close to the pool floor and contact with the puck during use.



## 8.5 Design Development & Refinement Continued

### 8.5.1 Testing & Feedback

After further testing and feedback from more highly skilled players, I am very happy with the suitability of this base design, and there are two more small adjustments that I want to make to the design before I think I will have highly suitable final model, especially given the overwhelmingly positive feedback I have received from a range of sources (not only a range of uwh players but essentially everyone who is willing to listen to me talk about the design and tell me what they think: family, friends, classmates etc). This feedback has been especially good in regards to the handle, the flicking capability, and largely positive towards the hook design, with the main concerns being focused on the difference in angle between the handle and blade. Taking all of this into account, I want to finish refining the handle with a small thumb indent for further purchase and support, a slight ramping on the bottom edge at the end of the blade to allow a slightly lower profile when the handle end is elevated for better surface area and contact with the puck, as well as looking at

adjusting the angle between the handle and blade slightly, to look into the brief concerns raised by a couple of the players I spoke to at my club.

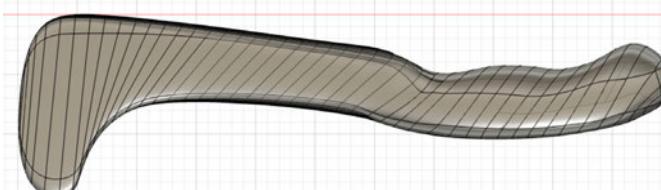
**Prototype Breakage:** During my use of the 3D printed prototype stick in training and games, it finally broke in the third night of use and gave considerable insight towards the weakest part of the stick, along with factors to consider in the avenue of 3D printing as a manufacturing method. The stick broke when it was stuck with considerable force on the front edge of the blade, while held in my right hand and braced diagonally against one of the side walls of the pool - while attempting to defend a goal. My analysis of the stick's breakage, is that when it was struck partway down the blade - the second weakest impact point - the stick buckled and warped to a degree at the weakest point (the connection between blade and handle - as is visible in the photos), compromising the structural integrity of the infill, and thus causing the stick to snap and tear at the second weakest point, where it received the direct impact - as well as chipping some of the bottom layers off of the stick towards the end of the blade, where it was unintentionally braced against the wall, this being another factor I suspect largely contributed to the breaking of the stick. I believe the primary reason the stick broke was not due to the design, but the lightweight and low density manufacturing method of the stick, only having 35% infill on the 3D print, and being constructed of PLA plastic, as well as the compromising position the stick was caught in.



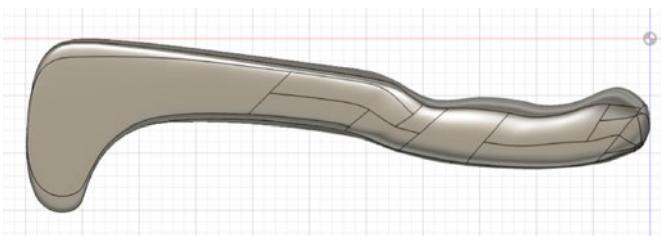
## 8.5.2 Design Changes

This development refinement included both of the changes that I mentioned: a thumb support indent, and a subtle scoop towards the end of the blade, but more significantly I decided to try and address the primary issue raised when I showed the 3D printed prototypes to professional players at my club: the blade and wrist angle. It was mentioned by 3 of the higher level players at the club, that the angle at which the blade extended from the handle and thus the wrist, was fairly significant and that while swimming with the arm fully extended, it could cause you to have to rotate your wrist to keep the front edge of the stick flat enough to carry the puck effectively. This rotation of the wrist weakens your wrist angle, and could potentially result in an injury if you were tackled with too much power while in this position.

Because of this I decided to alter the angle that the blade extends out of the handle, which will slightly decrease the overall curvature and leverage of the stick, but will avoid any potential injuries from this issue.



Prior Handle Angle



Adjusted Handle Angle



Thumb Indentation



Front profile with end-of-blade scoop



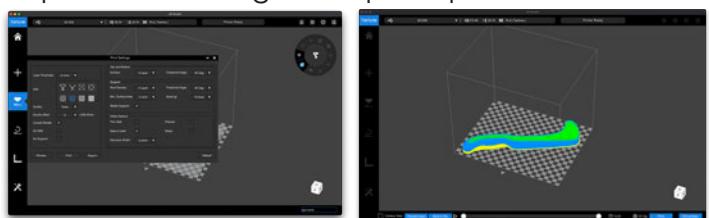
Refined Base Design Model V3

## 8.6 Prototyping Continued 2

### 8.6.1 3D Printing

Following the further model changes based on insights from using the 3D printed sticks and seeking feedback, I am going for what will hopefully be the final prototype of the base stick design.

Updated settings and print preview:



I had a successful print first time around, albeit again with some warping. I want to give some thought to the cause of the warping, and potentially do some research and attempt to implement a solution such as applying glue to the print bed before beginning the print. There was unfortunate warping towards the end of the front edge, causing an unnecessarily large and uneven taper towards the end of the blade, although this should not have a severe impact on the performance of the stick, most likely having a small negative impact on flicking capability. I also did sanding as usual and chisel supports off due to warping.



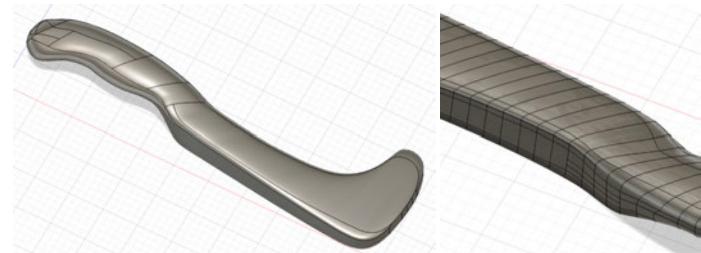
## 8.6.2 Testing

My initial thoughts are that the stick continues to feel very comfortable, and that it has a little bit more heft and feels stronger, thanks to the 65% infill. The handle angle change feels to be improving the thumb support, as well as the angle of the blade extending from the closed fist, and the thumb indent is also comfortable and suitably subtle.

After training and playing with the stick, I found it generally suitable, consistent with the previous models. I definitely thought that the altering of the handle angle made the stick a bit more comfortable and had good support on the thumb, though that the thumb indentation unbalanced the thumb grip support. Because of the curvature of the back edge of the blade, curving into the hook and the handle on either side, the indentation is also at an angle away from the thumb. This means that due to the angle, as well as the combination of the change in handle angle, the thumb ends up overextended and this would almost certainly have the potential to lead to complications when taking impact and potentially thumb injury.

## 8.7 Final Base Design Refinement

Based on the testing, results and feedback on the prior V3 model prototype, for the final iteration of my base design I will be reverting the thumb indentation as I think that any thumb indentation will likely be detrimental to the performance and injury potential of the design. After additional consideration I will also be increasing the vertical thickness of the blade and handle very slightly, as well as the width of the blade, to increase traction with the puck, having a slightly larger front surface, as well as making it harder for the puck to flip out of the hook and over the edges of the stick, along with an improvement to the comfort of the handle through having a slightly more rounded profile. I also want to further increase the thickness of the blade and handle, as I felt that the stick was still slightly too small and lacking a good feeling of solidity, as well as to account for the blade being narrower due to the increase bevels on the blade.

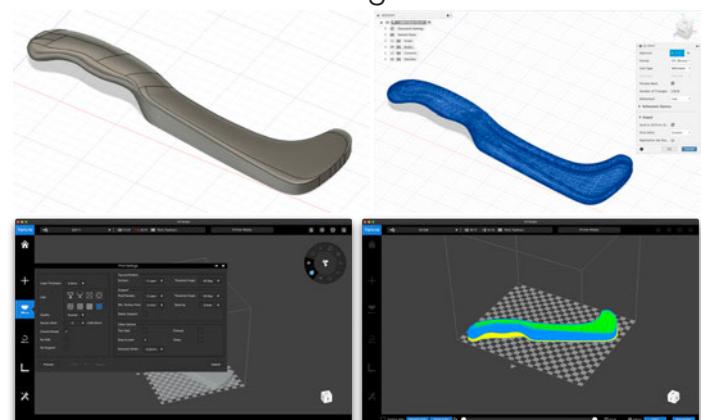


V4 Finalised Base Design Model - 1mm thicker and taller, reverted thumb indent.

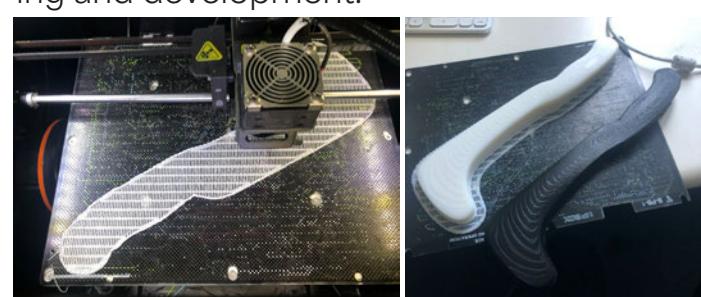
## 8.8 Final Base Design Prototyping

After these insights and final moderations and refinements to my base stick design, I moved on to printing the final higher density infill prototypes now that the base design for the stick was finalised.

I switched to an Upbox Tiertime 3D printer, which while (compared to the other available printer) only printed at a larger layer thickness, was able to do 100% infill, as well as reducing the print time from a very constricting 25 hours at the higher resolution, to a much more manageable 6 hours.



The first of my 100% infill prints in white filament was a complete success, however the second 100% infill print in black filament unfortunately warped during printing, although this is not simply a waste, as I will be able to use this stick for further future testing and development.



The third 100% infill print came off much more successfully, thanks as well to the

application of some EVA glue to the build plate at the beginning of the print, helping the raft to retain grip to the build plate and reduce warping, producing a matching black stick to the initial white one, completing the physical prototype set of the base stick design.



**Evaluation:** The final CNC product is a solid 3D printed model of the design that I developed in the conceiving and design phase, that was refined and finalised throughout the 3D printing (CNC Machining) process. It meets all of the specifications for designs as well as my working specifications for this stage of the product development in terms of materials, strength, functionality, etc.

- Material: The sticks at this stage are made out of suitable materials colour and strength wise, although they are limited by the time constraints of 3D printing, as well as the unpredictability of errors.

- Durability: Printing at 100% infill, these sticks are extremely tough and durable, able to be used in real games at a high level and maintain impressive performance.

- Manufacturing: The manufacturability of these sticks is not reasonably good despite the time constraints of printing. There is still the possibility of using these as a stepping stone to creating moulds to cast from, or machining moulds for the final design, but 3D printing may end up being a more suitable method of manufacturing.

Overall, I am very happy with the turnout of the physical production through CNC machining of my product. Refining the design has been very beneficial, as well as having sticks that I could play with and test practically. The end result is a highly effective and suitable product that is usable and compa-

rable to high end products at a high level of play, as well as a possible stepping stone in the process to further improve the product. I additionally met up with my Client / Stakeholder [REDACTED] at the annual north island club tournament. I showed him my final base model design prototype, and he told me that it looked and felt really good, and he was looking forward to seeing the additional features.

## 9 Pre-Manufacturing Research

### 9.1 Brief Check

[Some attributes and specifications were complete at this point in the project while some were completed later - so I came back and added descriptions afterwards. All attributes and specifications were checked off by the end of the project, and I have only shown ones here that I had descriptions for.]

#### Attributes:

- Sustainability of design needs to be considered in your product.

I have researched sustainability, product life-cycle, sustainable materials and processes, and been implementing my research in the project, such as using plant-based PLA plastic for all 3D printed prototypes, reducing waste by re-purposing warped prints (e.g. testing drilling holes & engraving patterns). I have given considerable thought about how to carry out the manufacturing of my product in a sustainable way through the materials that I use and recyclability of both the waste and the product at the end of its life-cycle.

- It must be designed with multiple stakeholders in mind.

I have designed this project with numerous people and parties in mind, primarily I have designed the product with my own Underwater Hockey experiences in mind, but with the specific clients of [REDACTED] of [REDACTED] - the [REDACTED] - providing advice and feedback, along with the wider stakeholder base of my underwater hockey club, as well as the wider play-

er-base around the country and the world through surveys.

- The product/s should be designed innovatively and attempt to incorporate a feature that does not yet exist.

The product utilises both design features and a production style that is not currently available or utilised in the market, with the complex organic and ergonomic handle design, the puck bevels to allow advanced puck maneuverability, as well as the PLA 3D printing manufacturing which increases ease, sustainability of manufacturing and strength, while decreasing likelihood of failure, manufacturing time, product imperfections and cost (all in comparison to the industry standard).

- The product should incorporate researched techniques and elements such as ergonomics and hydrodynamics.

I used all of my researched design conventions specific to underwater hockey stick design as well as other relevant conventions, to inform my design process and ideas, as well as through my prototyping and testing to develop the refined product model.

#### **Specification:**

All met, no additional descriptions required.

## **9.2 Manufacturing Research**

In my initial research, I considered a variety of manufacturing approaches, while using hand construction followed by 3d printing for concepts and prototyping:

Moulding, 3D Printing, CNC Routing, Hand Manufacturing (band-saw, Sanding machine, carving, etc), and Hand Layup.

In my research so far, I can preliminarily eliminate hand manufacturing and hand layup as these are simply not efficient, sustainable, or scalable for a business model, as well as the prohibitive cost and difficulty of use for materials in terms of hand layup.

**Moulding:** is the industry standard, with this being the method used by my stakeholder / client [REDACTED] and his company [REDACTED] as well as many other companies worldwide.

[REDACTED] has also over the course of this project branched into injection moulding which seems to be going successfully. It is a finicky and time consuming process which is very difficult to get correct initially and is not always consistent in results. It is difficult to

create a quality initial mould, and along with this it is time consuming to let the moulds set for each product, as well as the finishing that is required after mould removal. Along with this, moulding materials are very expensive and it is more difficult and more expensive to get sustainable moulding materials. There is also the question of material suitability, as cast-able materials are naturally less structural and require significant reinforcement with materials, increasing the difficulty, time consumption and expenses of the project. Moulding is a very involved process and requires a lot of attention at various points throughout the process, as well as having scalability that is severely limited in terms of expense, with the main step up being injection moulding which is a big job and a \$20,000 commitment for a tooled mould.

**3D Printing:** is what I have been doing to this point, and it has been very effective and albeit including a time loss, this was not a significant issue as I am currently operating over a long time schedule, although this would have to be taken into consideration. 3D printing does use sustainable and varied materials, with the main environmental draw being from electricity use which can be accounted for through the use of solar panels or other sustainable energy general, but is important to take into account. The materials used in 3D printing are a lot stronger and do not require reinforcement - I have been using a prototype structurally impaired stick for months in real games and trainings with little to no damage and no signs of breaking - which reduces the difficulty of the manufacturing process in comparison to moulding. In terms of active attention this is fairly easy, as printers have protocols set up that decrease the requirement for human supervision - such as printing multiple sticks in a row without supervision - which would increase efficiency and save time. There are also various different machines with different capabilities that could be similarly beneficial such as conveyor belt or dual nozzle printers. A decent quality printer is a fairly small initial commitment for a business, as you can get a good printer anywhere from \$300 dollars, and it is extremely scalable as profit from

the business could be reinvested into the business over the course of growth, such as in the form of more printers with additional features to increase and streamline production, leaving the only human parts of the process being any finishing which is required no matter the manufacturing method.

**CNC Routing:** is the most unknown manufacturing option remaining, as I don't know any companies or products that use this approach. I have experience using CNC routers from previous years tech projects and it is a difficult and fairly time consuming process. I think that the cnc router could have fairly significant limitations for creating the complex and organic shapes that I am working with - additionally the router I have access to currently is primarily workable with wood - I could potential purchase a block of plastic to cut down but this would be difficult and the other issues would still remain. The use of a router would also potentially be better for a more complex for potentially mechanical product, such as the modular stick idea that I considered that would likely have a metal core. This makes CNC routing a dubious route for my product, as well as having all of the potential environmental considerations of 3D printing and much less of the scalability due to the nature of CNC routers.

**Overall:** with this research and consideration, I think that continuing with 3D printing is the most logical as well as best for my project. 3D printing is very strong, sustainable, relatively time efficient including production automation, allows varied materials, and most importantly is extremely scalable and versatile in terms of running a business, producing and selling products.

## 9.2 Material Suitability

By this final prototype / manufacturing stage of the project, a number of constraining factors as well as design decisions have already limited my options and necessarily reduce the pool of plausible materials significantly from the original researched options.

My best manufacturing method option has been narrowed down to continuing with 3D printing, while the coating method is

similarly limited to what will be an effective solution for the manufacturing method and material used, as well as the potential inclusion of a hydrophobic coating.

**Polylactic Acid - Plastic Filament (Core Material):** PLA filament is the primary 3d printable material that would be plausible for my product. It is a renewable bio-plastic resource that is economically produced from polylactic acid making it environmentally friendly. Other than environmental suitability, PLA is cost effective, structurally strong with high strength and good layer adhesion, it is of course requiring of a 3D printer to be printed from, and reasonably extended time periods for the printing process, although this is a fairly simple and repeatable process with minimal additional effort required other than to remove print supports.

**Plasti-Dip Rubber Spray Paint (Outer Coating):** "Plasti Dip is an air-dry, specialty rubber coating. In fact, it's the original peel-able, flexible, insulating, non-slip, durable rubber coating. The Plasti Dip product line provides a wide range of coating solutions from automotive customization to home improvement." This is a spray-on rubber coating (typically used as a removable paint for cars) that comes in both white and black, as well as providing a rubberised non-slip coating that works well on plastics. This makes it a reasonably suitable solution for my purposes, however one potential issue could be with limited durability. Despite this, it is the most cost effective and accessible product with good suitability for my project.

**Flex-Seal Liquid Rubber Dip (Outer Coating):** Flex Seal has a range of Liquid Rubber dip products, that through my research would be a very suitable and effective solution to creating a rubber coating. This is a product specifically intended to create a 'super strong, no slip, rubberized coating on the surface' and would be potentially ideal for my purpose. However, being an American manufactured and distributed product, along with being already fairly expensive, it is not only very difficult to find a provider of the desired products in NZ (either the black, white or clear liquid rubber) but also prohibitively expensive to acquire

if even possible to do so due to the combined cost of the product and the shipping. As such, I was not able to get this product, and had to use the closest equivalent plausible.

**Roof & Gutter Silicone Spray Sealant (Outer Coating):** This is an alternative option that I looked at for soft coating prior to Plasti Dip. I briefly tested it on the initial prototype stick after it broke. This is a transparent coating that is made to seal holes in roofs or gutters and sets into a firm silicone coating material. In my testing I found that it was fairly firm but had some bubbles in the coat, and thought that it wouldn't be an ideal product for my purposes.

**Hydrophobic Coating (Outer Coating):** In my research I have discovered that there is actually no product matching the mental image that I had - there are certainly hydrophobic coatings but nothing with suitable industrial applications like I would need. The closest products would be either Scotchgard (or similar) - which is a hydrophobic coating for fabrics, the various liquid coatings that intended for glass or windscreens and are not permanent, or automotive hydrophobic lubricants which do not set in and are again not permanent. As a result of both the lack of viable products, and the natural water resistance of the intended rubber coating, I believe that a hydrophobic coating would be largely redundant. There is one potential version of [REDACTED]

- that could

be beneficial to the performance of my product by increasing the water resistance and thus grip of the rubber coating, but using this may not be beneficial and would depend on cost and time constraints.

typing of additional features that I want to include: A grip texture for the playing edges, as well as a modification for additional puck maneuverability, and a cutout in the blade to reduce mass and weight. After this I will also need to prototype the rubber coating and water resistant coatings that I intend to utilise on my final product. With the degree of research, consideration, development, prototyping and testing repeatedly going into the initial base design of the product, at this point I was relatively limited on time remaining in the year and had to undertake the remaining design development cycles somewhat simultaneously.

## 10.1 Feature 1: Blade Cutout

### 10.1.1 Initial Prototyping

The first advanced development is to create a cutout that I plan to add in the blade; this is an existing design convention, and will help to reduce both the mass and the drag underwater, allowing for significantly improved speed and maneuverability during play.

The cutout should be towards the end of the blade, taking some material out of the largest segment of the blade at the hook. To prototype this, I used a slightly imperfect model to test on - the same one I had already used to test texture so as not to increase waste:



I started by drilling holes to mark where the cutout should be, before using a hacksaw to cut out excess material, and finishing with a dremel to fine tune and smooth the edges. I have done fairly extensive testing with this prototype, using it in practice sessions as well as during numerous games, and had a similarly successful result to prototyping the texture, as it achieved the desired results, decreasing the drag and weight in the water. I did also feel like the thickness

# 10 Additional Features

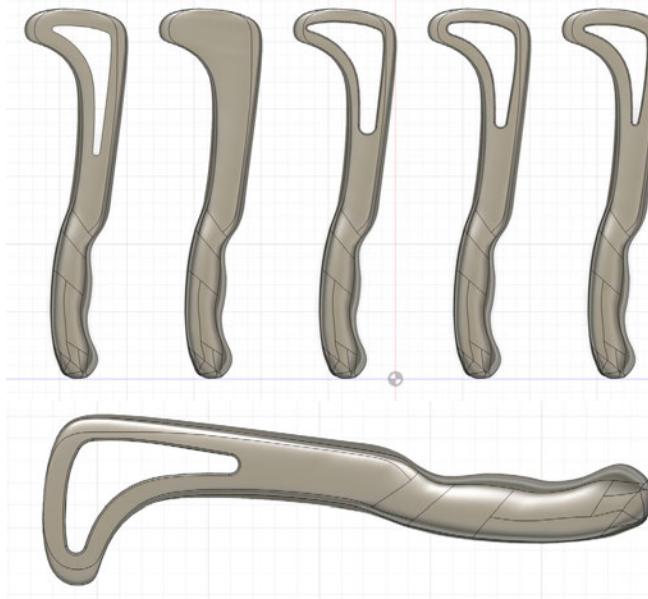
## - Concepting, Development & Prototyping

The plan for this products second stage of prototyping is adding to the base model through the development and proto-

of the blade surrounding the cutout was in no danger of damage or breaking, and thus could be even further decreased in the final design.

### 10.1.2 Development

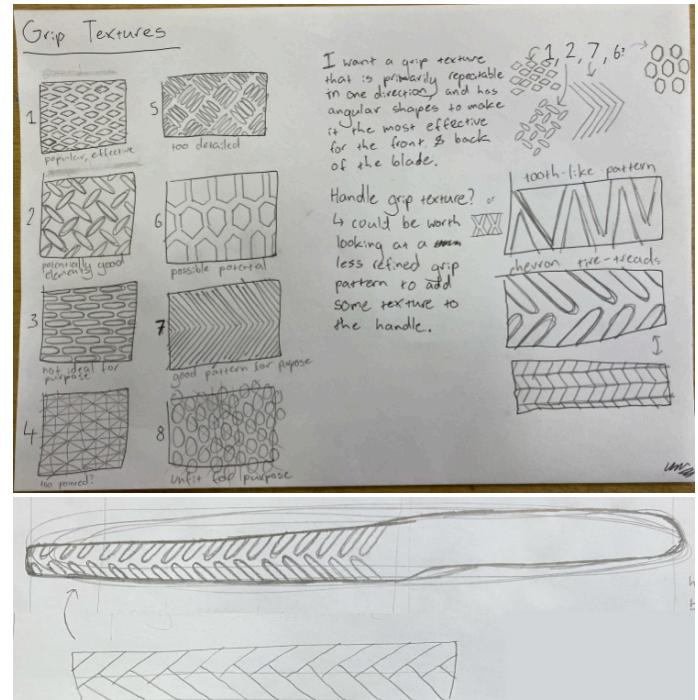
The next step is modelling this cutout on the base stick design in Fusion360: Looking at a couple of different shapes, followed by a range of sizes, I drew my conclusions from my testing of the modified prototype stick with a cutout as well as consultation from my teacher about the structural solidity of the different cutouts, selecting the mid-size cutout as the optimal design to proceed with - however if in my next round of testing this is a volatile design, I will be able to come back and make any necessary adjustments.



## 10.2 Feature 2: Grip Texture

### 10.2.1 Concepting

After some research, I think the most effective way to go will be to take inspiration from existing patterns, such as handles and tires. For my purpose the most effective pattern will most likely be something angled to retain edge grip in the widest surface area possible no matter where the puck is contacting the stick, as well as maintaining a good degree of grip and thus control over the puck both horizontally and vertically.



This pattern can either be inset into the blade, or extrude from the surface - tire treads are typically inset, whereas the textures on rubber handles and grips are usually extruded.

### 10.2.2 Prototyping

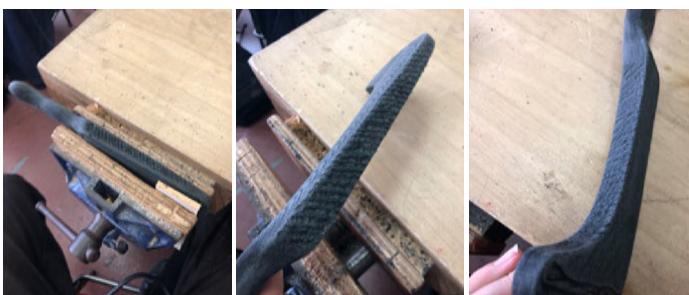
I went back to my initial concept mock-up polyurethane models to do initial testing.



I think that based on my research, an inset grip pattern will most likely be the most effective option, as by having the larger portion of the surface at the exterior, there will be the largest surface area possible, while creating edges to increase grip at different angles. I additionally tested this on a previous iteration of stick prototype, using a sanding bit on a dremel to engrave the slightly wider and shallower grooves, which appears effective.



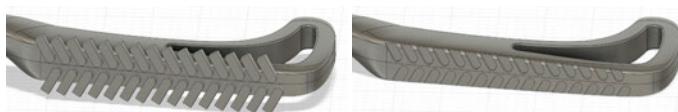
I additionally tested these grooves on a solid version of the base stick model so that I could play with it in games and get a better sense for the effectiveness of this feature.



I am confident in implementing this texture to my model based on this prototyping. Particularly, the engraved solid prototype showing significant success during use in training and games, most obviously demonstrating better grip and flicks, and being considerably preferable - to me and every other player that I asked for feedback - over untextured prototypes.

### 10.2.3 Development

I created a shape to indent into the front of the blade and used the 'Pattern on a path' feature to repeat it down the front face before subtracting the shapes from the overall model, I did however have issues with creating filleted edges on the indentations so this may not be the most effective technique.



I made a second attempt using the pattern on a path tool with a different set of cutting bodies, to make them smaller and more compact, as well as pre rounded to avoid issues with rounding after subtraction of the cutting bodies from the larger stick model. This creates a nice even pattern that should print without much difficulty and provide significant benefit to puck grip on both the front and back edges.



## 10.3 Feature 3: Puck Gripping Edges / Bevels

### 10.3.1 Prototyping

For the last additional design feature I want to add raised edges on the bottom of the stick to allow the use of a specific skill that is popular among players, which is to place the stick on top of the puck and move it with greatly increased maneuverability, maintaining horizontal grip on the top side of the puck using edges and creating pressure between the puck and pool floor.

I tested where a comfortable position for the puck to sit on the bottom side of the blade is, and used cardboard to find an outline, before cutting smaller cardboard pieces and attaching them to my wooden prototype stick.

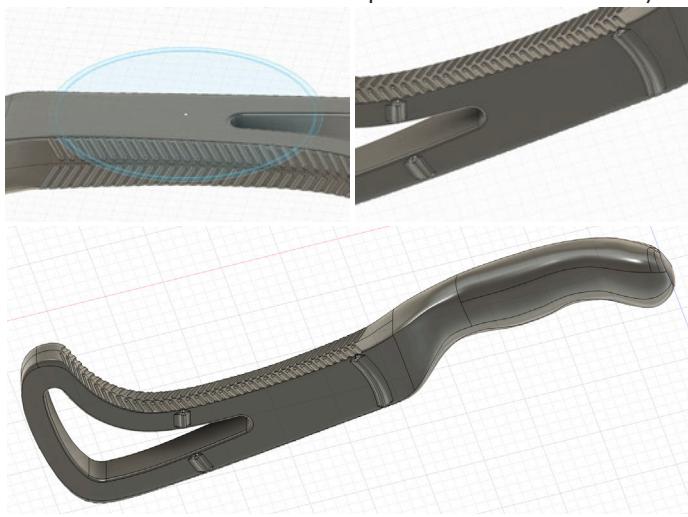


This was surprisingly effective, allowing me to slide the stick over the top of the puck until it slotted into place, then providing impressive grip on the puck most prominently on the horizontal axis, but generally creating a significant increase in mobility for a period of time when using this feature.

### 10.3.2 Development

I started by placing an outline of the puck diameter on the bottom face of the stick, then sketching the tolerance and width of the edges / rim. I then extruded the rim and rounded all of the edges to create a more seamless feature that should still create the desired effect. One fairly significant consideration will be the impact of this feature on 3D printing, as this most likely will require a layer of supports between the raft and bottom of the stick so that these edges can be included in the design, and it is difficult to

predict how successful and consistent this will be and the exact impact that it would have on the print quality of the stick as printers and conditions are prone to variability.



#### 10.4 Feature 4: Rubber Coating

After the design and development of these advanced features in the model, I of course need to prototype them physically and test them in practice and games to confirm their suitability and reach the final prototype / product.

I applied 6 coats (roughly 0.25mm thick) to the blade of an old prototype stick over the course of 2 days, before feeling like there was enough of a coating to work. Initial impressions were very promising, with the stick demonstrating much more grip as well as some compaction from the coating.



After this I took it for an initial testing session in which I found relative success, showing that it was providing grip, although the extent was hard to gauge due to my use of a past prototype model as the test stick, and

I will be able to get a better sense of the actual impact on performance when using a newer prototype which I plan to do once I have fixed the issues with the initial advanced feature development prototype.



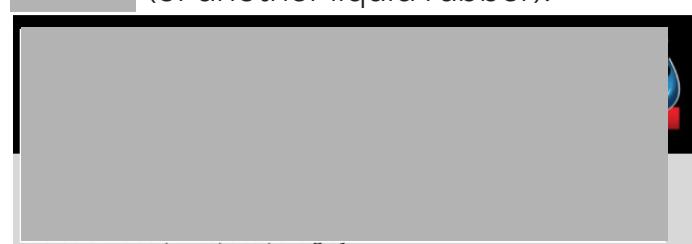
After the initial testing I thought that the stick performed reasonably well, although there was some damage to the coating at the bottom front corner of the blade - which is consistent to where I have noticed the most damage on my solid final base prototypes that I have been playing with for the past month or so. This damage was a tear in the coating that could potentially cause the coating to peel.

There were a number of production related factors potentially holding back the performance of the soft coating; the old prototype I used will not have been the best base to coat or have provided the best bond as there were a number of smooth surfaces due to usage, some of the coats were slightly hastily applied and I could be more patient during coats and in-between coats to get a better result, as well as that the stick could potentially just have done with some more coats to create a better effect.

These could be the reason the coating was more likely to peel, although if this is a persistent error, another solution could be masking off the front corner of the blade during coating so that there would be no rubber coating to damage in play and potentially cause peeling.

I asked my client for feedback and he said that this sounded like a good and cost effective method of rubber coating, and to make sure to get as strong a bond as possible with the plastic.

Alternatively, it could be worth exploring other options to try dip coatings, such as (or another liquid rubber):



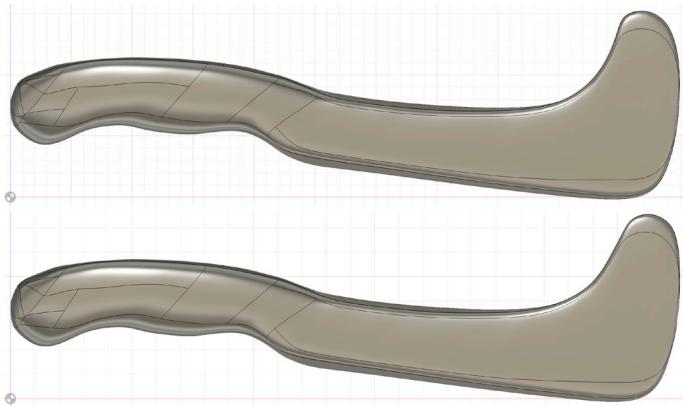
The issue with these products is the prohibitive cost, ease of access, and colour options. [REDACTED] - which has the right colour options (black, white, clear), good product sizing, and the right properties, is relatively expensive but more pertinently, it is very difficult to obtain the liquid flex seal in NZ, with no local retailers carrying the product, and online shipping increasing the price drastically as well as involving shipping times and customs errors. The NZ company equivalents of this sort of liquid rubber dip product, however, are significantly more expensive, come in very large quantities, and don't offer products in white (or clear). Not to mention that these products also require much longer drying times, with a minimum of 24 hours and 48 hours or longer being recommended.

Due to this, the most practical and realistic path forward with which I can continue is to use the rubber spray paint which I already have - as well as purchasing a white can - and making sure to learn from my mistakes in the previous prototyping, making sure that the plastic surface is sanded and adequately rough for the best bond possible, waiting the full amount of time for the coats to set, and doing more coats to create a thicker and stronger end coating, which should be more suitable and durable. This will also help to keep the product as cheap as possible to allow for sales with a good margin, so that the business will be able to grow and explore different options as there is more expendable revenue.

## 10.5 Hook Consideration

I received some more advice from the head of my club [REDACTED]

) about the shape of the hook. He suggested a small modification to the base design in terms of the hook: Opening the curve of the hook slightly to potentially allow for better hooking the puck as well as better back flicks (a less commonly used skill).



This is a minimal change but slightly alters the way the hook would be used, as it also slightly reduces the hooks wrap around the circumference of the puck which I feel is one of the defining features of this stick - the really secure grip on the puck that it provides.

Nonetheless I printed a test version of the stick with the suggested modification which I tested in multiple games and trainings.



Side by side physical comparison.

The result of this was finding that I felt like although the modification could be a potentially good change, it reduced the security of the hook which I found to be too much of defining feature of my design. Along with this, it is quite a minimal change so not implementing it is not causing any great issues in the design. The issues raised were also likely only something that would effect someone playing at a very high level and the primary body of players that would want to purchase and regularly use this stick are most likely not going to be at the utmost highest level as there is already an industry standard for good reason.

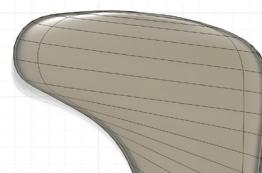
## 11 Final Refinements

### 11.1 Prototyping

I will be 3D printing the advanced model

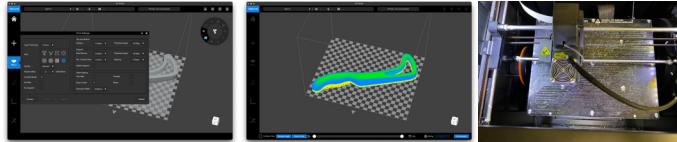


Original Hook



Modified Hook

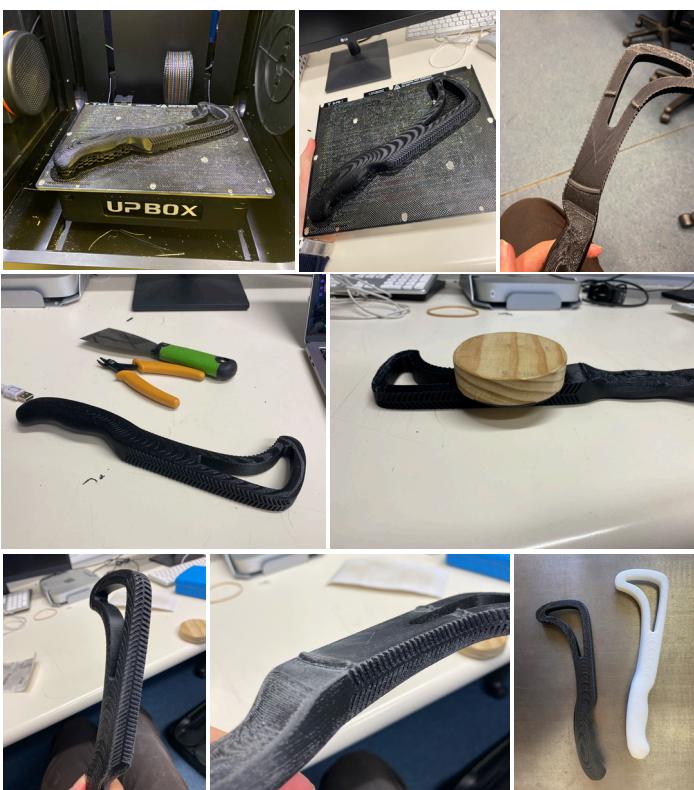
of the stick to test the suitability of all advanced developments, before continuing on to producing a final prototype set of a black and white sticks after any final developmental changes or refinements, complete with rubber and hydrophobic coatings. For the prototype I will be using the same settings as my final prototypes of the base design and adjusting from there if necessary, although this should be unlikely as I refined the settings until getting very good and significantly consistent results.



Another benefit of using a cutout is reducing time to print, as this stick can be up to two hours faster than previously, although I have chosen to select a slightly higher quality level to increase likelihood of success, still saving an hour in print time as well as around 30g of PLA.

I used insights garnered from prior 3D printing prototyping when setting up this print, with optimised settings as well as using features of the printer such as print bed pre-heating, and glue stick on the heated bed to further increase base layer adhesion.

The first print was a complete success with the stick printing perfectly and the supports coming off with relative ease - made easier by my experience with prior prototypes.



Immediately there are some changes I notice that could be made to potentially reach a final advanced development design - I initially noticed that some edges, such as the edge of the cutout, could do with a larger fillet to create a smoother curve, as well as some things I noticed after a bit of consideration, such as that the puck edges/bevels could be placed closer to the handle for ease of use and maneuverability as well as have the tolerances decreased slightly, the cutout should have one or multiple struts crossing it so as to prevent anything getting caught in the cutout with the added benefit of some potential minor structural reinforcement. After seeing the physical result of the 3D model I will also potentially want to adjust the design of the texture, as from my experience slightly shallower and wider texture indents will likely work to greater effect.

I asked my client for feedback on this iteration of the final product and he said: "For grip patterns and rubber coating, yeah you do need a bit of texture on it but worth the 3d printed effect that provides it by default, not really anything to add... shouldn't be an issue. What you have already should work well with the tread." Overall he seemed to be saying that the tread pattern would work fairly well and anything of this sort of design would be effective - but I would like to modify it as mentioned above to help with greater surface contact as well as rubber adhesion and stopping the rubber from filling the tread holes and negating the grip pattern.

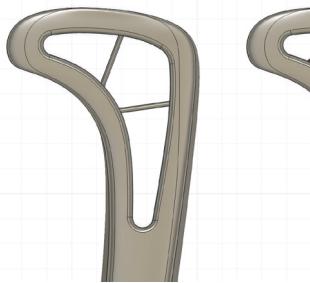
I have also been seeking feedback from players in my community throughout the process, and received generally positive feedback on the changes.

Moving forward from this prototyping, I need to develop the final iterated design changes to solve the final issues from the previous advanced development model. The primary changes should be adding struts to the blade cutouts - preventing anything, mainly other sticks, from being able to get stuck in the cutout hole - as well as modifications to the stick in spacing of both the puck bevels and grip textures.

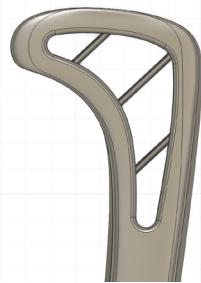
## 11.2 Development

### 11.2.1 Cutout Struts

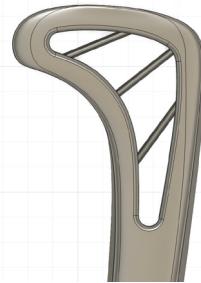
Because I ended up not changing the shape of the hook I was able to keep the previous cutout, as it proved very suitable throughout my usable of the previous iteration of stick. I wanted to keep these struts reasonably small and spaced out to prevent anything from getting caught in the hole, and I liked this slanted design because it helped to fill out the space better, as well as not needing much structural consideration as these will not be able to provide much strength and support no matter the design.



1st Design



2nd Design



3rd Design

### 11.2.2 Puck Bevels

I wanted to increase their practical usability, as in the first iteration they did not manage to provide a usable grip on the puck. I started by experimenting with a few different approaches to finalising this design before settling on the direction for this iteration.

I improved the design by increasing its protrusion from the base of the stick by a few more millimetres, rounding the inside edges less and the outside edges more - to give a cleaner edge to contact the puck with, and a smoother outside edge to slide over the top of the puck or anything else. I also tightened the tolerance of the bevels so they would have a closer fit to the puck and provide a better grip, as well as moving the bevels closer to the handle both so that the puck would be closer to the hand and more within the players control, and so that the bevels don't obstruct the usage of the rest of the stick or impact the ability to get the end of the stick flat to the tiles.



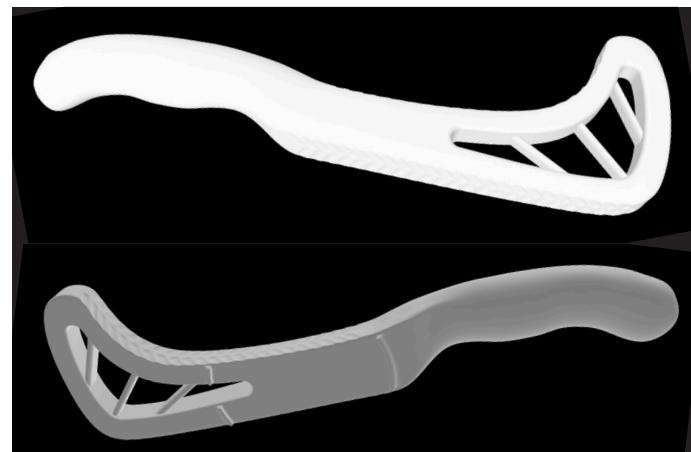
### 11.2.3 Grip Texture

I used a different shape this time, going for wider and shallower indentations, being twice the width and half the depth of the first iteration. This design required reasonable tweaking to get the correct rounded and repeatable shape, as well as in the right position and correct angles to interact with the stick model. I experimented with variations of this iteration to be sure that I was going in the right direction, before subtracting the repeated shape along the curve of the blades front surface and repeating the process for the back surface:



## 11.3 Final Advanced Design

With these developments, I have reached the final product design, barring any issues with the stick, and the final steps will be to manufacture the final product (prototypes) through 3D printing and rubber coating.

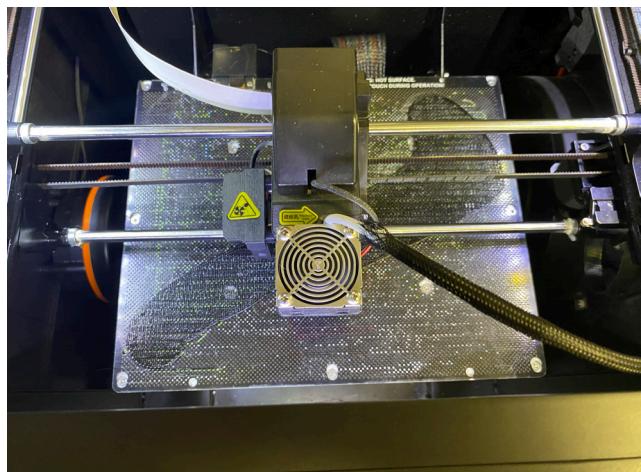


# 12 Manufacturing Final Prototypes

## 12.1 3D Printing

After the final iteration of the advanced developments, I started the first of two final prints for the set of black and white sticks. The first one printed flawlessly in white. The revised grip texture seems a lot more initially suitable and should find significantly more traction on the puck especially after the addition of the rubber coating. After removing the supports, the struts felt impressively solid for how thin they are and will well suit the purpose of stopping anything from getting caught in the cutout, while the puck grip bevels showed promising success on my wooden replica puck and should be suitable for use in a real game.

I then started the second print for the black version to complete the set - continuing to use the insights garnered from prior prototyping and experimentation, such as applying glue to the print bed, refined settings for my type of material and model, and printing overnight to maintain a more consistent ambient temperature. This print was also perfectly successful.

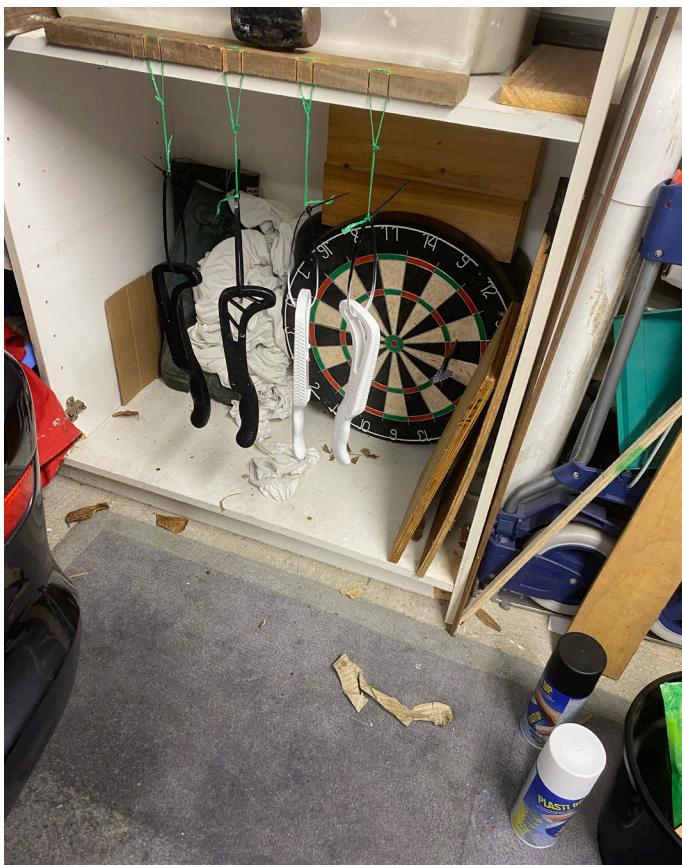


## 12.2 Outer Coating

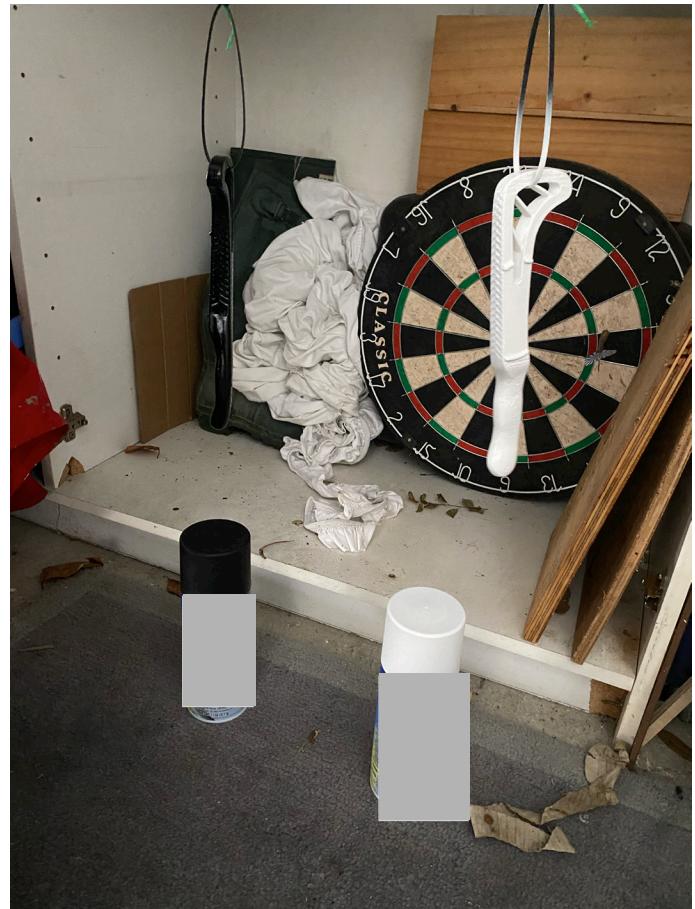
Next in the manufacturing process I set up a way for the sticks to dry between rubber spray-coats, using zip ties for their rigid structure to minimise contact with the painted surfaces of the sticks, then attached to string tied in loops to be easily attachable and removable from notches cut in a length of wood, allowing them to hang and dry after applying coats outside in an appropriate area.

I gave the two pre-final prototypes half as many coats as the to focus on developing optimal final prototypes, while still being able to play with and further test a more modern rubber-coated model than my initial soft-coating test which

used a significantly older prototype. The testing was relatively effective - the coating provides reasonable benefit during play, albeit is not as durable or effective as the commercially available sticks with soft coats: essentially this is not the perfectly suitable material for my purpose but is the most effective material I was able to acquire considering access, cost, and time constraints. The materials used would potentially be something that would require further conversation with my client before going into manufacturing.



After 5 coats - once an hour or more - I left the pre-final prototypes 24 hours for a final drying period, while continuing the coating process with the final prototypes. As additional finishing touches for my final product prototype, I took insight from my previous prototyping, testing, and material suitability research: While the 10th Coat of Plasti Dip (creating a 0.5mm thick rubber coating), was drying, I added a final coat of Heavy Duty Water Guard for its hydrophobic properties, as this should hypothetically improve hydrodynamics by helping the sticks pass through the water with less resistance and thus more speed.



Final product prototypes hanging for final drying period.

### 12.3 Completed Product



## 12.4 Client & Player Feedback

I was able to meet in person with my Client at the high school underwater hockey nationals, and show him my final product, with his feedback being that the cutout struts looked effective, the rubber coating had a great grip, colour and finish to it, the texture pattern felt effective and the buck bevels seemed suitable and had good potential. This, in addition to the widespread feedback from players in my community throughout the project and especially towards the end with the final designs, has been overwhelming positive, and I am very happy with how this product has turned out. While time, money and accessibility limitations forced me to keep my ideas and plans realistic, I think that the final result is highly suitable to my initial intentions, and has room for potential further development if desired, particularly to develop my design into a manufacturable product to be sold by my client.

'playing area' of the stick is that area not covered by the protected hand and forward of the thumb and index finger where they rest on the stick.]

- The stick must be considered safe: must be structurally sound, have no sharp edges, be unable to cause harm, etc.
- The product/s should be designed innovatively and attempt to incorporate a feature that does not yet exist.
- It should have a defined 'blade' aka 'playing area' and a defined handle.
- The product should incorporate researched techniques and elements such as ergonomics and hydrodynamics.

Specifications:

- The product must fit inside a box with internal measurements of 100mm x 350mm x 50mm.
- Must have a minimum corner radius around the perimeter edge of the entire stick of 10mm
- Edges where surfaces intersect must be rounded.
- The stick must be uniformly black or white. [This is to distinguish what team each player is on]
- It must not surround the puck or any part of the hand, nor encapsulate the puck more than 50%, or lock it in place.
- It may not protrude of the heel of the hand by more than 25mm.
- Multiple materials can be used: wood, plastic, metal, glass, rubber, etc.
- You need to have some form of electronics in your project, or alternatively use complex processes to manufacture, providing your product with a point of difference from other available products.
- It must be assembled with simple tools or no tools.
- At least 2 parts of your design must be CNC machined.

Based on my brief check, the product meets all of these specifications.

## 13 Final Evaluation

### 13.1 Suitability to Brief

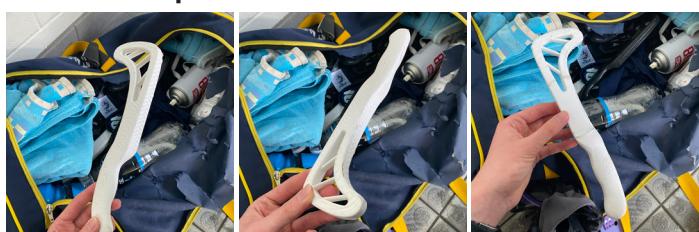
My brief was to design an Underwater Hockey stick that is at the same level of quality as those professionally available, that is broadly usable / applicable, and generally fit for purpose. I wanted the product to include advanced features, along with a feature that is not currently available in existing products, in terms of design and production. Additionally the product is supposed to have environmental and sustainability consideration, as well as being a viable product for production and sale in the NZ and international UWH gear market.

The exact initial Attributes and Specifications for my product were:

#### Attributes:

- Sustainability of design needs to be considered in your product.
- It must be designed with multiple stakeholders in mind.
- The product must be able to be held in a way that the stick has a defined 'playing area' where it extends from the hand. [The

### 13.2 Implementation in Situ





Final Product in intended environment.

Below are links and timestamps for some moments of me using the final product during the [REDACTED] representing the Northern region A team:



[REDACTED], due in part to my impact on our games with the Kusarigama sticks - I'm sure.

### 13.3 Evaluation

The product continues to be a very suitable solution to all of my attributes and specifications, as well as a generally good stick to use. I have found all of the design decisions and fulfilling of my attributes and specifications to make the stick a great product and very effective for use in games.

The overall shape which took up a large part of the development of my product, is a very effective shape which a secure, comfortable and versatile handle, an effective front edge for tacking and flicking, a strong hook for back-tackles, skills and puck control, as well as aesthetically considered organic contours and curvature.

The advanced features also provide suitability to the product, with the cutout decreasing mass and drag for faster movement along with the struts to increase structural integrity and prevent anything passing through/becoming caught, the refined grip texture on the front and back faces of the blade to increase traction with the puck, the rubberised / hydrophobic outer coating to further increase grip plus speed, and the puck bevels to allow for a new and very quick movement style with the puck.

The manufacturing process is also a good solution for the product in terms of strength, durability, sustainability and marketability.

In terms of my design process, I wanted to split the project into parts, making it easier to focus on different aspects of the design at a time. The primary parts I split the project into were base design and advanced features, and within these two main design attributes of the product were the more specific features of the product that were conceptualised, designed and tested within the wider part of the process. I think that by splitting it up into a branching segments of design problems, I was able to reiterate my designs and ideas very effectively to reach more suitable and effective solutions more efficiently as opposed to, for example, creating one whole version of the product and having to go back and reiterate and develop the product from the very start.

I am most happy with the overall design of my product, especially the design and

shaping of the handle and blade, as I have found I created a very comfortable and secure design, as well as an effective, quick, maneuverability product in terms of puck control. The advanced features I also believe are very fitting and suitable, elevating the carefully considered and designed shape of the stick with improving and innovative features.

If not for the constraints of my project, there are definitely some things that I would have done differently. The biggest constraints and limiting factors as previously mentioned, were time, money and accessibility. If these three were less of an object, I would have potentially been able to even further improve the final design, whether this would be through having more time to develop, or access and means to purchase to better materials or explore different options - such as different soft coatings - that were not accessible, or were prohibitively expensive. I would also potentially have been able to explore some different avenues or features in my design, and develop even more innovative or creative solutions to gaps in the UWH stick market. Despite this, I do think that my product is very effective and up to standard with the highest quality sticks available.

### 13.4 Client Feedback

My client gave me feedback on the completed project, simply saying that he thought it was a very good design, well completed by the advanced features. We discussed sales, and he agreed that he would be very happy to carry my product at [REDACTED] - with the potential of working out a manufacturing agreement, which was one of the end goals since the inception of this project, to develop an effective and suitable product that my client would be happy to produce and/or sell through his company - this may take additional discussion and set up but this is a great result for my work and my product.

### 13.5 Improvements

As developed and refined as this product is, there are definitely changes, developments and improvements that could be made the design and the product as a whole. I am still

a fan of a lot of the idea I came up with earlier in the year for conceptual experimentation, that I was unable to pursue due to resource and time constraints. My top conceptual ideas were definitely a core and sleeve design, a gel handle, or a modular stick design, along with a number of other possible features that it would be interesting and fun to experiment with.

In terms of my final product, I think the most suitable improvements that could be made are potentially additional refinement to the puck gripping bevels as I think their effectiveness could be further improved, as well as further research and development of the soft coating, as from my current research I am sure there are more suitable products, but once again due to limitations I was unable to explore these avenues in this project. This is definitely something that I would like to continue working on, developing and improving in future whenever possible, as well as exploring other avenues of design such as different manufacturing options.

### 13.6 Moving Forward

The future of my product will hopefully be sale on by [REDACTED], as well as potentially some in person sales at tournaments - I will likely also do some direct sales in addition to retailing through Hydro as there are a number of people in my club and local vicinity who want to purchase a set and it will be more efficient to sell to them myself. In terms of the product development, this is something I have thoroughly enjoyed and that I will want to continue developing in future, potentially with exploring more advanced features, or manufacturing styles that I didn't have the opportunity or resources to look at in the span of this project.

**Naming:** I chose to name the final products 'Kusarigama', a Japanese word directly translating to mean Chain-Hook. Kusarigama are ancient Japanese weapons commonly utilised by Ninjas, comprising a handheld scythe-like blade- representative of the stick design, specifically handle and hook - and a chain - representative of the use of the stick, swinging it around your body. This name is in line with the trend of naming sticks after a weapon, but more importantly it links back to club, [REDACTED] mean-

ing [REDACTED], with its historical use by Ninjas, along with the sticks suitability for surprise / steal tackles.

**Sale:** [REDACTED] has stated his desire to retail my product through [REDACTED], and we are currently discussing the possibility of Hydro handling the manufacturing of the product and the processes surrounding that, but hopefully this will eventually be the final outcome of my product design and implementation - Otherwise if it doesn't work out and I continue to develop new sticks and products, I may start my own UWH gear company in the long term.

In the mean time, I made mock-ups of what it will look like when my sticks are (eventually) being sold by [REDACTED]

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Log in or Create an account - All prices in NZD (change)  
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2 items - Check out  
\$0.00 NZD

Soft Kusarigama  
Hydro Underwater Hockey

\$91.00 NZD

Style  
Right Handed

Handle  
Blank

Quantity  
1

Add to Cart

## Soft Plastic Sticks

Browse by Tag All Sort by Featured

Our Soft Plastic Sticks are the most advanced technology available in the market today, and have gone through multiple iterations of prototype testing over many months and major international tournaments. Otherwise known as "rubberised", "sticky" or "rubber" sticks.

They are constructed from a tough polyurethane core, reinforced with a Kevlar-Carbon hybrid material to give maximum strength, impact resistance and the right amount of springy stiffness. This core is then coated with a layer of softer material that grips the puck and absorbs impact.

The outer layer is a constant and standardized thickness allowing consistency in performance not possible with brushed on coatings. The result is a stick with another level of puck control and feel when compared to a standard hard plastic or wooden stick.

The core design includes ribs that run along the edges of the passing surfaces, and around the end of the stick where the stick will contact the tiles. The hard material of these ribs takes the brunt of the wear on these edges, and also presents a hard slippery contact to the tiles so the rubber doesn't grip the bottom. The rubber grips the puck in the same way that car tyres grip the road, using grooves and textures to channel water away from the contact area.

The result? The best grip, puck control and handling possible, and a huge pass with all manner of pucks. The pucks bounce off your stick is greatly reduced and this allows levels of control unreachable with wooden or hard plastic sticks. You can use faces of the stick to move the puck in ways that aren't possible without the grippy coating... going back to hard sticks after getting used to soft ones is a very noticeable drop in performance.

Our soft coating is UV resistant, holds a clean bright white and won't turn yellow in your bag overnight.

We can customize your sticks with a name on the handle just like our regular sticks.



Soft Katana  
From \$91.00 NZD

Buy

Soft Tomahawk  
From \$91.00 NZD

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Soft Numbat  
From \$91.00 NZD

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Soft Pixie  
From \$91.00 NZD

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Soft Kusarigama  
From \$91.00 NZD

Buy

Soft Tomahawk Ghost  
2.0  
From \$116.00 NZD

Sold Out  
Buy

\$91.00 NZD \$116.00 NZD

## 13.7 Reflection

This is certainly the most complex and comprehensive design process and project I have ever undertaken. I learned an immense amount about underwater hockey, stick design, and more importantly about the difficulty of developing and implementing an effective product. I thoroughly enjoyed this process despite the difficulty and having to somewhat significantly reduce my hopes and desires for the end product throughout the year.

I am however fairly happy with the compromises that I had to make due to lack of time or more frequently lack of resources - whether it was materials I couldn't obtain, or processes I was unable to perform - despite the fact that these closed off a number of avenues for me, I am very proud of the final product and the level of quality I was able to produce them at. At the time of writing this, I have been playing with only my developing prototype sticks since completing the first 100% solid prototypes, and I have had no issues or desire to swap back to a [REDACTED] made stick, along with numerous expressions of interest from others about purchasing a pair.

As always in life, I could have improved on my time management, as there were some stages that were daunting and new to me - such as learning a completely new discipline of 3D modelling - and in hindsight there were definitely ways that I could have

cut down on time loss, allowing more development in the end stages of the project, although overall I don't think this had as big of an impact as it could have.

This project has also really helped me realise my passion towards product design and development, and has played a considerable part in wanting to pursue industrial design at Massey University next year.

Overall I have learned a great deal from this project, as well as greatly enjoying all of the time and effort that I put into it throughout the year, resulting in a very fit for purpose and successful design, with securing a retailer and potentially a manufacturer. And once again, I have to say a massive thank you to all the people who helped me over the course of this year.

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[https://www.bunnings.co.nz/selleys-315g-roof-gutter-spray-seal\\_p1230179](https://www.bunnings.co.nz/selleys-315g-roof-gutter-spray-seal_p1230179)

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[https://www.bunnings.co.nz/3m-297g-scotchgard-heavy-duty-water-shield\\_p0238847](https://www.bunnings.co.nz/3m-297g-scotchgard-heavy-duty-water-shield_p0238847)

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19th October 2023

### Stakeholder Feedback: [REDACTED] Kusarigama UWH Stick Product

As the founder and owner of [REDACTED] past [REDACTED] I am immensely impressed with the outcome and degree of consideration that went into [REDACTED]'s product. I have made a lot of underwater hockey sticks in my time and he has managed to create a highly refined and completed design in a (from the sounds of it) considerably restricted period of time. Underwater hockey sticks are highly complex products where every measurement, however fractional, can impact the functionality of the stick to a large degree. Designing a good stick is no small feat, especially when attempting to introduce various new ideas.

I have had extended discussion with [REDACTED] as well as meet with him, where I was able to see and try his product. The stick he has managed to design is very good. Its very suitable to the purpose, easy to manufacture, cost effective for both production and consumers, as well as taking sustainability into impressive consideration for a fairly small scale project like this. This stick, and project like this, are very important to the underwater hockey community, as a small community. By doing this and sharing his work and experience and even passion for the sport with others, he is helping bring a wider audience to our reasonably niche sport - which is always a good thing - as well as to promote further development and innovation in the market.

If I were to suggest any improvements to this design, I would encourage [REDACTED] to keep exploring and experimenting with his ideas - push the envelope and really see where he can take this. More specifically for this project, I think my main concern would be some further refinement of the outer coating if possible; he has of course shared with me the difficulties surrounding availability and cost.

Overall, in my opinion the product that [REDACTED] has produced is an exceptional piece of design work, with the honourable aim of contributing to and spreading awareness for something he is passionate about, and is highly impressive at a Year 13 level, especially considering the limitations he faced. I wish [REDACTED] nothing but the best for his studies next year and any other future endeavours.

Best regards,