The Design and Manufacture of a Handheld Games Console

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"There are no mistakes, only skill building opportunities" - Steve Ramsey

Contents

Text that is **Bold** denotes technical terms which I will document in the Glossary.
All images used in this document, and others, are in their relevant Appendices.

Design Specification

Before any aspect of the product can be designed or researched, it is vital to construct a Design Specification, which can be referred to when making decisions concerning the design and manufacture of the product. I identified 8 key areas to analyse and define in order to have a sound understanding of the requirements of the end product. These areas were: Aesthetics, Cost, Customer, Environment, Size, Safety, Functionality and Materials.

Aesthetics: The key focus of this product is to show that the design of handheld games consoles is not strictly limited to cheap, plastic, toy-like designs, and as such, it is imperative that the product looks stylish, elegant and mature. This could be reflected in the palette of colours used, materials, or finishes used, but it is very important that the first impression a consumer has of the product is that of maturity and quality.

Cost: The cost of this system, like with any other product, should be kept as minimal as possible. This can be achieved through the use of complex machinery optimised for manufacture, or perhaps through economical choices in the resources that should be used. It may even be beneficial to attempt to reduce the price of materials by forming and using links between myself the manufacturer and the suppliers, though I suspect this would only be viable on a larger scale. The finished design I would expect to retail at approximately £120, though depending on the finished article, this could be as low as £75. The costs of materials, and importantly, the value of the hours required to manufacture the product, not including primary research and development, should be lower than £75 in order to avoid making a loss on the product. Cursory research leads me to predict a material cost of approximately £45 - £60, meaning that, not including the cost of manufacture, each unit will make between £15 to £75, though the actual value will most likely be in the middle of those two values.

Customer: This is intended to show how console design has moved forward and matured, and as such, this product would be marketed to young adults, between the ages of 16 and 40. People within this age group have grown up with video games, and this more mature and sophisticated approach to design will appeal to those who wish to own a console that is more robust and well designed and at the same time is not childish.

Environment: Electronic products are infamously detrimental when disposed of incorrectly, and even the manufacturing process is harmful. It is important to, therefore, ensure all materials are responsibly sourced, and where possible to use recyclable materials. If, for any reason, this is not possible during the manufacture of this product on an individual scale, a more environmentally friendly solution must be devised for mass manufacturing, as I am unable to use many materials at this stage. However if this product was mass produced, a wider variety of materials and manufacturing methods are available, and some of these will be more environmentally friendly than the ones I will be using. These should be identified and highlighted at the end of the project. (See Appendix 10)

Size: Sizing is often overlooked, however it is a very key aspect of product design, as it is not simply limited to the width, length and height of the product, but it relates to the position, spacing, thickness, shape and form of each and every component of the product. As this is a games console, it is important that the ergonomics of the product be considered and thoroughly researched, as the device will be held for extended periods of time, perhaps even tens of hours in extreme cases, and as such, it is important that the device be comfortable to hold. The device should fit in a pocket easily, and should not be thicker than necessary.

Safety: The system needs to be safe enough to not cause harm to the user during normal operation, and as such, should be designed so that the electronics are completely isolated from any metal casing elements of the device. The device will also contain a lithium-polymer battery, which are very very flammable if they are misused, mistreated, or if they malfunction. Therefore, the system should be designed in a way that it is safe if the battery were to catch fire, however unlikely this may be.

Functionality: The system, at its very least, should be able to run a Game Boy Advance emulator, load game files, and save progress, as the original Game Boy Advance could. Support for other platforms, or even internet access is a bonus but not strictly necessary.

Materials: The materials used in this product are very important, however this project is not centered around any single material, instead the materials should be considered mainly depending on aesthetics, ease of manufacture, and cost, using the criteria established above. However, before these are considered, the strength and availability of the material must be taken into consideration. Using paper would not be appropriate and neither would be titanium, due to the aforementioned reasons. A chosen material must be strong and readily available before its aesthetics are considered.

This specification should be used when making decisions on the product, as the outcome of the decision should be the outcome that satisfies most of the criteria here. While these criteria allow for artistic freedom, they are fixed in terms of the nature of the final product: in essence, a low-cost, high-quality, handheld games console that would appeal to all older gamers.

Literature Review

Due to the very nature of this product, research needs to be done into a wide variety of fields, such as materials, pricing, and ergonomics. Every project needs inspiration, and for this I read *The Design Handbook* [1], a book which contains a wide variety of styles and techniques used over time in the design and creation of products. One of the points highlighted by the client in the specification was that the console should look “stylish, elegant and mature” [2], and the styles of Breuer [1, p.44] and Le Corbusier [1, p.104] were the styles that fit the specifications most accurately. This was the starting point for designs and ideas, and research. I decided to research into available materials, around which I would design the form factor of the device. The the chromed metal, black leather and the tan/sierra wood which appeared in Le Corbusier[1. p.104] were styles that I wanted to be used in the final piece, and thus I researched each individually, beginning with the metals.

It is vital that the cost of the product be as low as possible, and as such, only two silver-coloured metals were viable for the product: Aluminium and Steel. Both of these metals are commonplace, recyclable, and most importantly: cheap. However, these materials are very different and their properties needed to be compared and contrasted in order to make an informed decision. While aluminium is more easily dented and more expensive, it is more easily machined, it is naturally corrosion resistant and it can be shaped into more complex shapes than steel can. [3] As such, Aluminium was chosen for the product. Plastics were the only other major component of the system, as the wood, as with Le Corbusier [1, p.104], would only be used as an accent tone.

The most readily available plastics are Polycarbonate, and Acrylic. These plastics are both clear and would be backed with a black material to give them the colour in the appropriate areas i.e. not over the screen. Polycarbonate is more impact resistant than Acrylic, and is also less likely to chip [4, 5], which is important as the client placed an emphasis on durability along with design [2]. However, scratches on either material are unavoidable, and Polycarbonate cannot be polished and yellows with time. [5] While this may be reminiscent of the “quality products” mentioned by the client [2], they are unacceptable when a cheaper alternative that does not have these issues is available. Polycarbonate can also not be laser cut, meaning a skilled machinist must machine it to the correct specifications without scratching it. All this means that, while Polycarbonate is tougher and less likely to chip, [5] Acrylic’s ability to be polished and laser cut, combined with its cheaper price and its capacity to maintain its clarity [4, 5] makes it on the whole to be a much better choice. These facts were sourced from the websites of metal and plastic companies, which means they are, within reason trustworthy.

No matter how attractive a product, it is useless if it is painful to hold. [6, Comment 8] And as such, it is important that any product that is held in the hand for a significant length of time be comfortable to hold, especially when it is quite heavy [2]. The key aspect that was important to me were the spacing of the buttons: too sparse and your thumb is doing too much work getting from one to the other, too close and players run the risk of mispressing buttons, or developing repetitive strain injuries or even a case of Nintendo Thumb [7]. Due to this, I decided to do both primary and secondary research on this topic, with the DS players preferring the older, spaced out buttons more [6, Comment 24].

The DS had a rival handheld console, the PSP. The DS had a rectangular profile whereas the PSP has a elliptical/rounded rectangular form, and I also wished to research this and determine which was more ergonomical. The very nature of ergonomics means that all of the evidence for one being more ergonomic than the other is anecdotal, and the only way to judge a “winner” is to take a majority. In this case, the PSP took the victory, with users claiming the DS was awkward to hold and caused them cramps in their hands, while the PSP’s rounded design let it fit better in their hand. However, the DS was voted more portable due to its decreased size when carrying. And it is worth noting there were many people on the opposite side of the argument, claiming the PSP to be an “ergonomic abomination” [8] Due to this, I ruled that a rounded, yet compact design is the most appropriate, combining the better aspects of both systems. These sources were, unfortunately, much less reliable, but there was not much in the way of resources in this sector. The subjective opinion of users was all that was available to me, and as such, I should not entirely rely upon these sources. Instead, I should use them to supplement primary research later on in the project.

Now, with an understanding of the materials which were most appropriate for the product, and a small grasp on the basics of ergonomic design, I decided to analyse the process of creating sketches and technical sketches, as no idea is useful if it cannot be conveyed to others, however complete and perfect it may be. Given the complexity of this product, simply “remembering it” would have been grossly inadequate.

In order to study how to correctly draw a sketch, I decided to read *Design Secrets: Products* [9], a book containing information, designs and photographs on a wide variety of different commercial products. I decided to use these as I felt they were trustworthy - they were real sketches from the engineers who worked on these real-life products, and as such, I would be emulating the layout methods that professionals used. From these products, I identified 4 different types of sketches, some were designed to simply put across the form of the product, as with the *Black and Decker MOUSE* [9, p.46], where no details are given on the functionality; the sketches exist only to emphasise the ergonomics of the product, which is what the key focus of the product is. There were annotated sketches explaining how certain parts of the product function, as with the DeWalt radio [9, p.133-134], there were **CAD** renders [9, p.41], and finally technical drawings [9, p.34-35].

Each of these had their own merits and disadvantages, however I decided in the end to create two types of drawings for my ideas that reflected my skillset and were most appropriate. Annotated sketches were best for providing context to the model, explain what each component did. CAD models were best for producing a model that looked akin to the final product. Technical Drawings were most useful when manufacturing the product, and so I decided to produce sketches for each of my designs, before creating an annotated CAD model and a technical drawing for machining my final model.

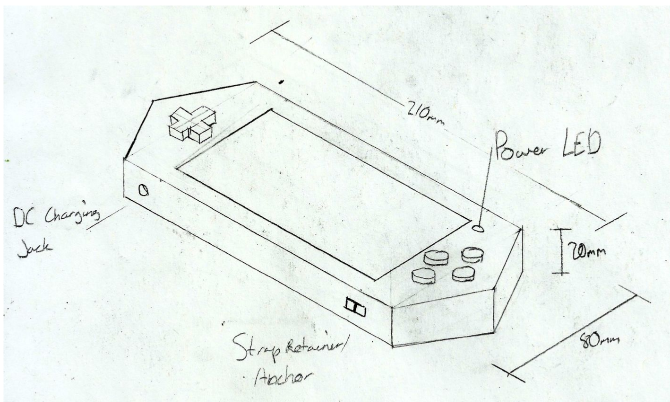
Now that the aesthetics of the product had been planned, it was time to research electronics. The hardware that I used depended on which main board was being used, and there were two which I considered to be viable for my product: the **C.H.I.P** and the **Raspberry Pi Zero**. The Pi Zero is smaller and cheaper, and features HD video output as well as an SD card slot, but lacks wireless connectivity or an on board **power supply,** whereas the CHIP comes with a **power management chip**, on board WiFi and Bluetooth, and composite video output. This means essentially, that while the Pi is cheaper, many other circuits would be needed to make it suitable for this product, it would need a circuit to charge the battery and another for WiFi and another for audio, all of which would increase its size and cost. The CHIP comes with everything need for this project, batteries can simply be “snapped in” and the board will control charging for them, the video output also outputs audio, which can be converted to a headphone output with a cheap £1 adapter. The drawbacks to the CHIP are its lack of external storage, and its video output, which is of a lower resolution to the Pi. [10] I decided those drawbacks were outweighed by the advantages and decided to use the CHIP for my project. I purchased a screen, battery and the adapter I bought for audio. However due to a manufacturer error leading to delivery issues, I switched to the Raspberry Pi. I discuss this later.

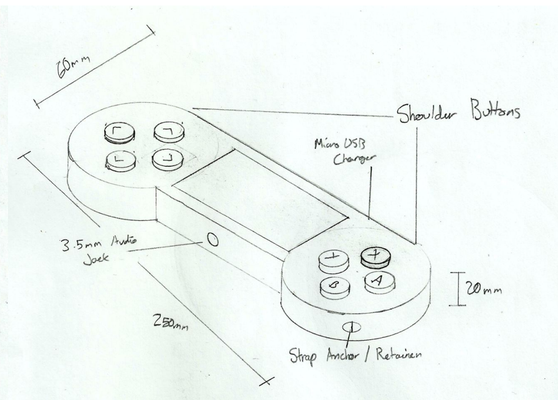
The research for my projects was very much simply fact-checking, decision making and problem solving. For each step of this research, I simply thought of what the next step was, formulated an appropriate question based on that, collated facts and made an informed decision on each. This served me well until I reached the manufacturing stage, where any plan, no matter how well formulated, would’ve been bombarded with problems, issues, errors, and delays until a point was reached where improvisation and trial and error could take hold. At this point, plans will need to change in order to reflect what is most realistic and achievable. I go over this in my Production Diary [11].

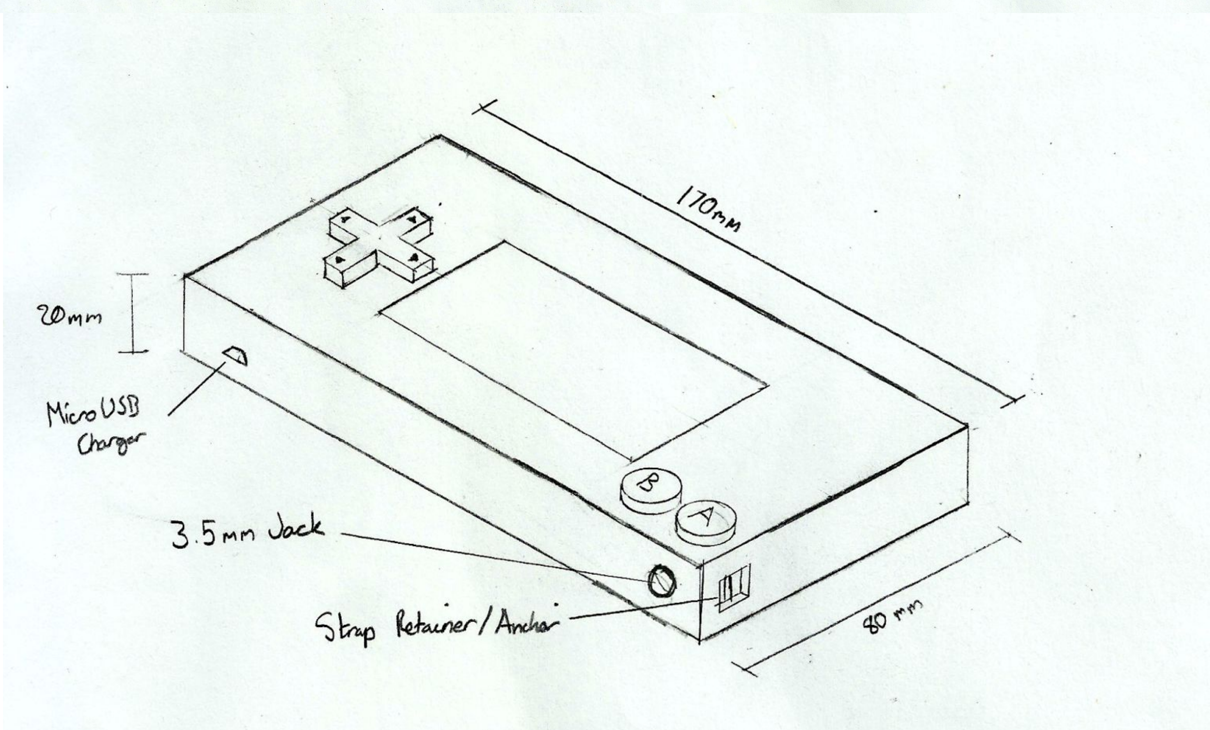
Initial Design and Plan

Design

I had drawn a few rough sketches in isometric to get a feel for the rough shape I was aiming for, adhering to what I had learned about ergonomics in my literature review, but not too closely as I wished to have a few unconstrained ideas before I could narrow down to the most appropriate one. I decided to base my designs off of the NES, the PSP and the SNES controllers, shown in Appendix 1.





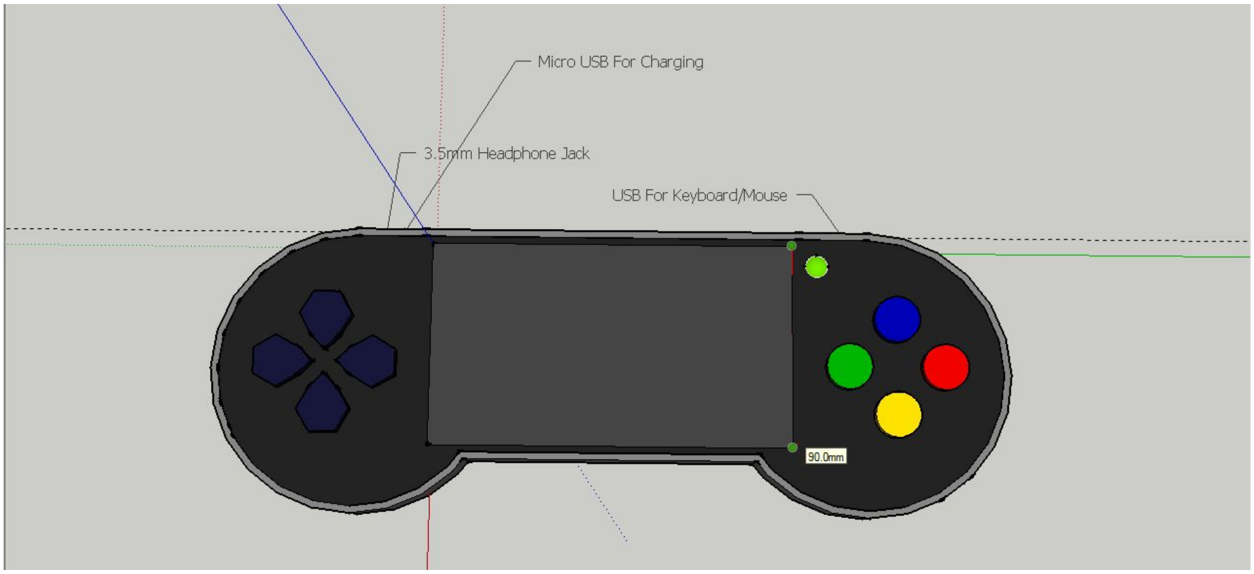


Looking at the three designs I was immediately drawn to the SNES Controller design (top right) over the other two. It was immediately recognisable, being an iconic controller, as it essentially began the concept of controller ergonomics. The SNES was also my first console, and I wanted to pay tribute to the platform. I recognise that this is not an appropriate factor were this a professional environment, and as such, it was not in any way the key factor with which I chose the design. The key reasons I chose this design were its identifiability and its ergonomics.

The reason I decided to base my designs off these old controllers, and the reason I am using identifiability as a criterion to compare between designs relates back to my Design Specification [11]. The console is marketed at users who are between the ages of 16 and 40 who will have grown up with consoles of varying age [11, Customer]. I wanted the design of the console to be immediately appealing to someone within my target market. On top of this, a design that evokes a sense of nostalgia is much more likely to be purchased [13, Paragraph 4]

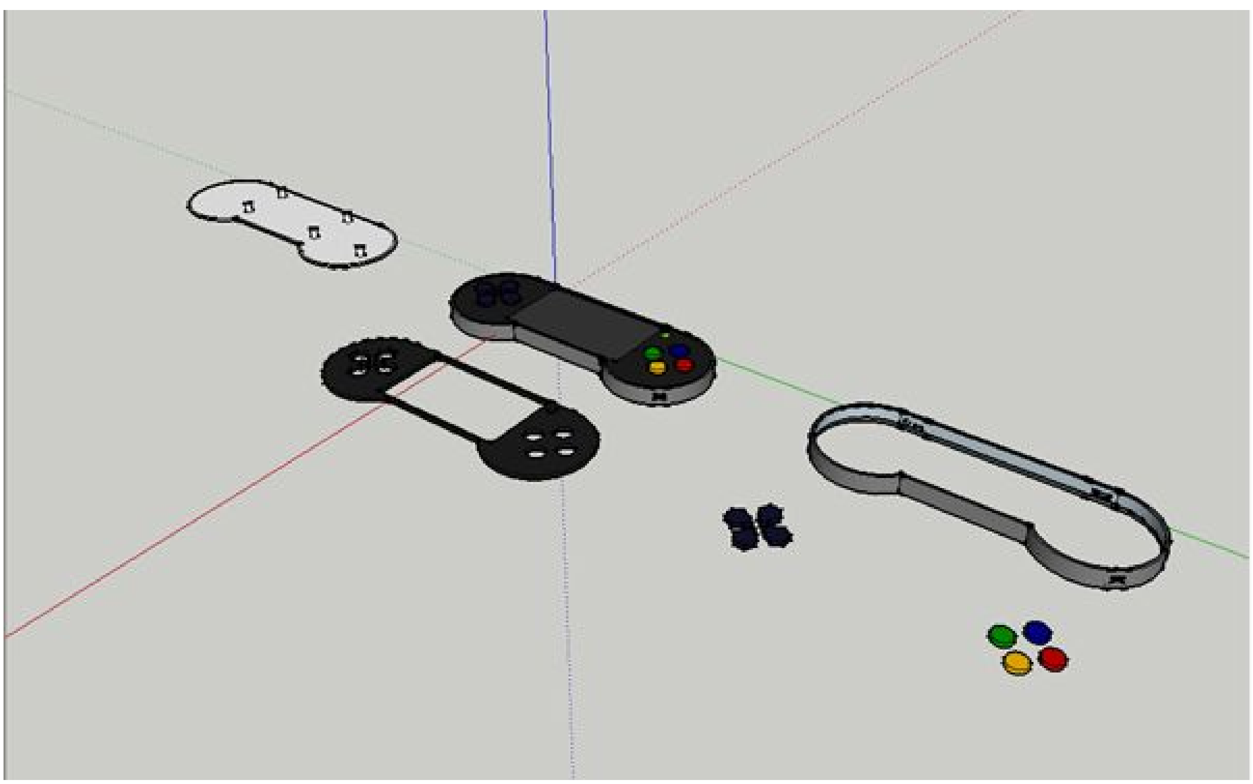
I rejected the PSP based design as it was very evidently difficult to manufacture due to its 120 degree angled corners, and it was very difficult to identify as being based off the PSP. The NES based design was the most identifiable, and assumably the easiest to manufacture, using a picture-frame like method, but as was the issue with the original NES, the controller has no regards for ergonomics, as the field was simply not there when it came to electronics at the time. Due to this, I traded identifiability for ergonomics, a field I had already identified as key [12, Paragraph 4], and chose to expand on the SNES based design.

Given all of my research, I began drawing up a design in Google Sketchup, a 3D **CAD** program, in order to obtain an idea of proportion, positioning, and aesthetics. In my Literature Review [12], I had researched styles and aesthetics, and I liked the combination between the chromed steel and the black leather most, and so I made a black backing and the aluminium surround the key focus of the design. I decided to copy the colour scheme for the action buttons from the SNES in order to make the console more identifiable.



I based the dimensions on a diagonal measurement of my phone screen, which has a 5 inch screen. I then modelled the other parts of the console simply by eye, using measurements that “looked right” as a size.

Then, I began looking at how the console might be put together, breaking it up into its constituent parts mechanically.



More in depth screenshots can be seen in Appendix 2.

The console would be composed of an Aluminium "Retaining Surround", inside which everything fits: First the Clear Acrylic, then the black backing material, then the buttons, screen and other electronics, before the lid fits into the surround, assumably held in by screws. The surround would have straight walls with a lip near the front that everything pushed up against. The Lid would have pillars to push everything against the surround, and then the screws holding the lid in would hold all of the internals. However, there would be a significant amount of compressive force, and electronics are delicate, so this must be carefully balanced so that the electronics are securely mounted, but not crushed.

The majority of my workshop experience was from GCSE Systems and Control, along with a few side projects I had done in my free time, and I used this knowledge to consider how the parts may be manufactured.

The acrylic and black backing material would most likely be **Laser Cut**, as that is the most reliable way of cutting plastics without them shattering. The round buttons would be turned on the **Lathe**, as that is the most appropriate machine for the job. The steel directional buttons would be cut on the **milling machine**, or alternatively filed from a larger bar by hand. I have no experience with the mill, but it is much more appropriate to the task than hand work. The lid would have to be cut with **tinsnips** if it was thin, or using **hacksaws** and **files** if it was thicker. The pillars could be made by cutting **threads** onto bar and into the lid and screwing them in.

The surround could only be machined on the milling machine as far as I knew, and as such I needed to research methods of its manufacture to great depth.

Plan

Tentatively, using my past experience at GCSE, I designed a rough plan that would have meant that I would finish at Christmas

30/09/2016	Folder	Plan	2 Hours	Need all of my plan done, as well as notes up to this point
03/10/2016	Research	Machining	3 Hours	Research how best to create the outer surround of the project, and create a new, more ergonomic remote shape and cut out of plywood for testing, before trying this with Metal
07/10/2016	Making	Frame	3 Hours	Machine the frame from aluminium given the dimensions of the technical drawing

14/10/2016	Folder	Research	4 Hours	Write up all the research and write down sources etc for research done so far.
21/11/2016	Folder	Designs	5 Hours	Add all my designs and technical drawing to the folder so it has all my research, designs, design brief
07/11/2016	Making	Outer Parts	10 Hours	Have all the physical components machined in time for the electronics, this includes lid and buttons.
16/12/2016	Making	Electronics	6 Hours	Flexible Deadline, depending on shipping. Wire up all the electronics and program in the code for the buttons
05/01/2017	Folder	Production Diary	3 Hours	Finish off the production diary with a list of what I've done along with problems and solutions
12/01/2017	Folder	Evaluation	3 Hours	Talk about the issues I faced, how I would tackle them next time, how I would improve the design and how I would mass-produce it.
17/03/2017	Presentation	Presentation	10 Minutes	Present my finished product, and talk about my journey and the problems I faced

In total, I would be spending around 40 hours on the production of this device. I am fully aware, however, that at this stage, without any primary research this plan is purely speculative, and that in reality I could possibly spend double or even triple the stated lengths of time on each step. After completing my primary research I decided to draw up a more accurate, realistic and in depth plan.

Primary Research

The primary research for this project greatly overlapped with the research and development of the product, and due to this, the product was constantly evolving as time passed.

Ergonomics

After selecting my design, I created a to-scale 2D technical drawing, from which I could laser cut initial scale models to get a feel for the proportions of the product. This was initially cut out of **Plywood**. This came from the 3D CAD mockup, however this had many issues. Firstly, CAD models can give a sense of shape and proportion, but they cannot give a sense of scale. I designed the CAD model based on the diagonal size of my phone, which seemed to me a reasonable size, however when the rest of the components were added, the console came out to a width of 30cm, which felt freakishly oversized. Going over the CAD model and technical model, it seemed that the entire model was too large by a factor of 2, and I shrunk it down and laser-cut a test piece to see its fit in my hand.

It was much to small and it was a poor fit in my hand. This is a drawback of CAD models, only a physical model will tell you what the product will feel like ergonomically. I decided to research further which sizes would be most appropriate ergonomically.

At home, I decided to drink a mug of coffee whilst I contemplated how best to find a cylindrical object that fit well in my hand to base my design off of. Then it occurred to me that the mug fit perfectly in my hand, and as the sections of the design that make contact with my hand are also circular, I decided to measure every mug I had in my house. While this was a bizarre approach, and not very thorough, it was simple and effective. I obtained a value of 40mm as a radius for what was most comfortable in my hand, and I redrew my design based on two of these 80mm circles. However, the first design was simply a scaled replica of the initial design, and I wanted to study further in depth the issues with my CAD model in order to rectify them for the final technical drawing.

I collected the responses of people within my target market on the shape, form and ergonomics of the product, and the almost unanimous response was that the device was too wide and narrow, and should be more square in its proportions. Approximately 70% of people also commented on the button spacing, saying they were spread too wide; that instead of rolling smoothly from one to another they were being interrupted. While seemingly unimportant, this is a massive issue, because the buttons are the user's only method of interacting with the device, and if that experience is unpleasant then they may as well buy another console. Interrupted key presses mean player's reaction times will be slower and the console will be negatively influencing their experience. The best interface is one so intuitive and pleasant to use that it is not noticed at all, as the user would be totally immersed in the game, not the buttons.

As a response to this, I made the design as compact as possible, and made it taller in order to leave more room for the screen above and below. I kept the radius of the curves the same, but positioned the 4 action buttons closer as well as the four directional buttons closer. All but 2 responses, over 96% of the earlier respondents, commented that this design was better, being more proportional, easier to hold, and said the buttons were better spaced, making it easier to move from one to the other.

While chiefly to test the ergonomic principles of my design, this wooden model was used to give an estimate of depth and structural composition. The idea of the product was to be composed of a lipped ring, against which the components would be held. However, it was quickly identified that this component would be almost impossible to manufacture with the tools available to us. This was my second and most major problem to overcome.

Machining the Surround

The surround is an entirely irregular shape as no cross-section of it is a simple shape. There is only one possible way of machining this piece within school: the material would need to be milled on the milling machine. However, the milling machine requires a trained member of staff to use it, and none were available. Other machines available to me were the lathe, drill press and bandsaw. The lathe could be used, but it would be very difficult to set up accurately, as the work must be centered to within 3 thousandths of an inch (0.075 mm), the width of a human hair, in order to get a high-precision cut, and this was simply not feasible. The bandsaw is unable to create the lip that I required and so was unusable, leaving the drill press. At this point, the use of aluminium seems more and more unfeasible, however, I researched milling machines and cutters, and decided to attempt to manufacture a **Fly Cutter**, shown on the left, with which I would cut a small circle all the way through, and then a larger one part way through in order to create the lip. This way I could use the drill press and a handsaw to cut most of the material away. The cutter was made from steel and took an entire week to machine.

The fly cutter held the bit with screws quite tightly, and staff at school were satisfied it was safe, however they suggested I first cut into some expanded polystyrene, and some PIR insulation foam, before attempting to cut metal. The cutter cut through the foam just fine, however in areas where the **feed rate** was too high or low, the foam tore a little. However I attributed this to the nature of the foam, not the cutter. I then clamped down a thin aluminium sheet and attempted to cut a circle from it. I tried to set the cutter to cut the maximum depth safely possible, however, this was only approximately 0.2 millimeters deep (it is difficult to measure). I was prevented from cutting deeper for two reasons: one was that the cutter was shifting up further as I applied downwards pressure, as I could not get the groove in the shaft completely square. This meant that if I pressed too hard, the cutter retreated and cut less. The second, more problematic issue was that the cutter was rubbing against the metal. Only the very tip of the cutter actually cuts, and so once it reached that 0.2mm depth, the dull section of the cutter started rubbing against the metal and exacerbated the issue of the cutter retreating. Therefore, the cutter could only be used once the majority of the inner material was removed, then, it would be used to finish up the hole. This effectively has the same problem as the lathe, in that once the majority of the material was removed, the centre of the drill would need to be positioned perfectly in the center of the circle. As a last resort the cutter could be used, but it is impractical.

In the ideal situation, we would have a **CNC Milling machine**, so that all that I needed to input was a scale 3D model, and the Aluminium would be machined to exactly the same shape. However, these machines are expensive, and it is difficult to justify the cost of one. Outsourcing my design to a manufacturing firm with one of these machine would be possible, and would not require much effort, however is prohibitively expensive, costing upwards of £75. This is almost 100% of the budget for the product [2, Cost] and so I decided not to outsource the machining of the aluminium.

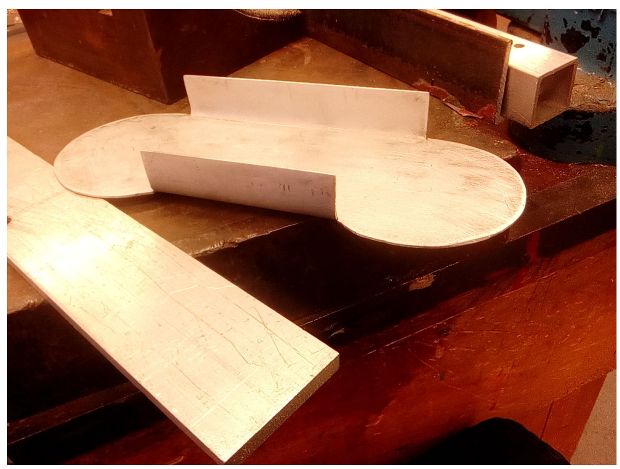
However, I do have access to a CNC router, similar to a milling machine, but in this case designed for softer materials [18]. I decided to adapt my technical drawing for the CNC router, and try cutting it out of foam.

There was an issue with the tool where it **lost its origin** and I had to start again, but aside from that the quality and accuracy of the cut is very high. Although it takes a long time to cut (approximately half an hour for foam), I can easily cut hardwood on this machine. If I used an epoxy resin to affix an aluminium plate to the inside walls, I could create a composite material that is thin, lightweight and meets the standards of aesthetics mentioned in the specification [2, Materials]. Most importantly, this material will be strong enough to hold screws despite the shearing force of the weight of the inner electronics and the lid, as well as the force opposing the lid's compression [14]. This would give much more internal space, as without the rigidity provided by the aluminium, the wood would have to be much thicker to have the same tensile strength.

Making and Polishing the Lid

Initially, I decided to have a lid that had two folded tabs which would screw into the wood through the outer surface. I took some sheet aluminium and cut it to the correct shape, having marked a contour for the lid, and two flaps. I cut these and made my own bending form to bend the flaps. This formed a perfect lid, which fit perfectly into the MDF wood demo piece.



Later on I had to change the design due to an unforeseen issue with the surround.
See the Production Diary [11] for this.

In order to polish this lid, I initially sat with varying grades of sandpaper, and I worked up through the grits, from the roughest to the smoothest sandpaper, which gave a very high quality surface finish, but took around 6 hours of hand sanding. I did not want to repeat that process for the final lid.

Therefore, I decided to create a sanding disk that i could insert into the drill press, spin and then use to sand the surface. To create it, I cut a plywood disk, put a large bolt through the center, and turned it round and flat on the lathe. I used double sided tape to attach sandpaper to the disk, which I then mounted in the drill press to test.

The sanding disk (left) would be used, then followed up by a traditional polishing mop (right).

This way, I wouldn’t have to scrub the metal for hours, instead I could hold it up to the disk. However, I spent over a day working through the grits in order to get to a high gloss finish, but nothing I tried worked, and I created many gouges in the metal, which were caused by me not holding the work flat against the disk, but at an angle. After a while I deduced that hand sanding was the only viable option, meaning I would need to spend a lot of time perfecting the final finish.

Mounting the Buttons

The buttons began as 20mm long sections of rod, which needed to be mounted onto tactile buttons. The simplest solution was to drill a hole through each button near the base and put a rod through the hole to act as a “pin” to retain the metal button, which would then sit on the tactile switch. However, this solution would likely rattle and would take up a lot of vertical space. The tactile switches are approximately 5mm tall, and I wanted to try to minimise the amount of space that was taken up inside the case by the buttons.

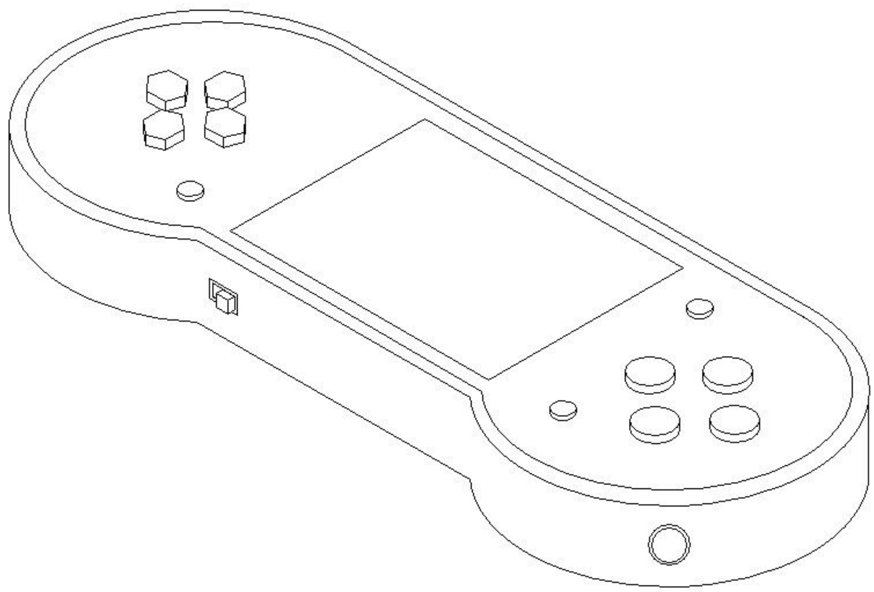
I decided to try turning a recess in the back of the switch in order to inset the switch and take up less room. I trimmed down the button and turned the recess using an **Endmill** and a **Boring Bar**. Then, this was attached using a very small square of double sided tape to the top of the tactile switch. The prototype worked well, and the button did not fall off. However, it was very easy to remove the button and as such I decided to use a strong glue due to the small surface area.

However, this approach failed miserably when I tried it on the circular buttons, the wall thickness was around 60 thousandths of an inch; about as thick as the walls of an aluminium drinks can. These thin walls either deformed or simply broke off every time. I could have done this recess on only the hexagonal buttons but for the sake of uniformity I abandoned this approach,

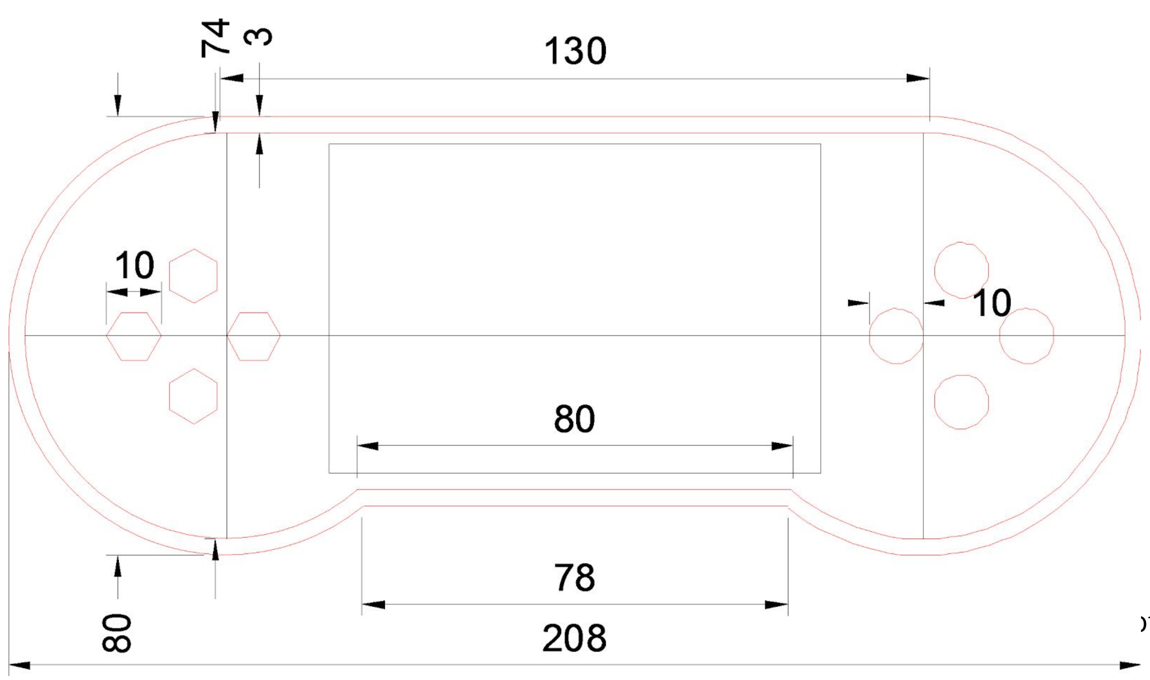
So instead, I decided to make the switches a feature. I modified the circuit board for the switches so that they could be pressed flush against the plastic, and simply glued them in place and glued the buttons to the top of the tactile switch.

Final Design and Plan

Design



After all of my Primary Research into materials, ergonomics and manufacturing processes, I decided on a final design, composed of a wooden surround, with plastic plates inside, brass buttons, and an aluminium back. There would be approximately 20 parts to machine, plus the electronics. In the drawing below you can see the exact sizes and positioning of every piece.



As you can see, the Radii of the circular sections of the device match what I found in my ergonomic research to be most comfortable, and the proportions of the device have been changed to match what people found most comfortable.

Plan

Now I had a more detailed plan of what the console would look like and how it would go together, I developed a much more in depth plan, from start to finish for this project, with much more data on what will be done, when by, and for how long, and I expect to adhere closely to this plan, though of course, it has to be flexible to accommodate for any future issues. I decided to write up and include all of the steps prior to this one, chiefly for the sake of completeness, but also as I wished to gauge the amount of time I have and will spend on this project.

15/07/2016	Folder	Design Specification	3 Hours	Write up a design specification upon which to base my research and design ideas, as well as on which to make decisions in the future
22/07/2016	Research	Style + Materials Research	8 Hours	Based on the Design specification, research into styles which might be appropriate for the console. Once these are established, research into materials that would be appropriate to reflect these styles
29/07/2016	Research	Initial Ergonomic + Sketching Research	8 Hours	Do some preliminary research into ergonomics, and look into how best to draw up my design ideas and final design
05/08/2016	Research	Electronics Research	6 Hours	Look into the most appropriate electronics for the console, their prices, how they work, and their suitability
12/08/2016	Folder	Initial Design Ideas	6 Hours	Draw up a few initial design ideas that relate back to the design specification, but are diverse enough that they can be compared and contrasted in order to find the best design
19/08/2016	Folder	CAD Models	12 Hours	Create a more detailed 3D model based on the chosen design that reflects what its final appearance might be, and how it may be constructed
26/08/2016	Folder	Initial Design + Plan	5 Hours	Based on the CAD model, draw up an initial design which will be researched for feasibility. Draw up a rough plan for how

				long the project should last, and where the most time will be taken up
02/09/2016	Research	Ergonomic Research	8 Hours	Create a physical model from the 3D CAD model, and modify as appropriate in order to create one or more different models which are an appropriate size and shape
09/09/2016	Research	Ergonomic Research	8 Hours	Informally collect responses in order to ascertain which model is most appropriately shaped, in order to create a final design
16/09/2016	Research	Manufacturing Research	12 Hours	Research how the surround might be machined from aluminum
23/09/2016	Research	Manufacturing Research	12 Hours	Research how the surround might be machined from aluminum
30/09/2016	Research	Manufacturing Research	12 Hours	Research how the lid might be made and attached
07/10/2016	Research	Manufacturing Research	12 Hours	Research how the buttons might be mounted
14/10/2016	Folder	Final Design + Plan	10 Hours	Decide on a final design and draw up a final, detailed plan to follow throughout the rest of the project
21/10/2016	Folder	Technical Drawings	6 Hours	Draw up the final design with full measurements for each part, as well as diagrams for assembly
28/10/2016	Folder	Technical Drawings	6 Hours	Draw up 2D design drawings as cutting templates
04/11/2016	Making	Machining the Buttons	4 Hours	Machine the Button Caps
11/11/2016	Making	Machining the Surround	30 Hours	Machine the Surround
18/11/2016	Making	Machining the Lid	9 Hours	Cut and Form the lid from Sheet Aluminium
25/11/2016	Making	Machining the Internals	3 Hours	Laser Cut the internal plastics
02/12/2016	Making	Creating the Electronics	8 Hours	Put together the electronics using the supplied connectors
09/12/2016	Making	Creating the Electronics	8 Hours	Flash the operating system in order to make the game works
16/12/2016	Making	Creating the Electronics	8 Hours	Have a working prototype circuit working for after christmas
23/12/2016		Break	0 Hours	Christmas Break

30/12/2016	Folder	Write-up	4 Hours	Write up any missing sections of the report in preparation for returning to school
06/01/2017		Mock Exams	0 Hours	Mock Exam week - No EPQ Work this week
13/01/2017	Making	Machining the Surround	8 Hours	Mill out the slots for the shoulder buttons, power switches and accessories, finish the surround with an appropriate surface coating
20/01/2017	Making	Machining the Buttons	6 Hours	Cut the shoulder buttons and mount them in the Surround
27/01/2017	Making	Creating the Electronics	9 Hours	Solder the buttons into the board and set them up
03/02/2017	Making	Creating the Electronics	9 Hours	Remove all the connectors and solder wires between the connectors
10/02/2017	Research	Manufacturing Research	10 Hours	Look into methods of finishing the lid to give a durable finish that meets the design specification
17/02/2017	Making	Machining the Lid	6 Hours	Polish and seal the lid using the same coating as the surround
24/02/2017	Making	Assembly	16 Hours	Assemble the parts outside of the surround for a final test
03/03/2017	Making	Assembly	16 Hours	Mount the parts inside the surround and test the device one final time
10/03/2017	Making	Accessories	3 Hours	Create any relevant accessories - packaging, carrying strap
17/03/2017	Folder	Presentation	1 Hours	Present the product
Average:	8.4 Hours		Total:	302.0 Hours

I have split the research into two sections, one for the main device, and one for the lid, as I do not want the lid to be made early on and then damaged by months of being in the workshop, as it will be sheet aluminium, provided I have no issues with my plan. I would argue the same applies for the clear acrylic front, however there is protective film on the clear plastic protecting it from chips and scratches. I have also given myself around three weeks work-free to focus on exams, which mean my project will only have around two weeks of leeway for delays, namely the last two weeks, where I develop accessories and prepare my presentation. I have given myself an entire school week, five 8 hour long days, for the surround, as the part is very intricate and needs to be manufactured to a high precision. As such, it must be machined in one sitting, else alignment errors may be introduced if a part is removed from a tool and reinserted.

Production Diary

Once I had finished with my primary research into the product, I began the final production of the casing, and the wiring of the electronics. However, I feel it is important to note that the final production and primary research were not split into distinct parts, rather the methods to manufacture each part were found through iterative improvement, and that I focused on each piece separately after the previous was finished. A list of components in Appendix 7.

Machining the Buttons

The first parts I machined, and the simplest geometrically, were the buttons. These simply consisted of eight 2 cm long brass pieces, four cut from 10mm rod, and four from 10mm **Hex bar**. I turned them on the **Lathe** and rounded one end of them with a **File** in order to make them more comfortable to hold and to make it easier to move your thumb from one button to another. I repeated this with two sections of 6mm rod for the “Start” and “Select” buttons.

The reason I abandoned the initial coloured metal buttons and switched to brass buttons that were a simple geometric shape was due to availability. The Hex buttons could not be milled, and aluminium dye costs upwards of £20 per colour, which is too expensive to justify colouring 4 buttons [2, Cost]. I could have switched to plastics, but that would contradict what the client had asked for in the Design Specification, where they asked for a mature design that wasn’t reminiscent of cheap, plastic, toy-like designs [2, Aesthetics]. I could have chosen steel or aluminium in order to match the styles I had preferred in my Literature Review, however they both tarnish and corrode without protection, and having switched from Aluminium to Wood [15, Machining the surround], I decided that it was appropriate to use artistic licence to modify the design and aesthetics of the product in order to meet the “stylish, elegant and mature” standards of Aesthetics given to me by the client [2, Aesthetics].

Then came time to machine the shoulder buttons. I searched for a piece of brass that would be appropriate however the closest thing I could find was some 16mm x 6mm Nickel silver bar. I could have purchased brass bar, however I was short for time, and the Nickel Silver was close enough to brass in colour. Nickel silver is an alloy of copper, nickel, zinc and in this case, silver, though usually there is no silver, the alloy is named for its colour not its contents. Nickel Silver can have varying compositions, and as such, the colours it can be varies. The specific alloy I used had a pale gold colour. This is due to the relatively high copper content of the alloy [16]. I cut two 6 cm pieces of it and marked on a curve for the buttons. I then used the **Belt Sander** to sand the two shoulder buttons down to the lines I marked on them. I polished these with sandpaper to finish.

Machining the Internals

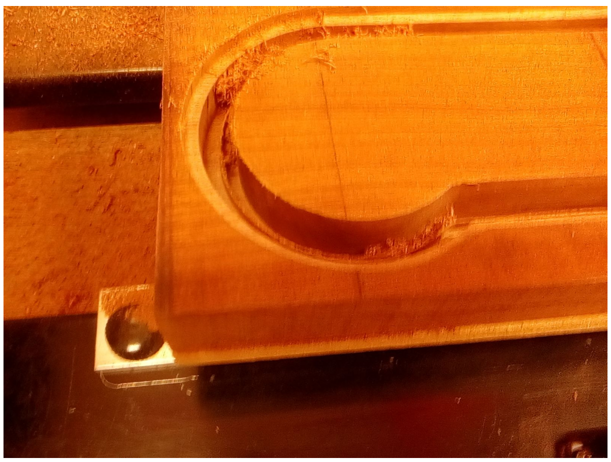
I **laser-cut** the clear acrylic cover and black acrylic cover, which was arguably the simplest part of the machining process. I drew the shape I wanted on a **CAD** program, put the material I wanted it cut out into the cutter, and sent the data to the cutter. However, I later discovered that the hexagonal holes were slightly undersized, as the CAD package measured the size of hexagons between opposing vertices, rather than sides. Along with this, the black cover was too thick, as nearer the end of the production I found the electronics did not fit. To remedy this, I recut it out of some 1mm thick **HIPS**, which gives more room for the electronics. This can be seen near the end of my activity log. While the process of fitting the electronics did leave me behind where I should have been in my plan, these modifications to the black plastic parts did not. The entire process was approximately ten minutes work, which is the key advantage of the laser cutter: I simply loaded my design and material, and it cut it out for me.

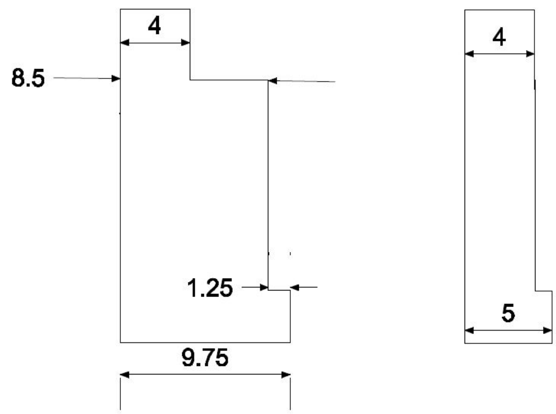
Machining the Surround

Then came the most challenging part to machine, the surround. I set up another 2D **CAD** drawing for a **CNC Router**, which contained a path for the tools and depth information for a depth of cut. I cut a block of wood (which I think was Mahogany), and attached it to the **bed** of the CNC using double sided tape and set it cutting. I assumed it might take 2, perhaps 3 hours, given that the tool was old and dull and that Mahogany is quite a dense hardwood. In reality it was closer to 40 hours, as the machine was cutting for five 8 hour long school days. The reason for this was **torque**. The Router simply didn't have enough, therefore it could only cut at a depth of 0.2mm per pass. It had to cover 3 different paths, each between 18 and 20mm deep, and approximately 600mm long. Each pass took approximately 2 minutes to complete. Even at this painfully slow speed, quite often the cutter would **seize** at denser points within the wood. For the first two days, to remedy this, I would pause the cutter, open the machine, vacuum the sawdust out and wait for the motor to cool before continuing. This worked for approximately 3 passes before the cutter seized again, and I spoke to my supervisor about this as I couldn't miss a week's lessons to operate this one machine.

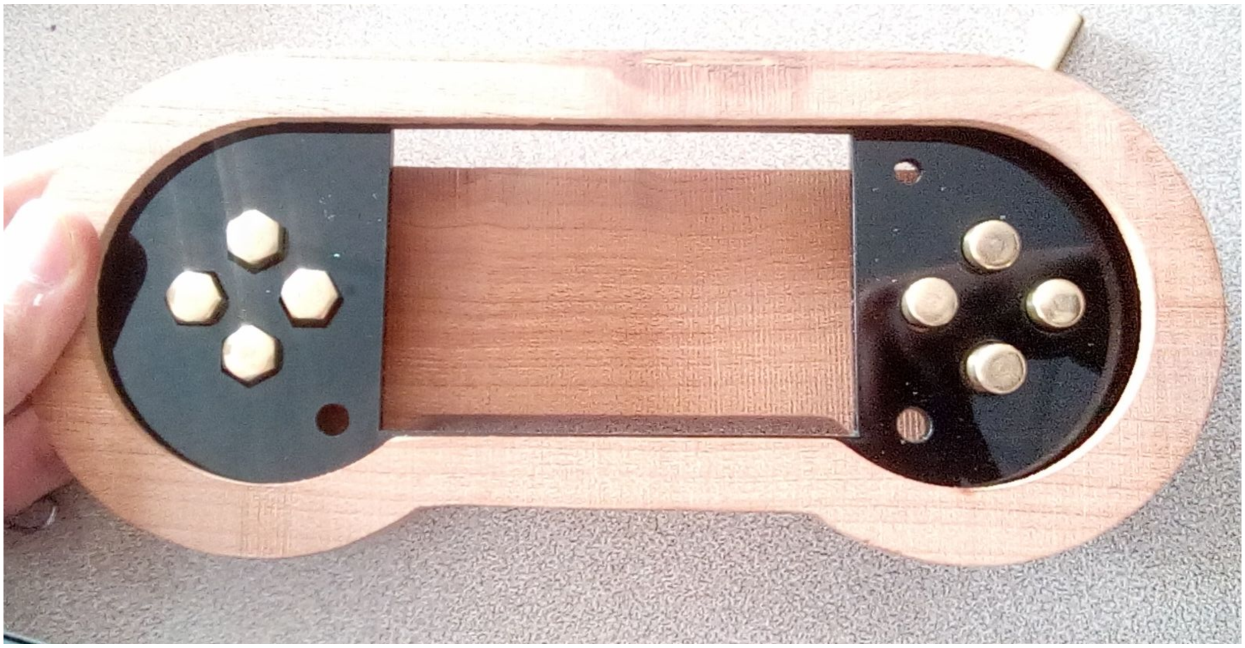
My supervisor offered to operate the CNC whist I was in lessons, but this was only a temporary fix. Halfway through the third day I discovered that the Router has a speed setting for the rotational speed of the cutter, which had to be carefully balanced to give the right ratio between cutting **torque** and cutting speed. Too slow and the cutter wouldn't clear a path fast enough and it might snap. Too fast and, as we saw, the cutter would stall on denser sections of wood. The ideal setting was around 60% of the maximum speed, and the cutter only seized once or twice per day from then on, due to a knot in the wood.

However, my issues with the surround were not finished there. On the final day, the router would have cut the outer surface of the surround; the surface that would be held by the user, leaving a 4mm wall thickness. However, the router seemingly decided to only give the piece a 1mm wall thickness. It cut this to a depth of 5mm before my supervisor noticed the error and shut off the machine. I inspected the CAD drawing, and there seemed to be no issues with it. Unfortunately, even if there was errors, my initial design for the surround would not be possible without a full recut. I did not particularly wish to spend another week cutting with this, so I decided to improvise.



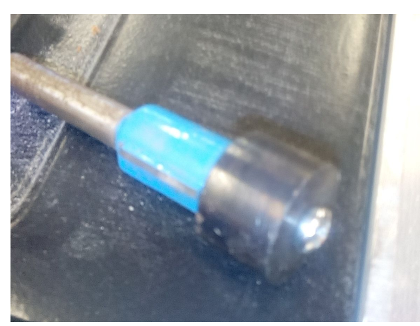


I removed the small 1mm wall created by the router, and marked with a compass a 4mm border around the shape. I cut this out with a variety of hand tools before sanding to the mark. This effectively gave me a 8mm wall thickness where the original plan was 4 mm. That would've been acceptable, had it not meant that the overall thickness of the surround was now 12 mm, not 8 mm. This was much too thick.



I had two options: Remove the outer 4 mm, or decrease the size of the inner ledge. The ledge was a 4mm overhang against which the clear acrylic and electronics would press, with the device being sealed by a lid which held the inside together with compression. As such, decreasing the size of the ledge would mean the sizes of the internal parts would have to be very precise in order to make sure there was a good fit. However this was a much more viable option, as removing the outer 4mm would also make my device 5mm thinner, making the case much thinner and weaker, contradicting what the client asked for [2, Materials]. Therefore, I looked into tools that I could use to thin this ledge. At this point I was around a week behind schedule, however fortunately I had enough room in my plan to accommodate errors, and this meant that I would still be finishing on time.

I decided to modify a **Flush-trim Router Bit** for the **Woodworking Router**. The bit is designed to trim an uneven surface to match a reference surface. It works by having a bearing that is the same size as a cylindrical cutter. The bearing runs along the surface and the cutter cuts. I wanted to reduce the ledge to around 2mm wide, and my thinking was, if I replaced the bearing with a bearing 4mm wider (i.e. a radius 2mm bigger), the cutter would create the right sized ledge. However, our department at school did not have such a bearing. The cutter would spin very fast and as such the solution had to be robust, simply wrapping the bearing in tape was insufficient. I decided to “cap” the bearing using a small cup I made on the lathe. It had a hole inside exactly the right size for the bearing, and had a 2mm thick wall, which was perfect. I put a screw through it to mount it onto the bit and used that in the router to thin out the



ledge. A process that, to my surprise, worked perfectly first time. Once this step was finished, I could proceed with my plan and try and regain some lost time.

Next, three holes needed to be drilled: One for the carrying strap, and two for the shoulder buttons. For the carrying strap, I simply placed the surround in a woodworking vice at an angle, made an indent in the wood with the point of a compass, and then drilled through using a **hand drill** and a **brad point bit.** I turned a small metal flange for the hole, then moved to the shoulder buttons.

I marked these on some masking tape that I stuck on the outer surface of the surround. I pierced multiple holes within the slot using the compass again, and then I bored around ten 1mm holes on each side, which I then widened to 2mm. The final thickness I needed was 5mm and I got to this final size by a combination of files and chisels, as my supervisor deemed making a circular cutting disk as “unsafe”, which it undoubtedly was.

I cleaned off the the surround with a damp towel and then begun the finishing procedure. I decided to finish the wood with a varnish, which strangely gave the wood a chocolatey smell. I applied 3 coats approximately 3 hours apart which darkened the appearance of the wood but gave a beautifully smooth surface texture.

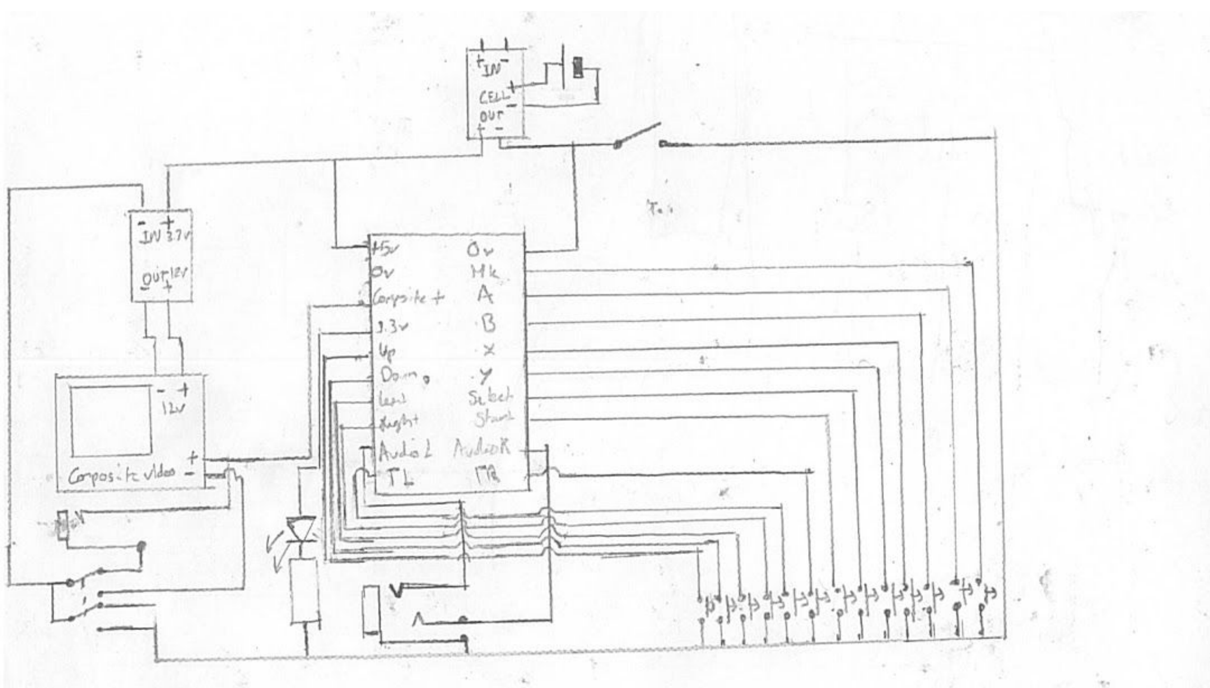
Machining the Lid

Then, I marked out the outline of the surround onto a sheet of aluminium, and roughly cut it out with **tinsnips**, before finishing off the outline with a file to get the aluminium plate to fit into the wood with a friction fit. I tried many methods to get a good surface on the metal, as I did not want to spend hours hand sanding, however unfortunately nothing I tried was satisfactory and 6 hours with water and sandpaper was the only solution that gave me a high quality polish on the lid.

However, near the end of the project, I realised I did not have enough space for the electronics, and I had to scrap the aluminium lid as it simply didn’t fit. To remedy this, I made a new lid from white acrylic. It was composed of multiple layers: one to lock into the wood as the aluminium did, another to cover the internals, and then 3 spacers to give a net 12mm extra internal room. This however doubled the thickness of the console, and was not acceptable, mainly due to the fact that the client asked that the console be no thicker than necessary [2, Size]. It also did not meet the standards of aesthetics given to me by the client. So I deduced that I needed to do some wire management to decrease the vertical height needed, and that I needed to create a lid that incorporated the aluminium. I managed to fix the electronics in with hot glue, and I decreased the thickness of the lid from 12mm to 6mm, which, while too thick for my personal taste, was the best I was going to achieve, and was still an appropriate thickness as it did not contradict the standards for ergonomics set by the client [2, Size]. This is documented in my activity log. This thinner lid had two spacer pieces, and had 2 ringed pieces. One fit into the wood, and another held the aluminium lid in place. The aluminium lid being the same lid that earlier I thought I would need to scrap. This final lid, however, was made in the penultimate lid as I first had to get the electronics working.

Creating the Electronics

Then came time for the electronics. I began by ordering all of the parts necessary to work with the **C.H.I.P**, which I ordered in June, before the project even began, due to large waiting times. The parts I initially ordered were just an **analogue LCD screen**, a **Boost converter** and a **lithium-polymer battery**. I was given some buttons and wire by the School, which meant I had very few parts that I needed, thanks to the CHIP. These parts were ordered around late September and arrived mid November. The CHIP was due to arrive Mid-October. However, there were manufacturing issues with the CHIP, which meant that it would not arrive until February, over a month past the deadline I had set myself in my plan to acquire all the parts and assemble the prototype circuit. Due to this, I ordered a **Raspberry Pi Zero**, a **Battery Protection circuit**, a set of right-angle **headers**, a 16GB Micro SD card and a few composite cables which I would dismantle for the internal connections. Thankfully, these parts arrived within 3-5 working days, and I soldered them all together as per these schematics:



(Shown in Appendix 6)

I have no electrical knowledge beyond my GCSE in Systems and Control, so I found this a little daunting. I could very easily assemble the parts together, but, as with most steps in this project, it did not work first time. It was very difficult to debug and fix the issues with the circuit, but I eventually discovered that it was an issue with the USB cable I was using to charge the battery.

The next issue was the more difficult to overcome, and it was the chief reason I was hesitant to use the **Pi**. I had to install an **OS** and set up the **Emulator** to work with the screen and buttons I had wired up. The reason this was so difficult is that I had run completely out of funds for the project, and I was missing many cables that I needed to properly set up the **Pi**. I tried to improvise a Female USB to Male Micro USB, but that didn't work and I couldn't find a HDMI to Mini HDMI cable that I could use either. So, I was back to sourcing these from elsewhere, as I would have with the Aluminium, had that been a viable material. I spoke to a programmer friend who was experienced with this and he flashed the SD card with an OS called **Recalbox.**

The reason I chose this OS over the much more widely used Retropie (Retropie having 4,257 Stars vs Recalbox's 1,375) [25] is due to that fact at around this time, I had seen a video tutorial on a project with electronics very similar to mine [17], which I had used as the basis for my circuitry. I found the ease of which the buttons were installed to be a key feature as it would drastically cut down the amount of effort required to set up the system. With Recalbox, I would simply need to change a setting in a file in order to tell the software to use **GPIO** Buttons, whereas on Retropie, I would likely have to write my own code [26] to detect when a button was pressed and fire the relevant keypress event for each game emulator.

With the OS flashed, setting the emulator up was easy, as I had wired up the buttons to the default pins, meaning I simply had to change a file to tell the **Pi** to use those buttons as a controller input. To do this I borrowed a Model B Raspberry Pi from the school. I chose the model B as it had the same CPU architecture as the Pi Zero, meaning the SD card could be transferred between the two without needing to reflash the SD card. I transferred the SD card to it and plugged it into my router at home to connect to it. Once connected, I modified the configuration file to enable the buttons and change the video output mode. Then I loaded a few games onto the MicroSD card, and gave the electronics a test run. Unsurprisingly, it did not work. The circuit worked when powered from two separate power sources, but when they were both powered from the same one, they did not work, and I had no idea why. It was at this stage where my inexperience very much showed: I could order parts that did what I wanted, and put them together in a logical order, much like lego, however when they did not work I could not do much other than turn things off and on again and check connections were correct. Eventually, I got the circuit working, with the exception of the external video. For some reason, the image quality at best was poor, and at worst, non existent. I attributed this to my poor soldering and went over every connection and resoldered it to make sure there was a good electrical connection. However, in doing so I melted the internals of my screen selector switch, damaging it irreparably. The switch was a **DPDT**, meaning that it had 3 pairs of contacts, one half of which were all **shorted**. I improvised with the other half of the switch. While this meant my battery life would be poor regardless of the screen being on, it did mean that my video quality improved dramatically.

Assembly

I mounted the shoulder buttons into the slot by drilling a 1.5 millimeter hole through the wood and metal shoulder buttons. I turned a section of rod to 1.5mm wide, and glued them into the wood to act as a pivot.

The electronics were hot glued where appropriate or simply held by friction, as the parts of the circuit were very close to each other. I used hot glue as it can be peeled off. While this makes it a poor glue, it is a disadvantage I am using to my advantage, just in case I made a mistake or a component needed to be replaced. The brass buttons were glued onto the small tactile switches, which were soldered to some stripboard, which was also glued onto the **HIPS**. The other electronic components, and the battery were left loose as it was not critical that they were flush against the front, and the lid would more or less hold them in place. While admittedly a poor solution, I was well into the first buffer week in my plan, and was nearing the deadline for this project, and my options were limited.

I mounted the headphone socket and the battery charger in the lid, as it was easier to have laser cut slots in the lid than it was to carve slots in the wood as i had with the thicker components. I hot glued in the two connectors, which looked horrible, but held them in securely. I did not want to leave these ports in that state especially after the rest of my product adhered so closely to the design specification. I decided to sharpen a craft knife until it was razor sharp, and then I used it to trim the hot glue flush. You can see this below and in the final project photos, in Appendix 9.

Evaluation

Having finished this project, I certainly have a lot more respect for the design process and the effort that goes into designing and manufacturing the products we take for granted. I do believe that I succeeded with my project. I set out to create a stylish, elegant and mature handheld games console, and I believe I have achieved this. I have learned many technical skills and I have learned much throughout this project. Not a single part of this project was without faults, errors or accidents, most of which were my own fault. I have learned a lot about how I would go about recreating this artifact, and a lot about what I would work on and improve, as well as what would be useful, were this artifact to be mass produced.

I think I overcomplicated the manufacturing process in many ways, due to the nature of the workshop. It is difficult to remove yourself from a situation and re-evaluate it objectively, rather than simply continuing, trying one idea after the other, and I think this is exactly what happened with the surround and lid. I spent a month attempting to source aluminium billet and attempting multiple machining techniques in order to create the surround, however when it became clear that aluminium was not feasible and I would be using wood, instead of contemplating and re-evaluating the methods of manufacturing available to me, I simply charged ahead, using the closest equivalent to a metal machining technique on the wood. In hindsight, if I were to machine the case again, I would simply use a set of forstner bits (large woodworking drill bits) in the Drill Press, as this would have been a much easier and quicker process than the week-long CNC process. Although this technique is not scalable to mass manufacture, it would have been more appropriate in this case.

However, the issues with the lid were more a lesson in patience. I had already cut three lids, and spent many hours polishing each, and I grew impatient as they all had their own faults. For the fourth and final one, I decided to make my own sanding polishing and buffing disks, thinking that more speed would equate to less work. Unfortunately, that was not the case and I spend a day and a half at the various disks attempting to get a mirror finish, whereas if I had simply initially sat down for an afternoon with some sandpaper, I would have had the job finished in a third of the time. I think that this was also a key lesson, as it it is similar with the issue I mentioned earlier. Spending hundreds of hours in a workshop, no matter how much you enjoy it, clouds your judgement and you make mistakes, you rush and you make problems for yourself that otherwise would not exist.

I think this is reflected well in my activity log. You can clearly see that I begun with a lot of energy, and I achieved a substantial amount every week, before burning out just before Christmas and slowing down my rate of progress. Ultimately, this lead to me being behind schedule and needing to rush near the end of the project in order to get it finished. While on the whole, I stuck fairly well to my plan, had I paced myself, and forced myself to take breaks, I believe I would have made much more uniform progress, and perhaps even produced a higher-quality device.

If I were to rework the design, perhaps for a second prototype, I would change a fair few things: the first being the buttons. Tactile buttons are in no way adequate, they require very little activation force and they have very little travel, which I find uncomfortable. I would replace them with keyboard-style switches, or more preferably, silicone switches similar to those found in most game controllers. I would also invest more time into ergonomic research, and perhaps let my design use more of the 3rd dimension, perhaps moulding the back to fit the human hand, similar to how the PSP’s case is shaped.
Most of all, I would invest time in improving my Electronics knowledge and I would improve the features of the system, with more power, extended battery life, greater storage, along with features such as bluetooth controllers, WiFi access, wireless video streaming, wireless charging among other things. The possibilities are endless, limited only really by the tools available to me and my budget.

Despite these areas for improvement, however, I do believe I have succeeded in my initial task, and I believe I have met all of the criteria given to me by the client in the original Design Specification. The contrasting styles of the console, the materials used, and the form of the console all, to me, meet the standard of elegance, maturity and quality. The total final material cost to me was around £50, exactly where I estimated it would be, and much below even my minimum asking price for the device. This does, of course, disregard the hundreds of hours of labour and the material cost of all of my prototypes, however these are irrelevant for a mass produced product.

Were I to mass produce this, I would firstly move to completely automating the entire process. I would cut the parts on CNC Machines. I would use a CNC mill to machine the surround from aluminium. This would require no man-hours machining the part and every part would be identical. I would use a metal laser cutter to cut the lid and shoulder buttons from raw metal, though equally I could stamp the lids from a large sheet of aluminium, which, while having a high start up cost, would be much more efficient in the long run. The plastic sections I would laser cut using tools no different to those I used at school, and I would machine the buttons on CNC Lathes.

The electronics would likely be completely customised to give exactly the features required for the final product, and to do this I would need to build ties with electronics suppliers in order to receive competitive prices. The aspect of my device that would benefit most from this is the battery life. For cost reasons I bought a screen designed for use with cars. It was cheap and easy to use, but unfortunately it drew around 800mA. At that rate, the battery would last around 2 and a half hours, which is much too low. With cheaper electronics and by leveraging economies of scale I could easily bump this battery life up into the 8 hour range without significant changes in cost.

The assembly process would likely be done on an assembly line, perhaps automatically. There would be around 10 stages to this, which I detail in Appendix 10.

Overall, I believe that I succeeded with my goal of producing a handheld games console. It is not as perfect as I envisioned it to be over 9 months ago, there are missing features, flaws, scuffs, rough edges, but the EPQ is about your journey, and to me this project has been a very long, detailed journey. I have expanded on many skills, I have learned techniques inside and outside of the workshop, and I have also learnt the value of less tangible skills, such as the value of research and planning, and the value of patience when faced with issues. I thoroughly enjoyed every minute of this project, even at points when I wanted to tear my hair out, the constant barrage of issues and problems has allowed my problem solving skills to grow exponentially, more than they would have on any A Level course. I have learned more about how to design products and packaging, and how to document and reference my research. There will always be things I could learn, skills I could improve upon, but the EPQ has left me leaps and bounds ahead of where I was back in June, and I think that is the most important thing.

Activity Log

Date	Summary	Nature?	Detail
July	Pre-research	Good	I researched available materials, and manufacturing techniques, and I drew up a 2D pencil sketch
August	Pre-research	Good	I researched further into ergonomics and design, and using this, I created a 3D model to demonstrate the assembly process.
September	Pre-research	Good	Laser cut first basic model to see how it its in the hand
19/09/2016	First Meeting	Needs Attention	I discussed the logistics of manufacture of the entire product, as well as potential hazards and pitfalls.
		Needs Attention	The left buttons are an irregular shape and were highlighted as difficult to machine by my supervisor
		Needs Attention	The action buttons will be difficult to color and this must be thought about, or perhaps redesigned.
		Urgent	The outer casing will cause a severe issue to manufacture and must either be made out of school or a way must be found to manufacture them in school
26/09/2016	Primary research	Needs Attention	I created first my first laser-cut dummy for ergonomics, with the initial feedback being that the shape was "Too wide and too narrow". I need to work on this design and improve it.
02/10/2016	Primary research	Needs Attention	I cut a second laser-cut wood dummy for ergonomics, this time more evenly sized. The surveyed reactions were positive
05/10/2016	Primary research	Needs Attention	Building on the First Meeting, I simplified the design to use hexagonal buttons. I attempted to machine from brass, which worked very well. The brass cannot be easily stamped or marked, to show what the button is. This needs to be looked into.
07/10/2016	Second Meeting	Urgent	No staff are available within school to use the milling machine, and as such an alternative must be devised, either another method of manufacture, another source of manufacture, or a total overhaul of the part in question
10/10/2016	Primary research	Urgent	I designed a special milling tool which can be used in the machines in school, which could, if it works, machine the aluminium and create the product
12/10/2016	Primary research	Urgent	Finished machining the milling cutter, however it could barely cut a sheet of aluminium 1mm thin, in order to

			machine the part, a series of progressively larger holes must be drilled before the part can cut the final diameter hole. As such, the tool is not very useful as a cutter.
14/10/2016	Third Meeting	Urgent	I evaluated the product with my supervisor. We agreed that the software will not be an issue, and neither will be any of the plastic parts, however the edge ring of the container is impossible to create given the materials we have in school, either the product needs to be outsourced, or the part in question needs to be re-machined
	Primary research	Urgent	Cut the ring from foam on the CNC machine, the CNC machine cuts well and accurately, but the DXF needs to be modified for the size of the cutter, and this lead to a small error in sizing. This method could be used in wood to replace the aluminium ring
	Design	Good	Developed and wrote up a complete final design and plan to follow
25/10/2016	Resources	Good	Ordered a screen, battery, and audio adapter for the project. Estimated arrival dates: 10th Nov - 15th Dec
27/10/2016	Redesign	Urgent	Price of a single block of aluminium was found to be £25, the material cannot be CNC machined, and neither can it be easily machined. Wood was not chosen as it was not as robust as aluminium and was likely to chip, however at this point, a wood/aluminium composite seems most plausible, with the ring being CNC machined, and the aluminium lated stuck on with epoxy resin in order to take the lateral load of the weight of the lid away from the thin wood and to give it some strength.
04/11/2016	Machining	Good	I turned 10 Buttons on the Lathe, longer than necessary so that they can be cut down.
11/11/2016	Machining	Needs Attention	I begun CNC Routing the case, spent approximately 30 hours total machine time
18/11/2016	Redesign	Urgent	The CNC Router made an error, and now the lid must be redesigned to fit as there is now an extra groove, which may be used to seat a new lid
25/11/2016	Machining	Needs Attention	I cut a new style of lid from sheet aluminium, it fits well and looks good, but is quite literally rough around the edges and I will need to make a new one. I also laser cut 3mm Black Acrylic and 3mm Clear acrylic for the front of the device
02/12/2016	Electronics	Good	Soldered Male Headers to the Pi and added a male composite connector to the composite pins. soldered in the

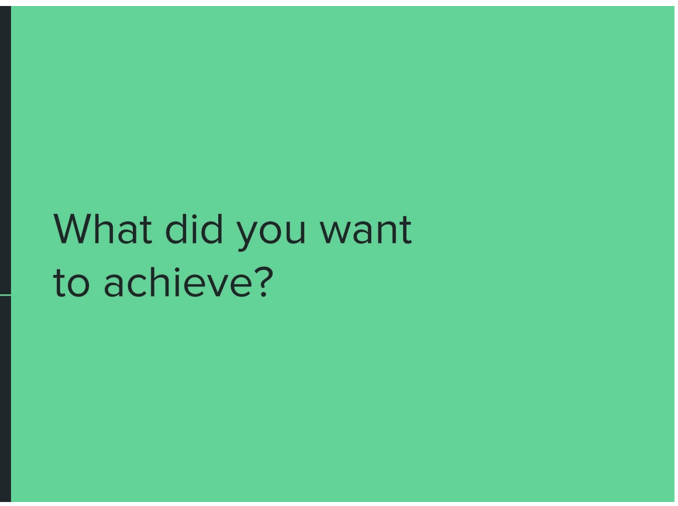
			Boost converter and connected it to the screen via a DC Jack and connected the input to the Pi's input
09/12/2016	Electronics	Good	I asked a Friend for help flashing the operating system onto the MicroSD card. I tested the sard in the Pi Zero and the activity light on the Pi flashes when the Pi is turned on
16/12/2016	Electronics	Urgent	Unsurprisingly, the initial prototype does not work. The Raspberry Pi's activity light flashes when the power is on, suggesting that it boots properly. Either the screen is not powered properly, the video is not being output properly, or the screen is broken.
23/12/2016	Electronics	Needs Attention	In a rare free moment, I tested the screen with my PlayStation, it did not run when powered by the boost converter, but it did display an image when powered directly by a 12v 1A power supply
30/12/2016	Empty	Good	Revision week, wrote up relevant sections on the manufacturing process
06/01/2017	Empty	Good	Exam week. Proofread.
13/01/2017	Machining	Good	Using a small drill, needle files and an assortment of chisels, I cut two slots for the shoulder buttons, and drilled holes for the Composite video output, power and selector switches, as well as the strap hole.
20/01/2017	Fourth Meeting	Good	I spoke to my supervisor, he was satisfied I was making good progress, but suggested I invest more time into the electronics as that is where I lack skill.
		Good	I cut the shoulder buttons from 16mm x 6mm Nickel Silver bar, polished and mounted in the slots in the surround
		Good	I finished the wood surround using 3 coats of water based varnish
27/01/2017	Electronics	Needs Attention	I had forgotten to trim the wires from the boost converters, they had shorted and blown the PWM chip on the board, which explains why the screen would not turn on when powered from the boost converter. I have ordered a new one.
		Good	Soldered all 13 buttons onto their relevant GPIO pins
		Urgent	I borrowed a Raspberry Pi B from school in order to test the video output of the Pi. Over the weekend I will need to check if the Pi is outputting composite video correctly, and adjust settings as needed
03/02/2017	Electronics	Good	Updated the OS settings to output composite video properly, external composite now works, and in theory, the screen.

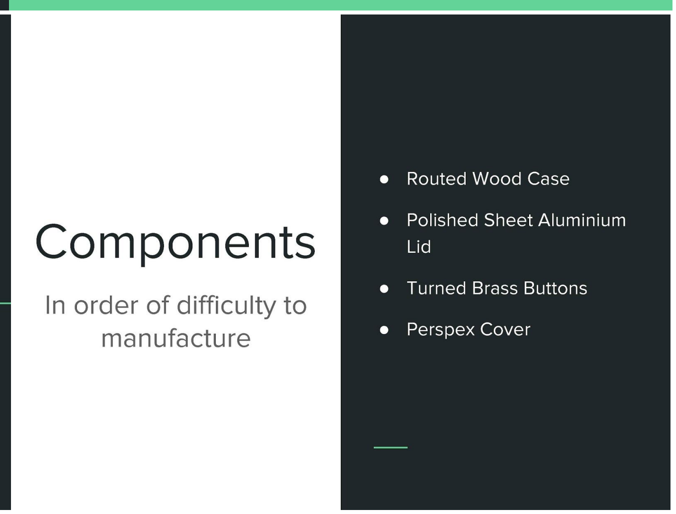
	Resources	Good	Boost Converter arrived and soldered in
		Good	Had a working electronic prototype created, using the connectors on the screen
	Redesign	Urgent	The electronic prototype does not fit in the case, perhaps it will when I remove the connectors, but I need to redesign the lid somehow to make it thicker
10/02/2017	Electronics	Good	Replaced connectors and wires to smaller wires of the minimum length in order to maximise internal space
	Redesign	Urgent	Electronics still do not fit - a redesign is still required
	Research	Needs Attention	Created various sanding disks in order to polish the new metal lid, none of which were very effective. I polished the sheet aluminium by hand, but I still need to change the lid design
17/02/2017	Machining	Needs Attention	Laser cut an acrylic lid which gives more internal space and fits well, but does not meet the specifications for style, sizing or safety, as it traps a lot of heat
	Machining	Good	Recut the black acrylic piece from 1mm matt black HIPS
	Electronics	Good	Begun gluing in the buttons to their relevant positions in order to prepare for the assembly stage
24/02/2017	Machining	Good	Redesigned an acrylic lid with inset aluminium lid, and two ports for charging and headphones
	Electronics	Good	Added a headphone port, tested and audio quality is good
	Assembly	Good	Mounted power and screen switches into case, wired in and system works perfectly
03/03/2017	Assembly	Good	Mounted all the electronics into their correct position on the HIPS using hot glue, system works, thought heat transfer is an issue
	Assembly	Good	Glued together lid and test fit over the electronics, all fits, thought the external ports need to be attached
10/03/2017	Assembly	Good	Trimmed brass button caps to size and mounted them on the tactile switches
	Assembly	Good	Mounted the composite output in the appropriate hole in the wood
	Assembly	Good	Glued the Headphone and Charger Ports into the Lid
	Assembly	Good	Tested the device, ran perfectly, if a bit warm
12/03/2016	Electronics	Urgent	I damaged the Pi Zero by trying to overclock it and had to find a replacement
17/03/2017	Accessories	Good	Created and mounted a carrying strap

	Report	Good	Had product pictures taken for my report
	Presentation	Good	Presented my EPQ to my supervisor

Presentation

Once I had finished my product, on the 17th of March I presented my project to my supervisor, teachers, visitors and parents at an EPQ Presentation Evening. I used the school Raspberry Pi B to output the below presentation to a projector using a composite video cable. I swapped this cable from the Pi to the Console to demonstrate it working.





Electronics

In order of purchase

- 3.5 Inch Analogue Screen
- 2000mAh LiPo Battery
- Raspberry Pi Zero
- 12v Boost Converter
- LiPo Charging and Protection Circuit

Problems

1. Milling Machine
2. CNC Error
3. C.H.I.P Manufacturing Error
4. Composite Video Output
5. Space Management
6. Overclocking

Demonstration

Improvements

In descending order of ease of implementation:

- WiFi + Bluetooth Support
- Carrying Case
- Dock
- Increased Battery Life
- Higher Efficiency*
- Better Switches
- Detachable Screen
- Custom Player 2 Game Controller
- Injection Moulded Lid
- Custom Fitted PCB

Any Questions?

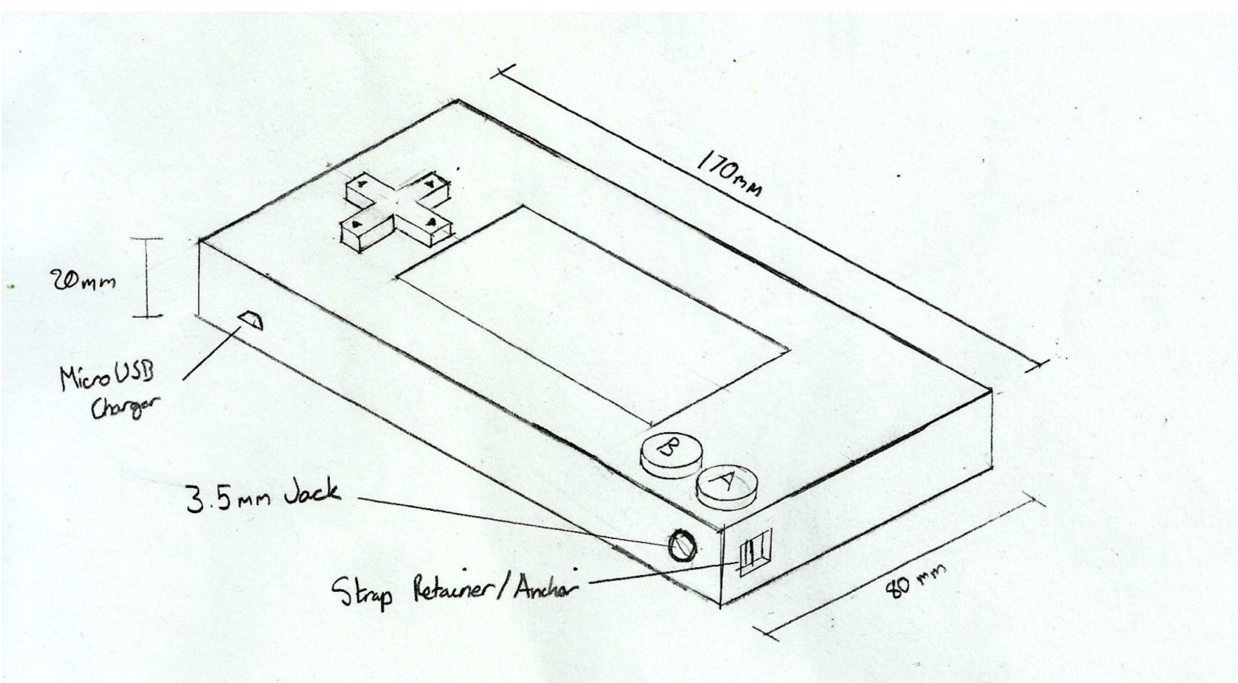
The finished product

Appendices

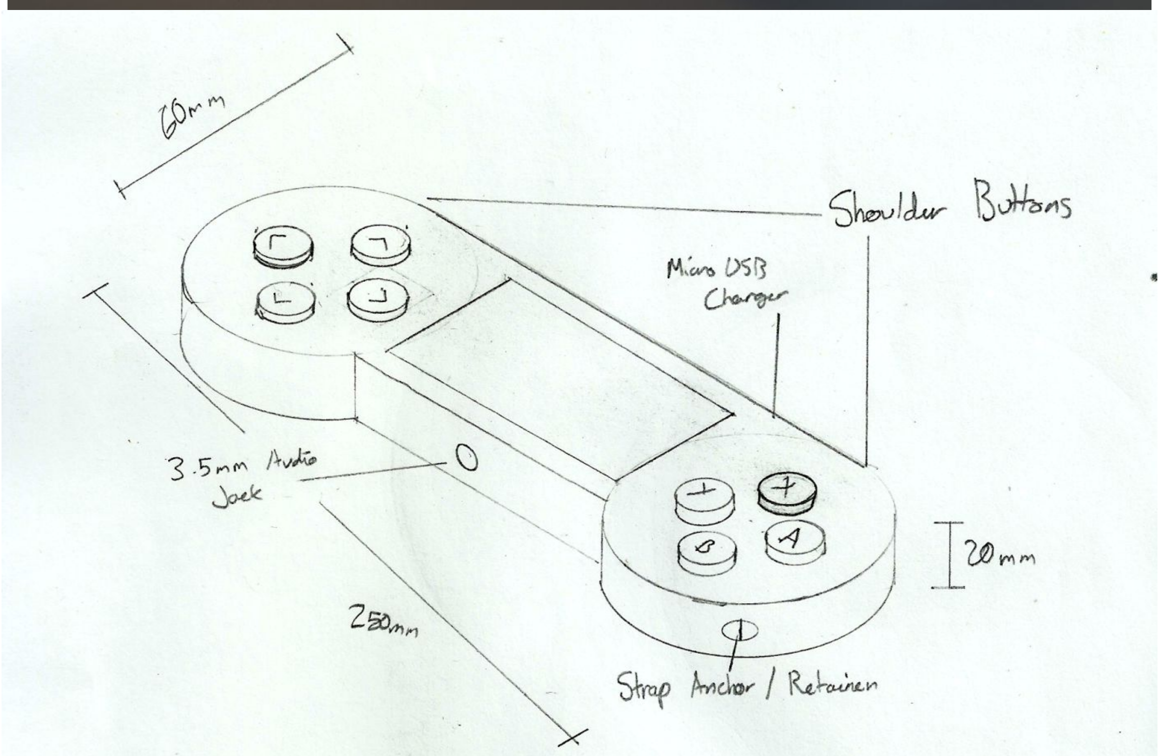
1. Initial rough sketches
2. Cad screenshots
3. Final technical drawing
4. Diagram of surround
5. Cross section of surround after CNC Error
6. Rough electronics schematic
7. Parts List
8. User manual
9. Final pictures
10. Guide to mass production

Appendix 1: Initial rough sketches

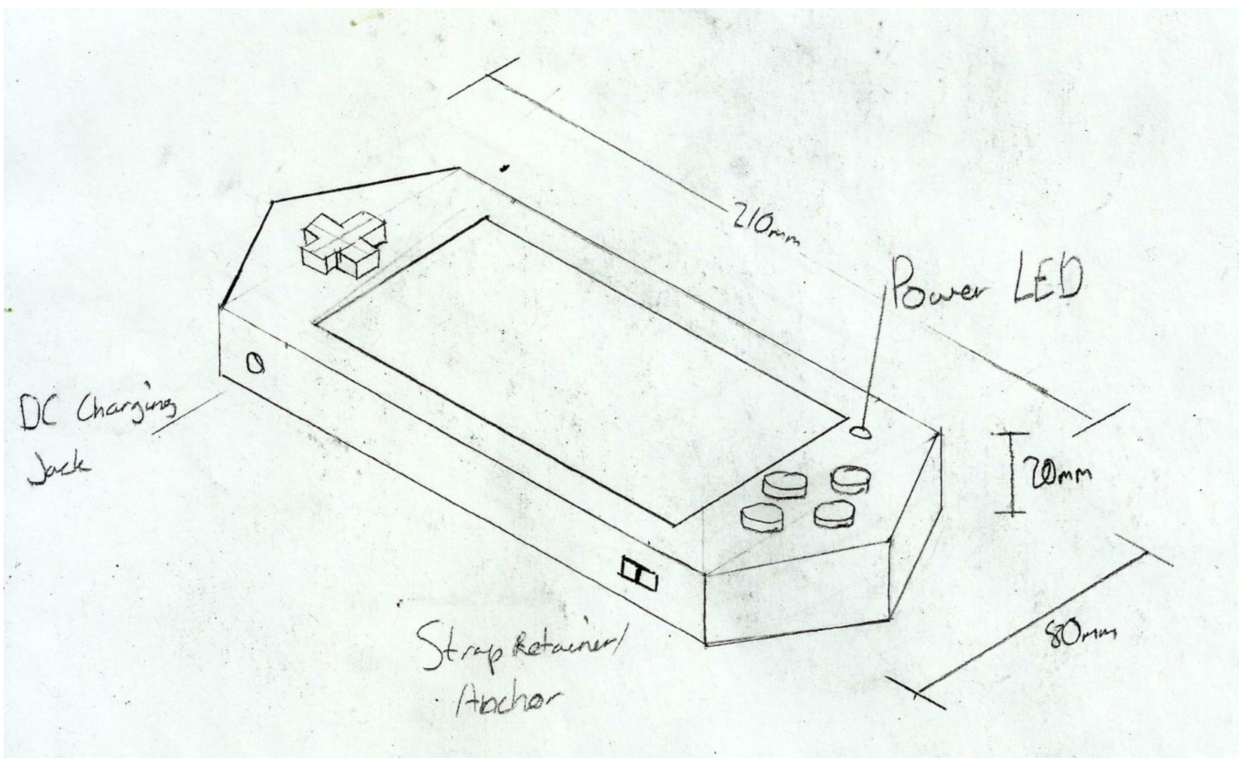
Reference image: NES Controller



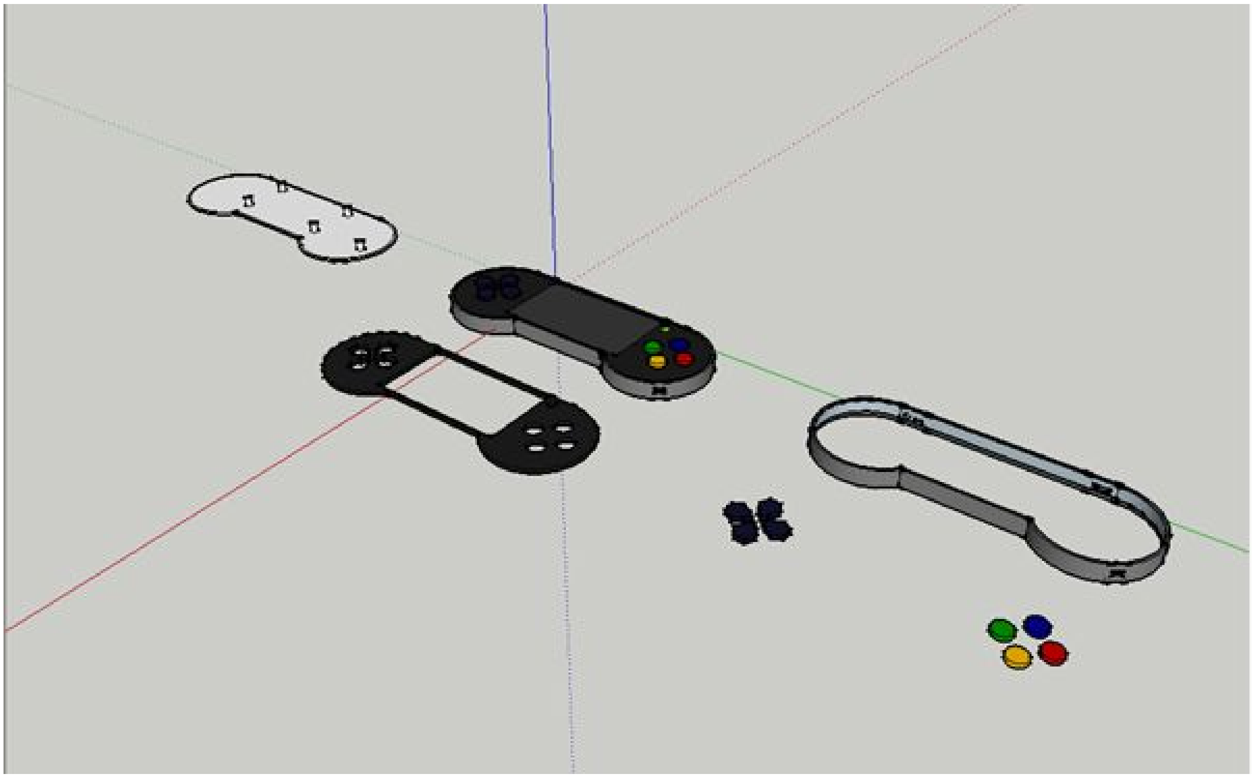
Reference image: SNES Controller



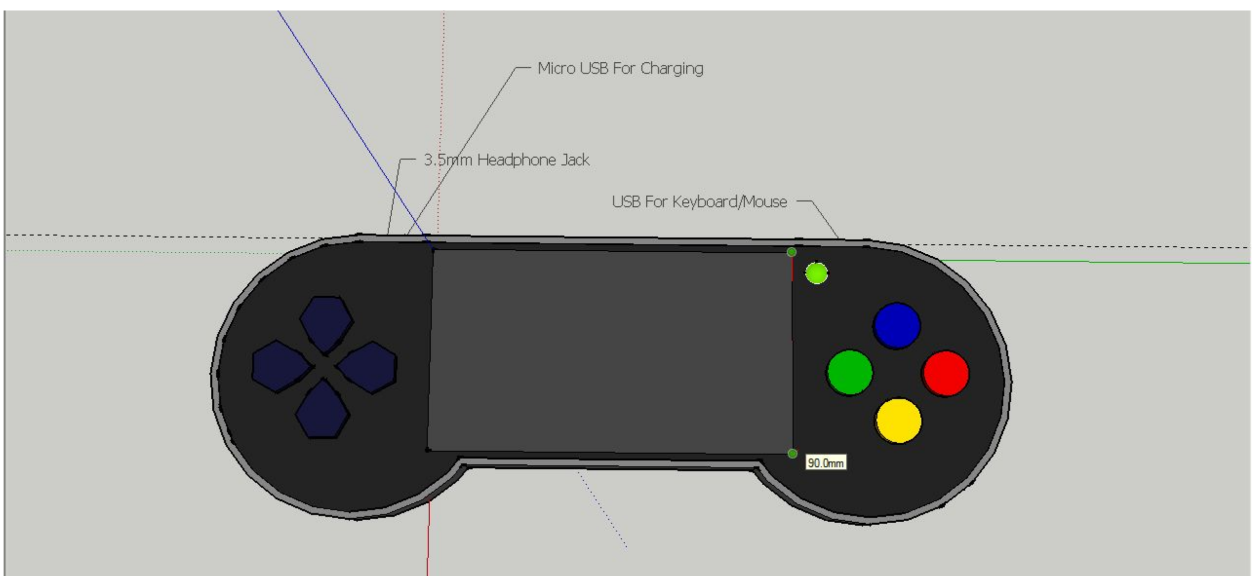
Reference Image: PSP 1000

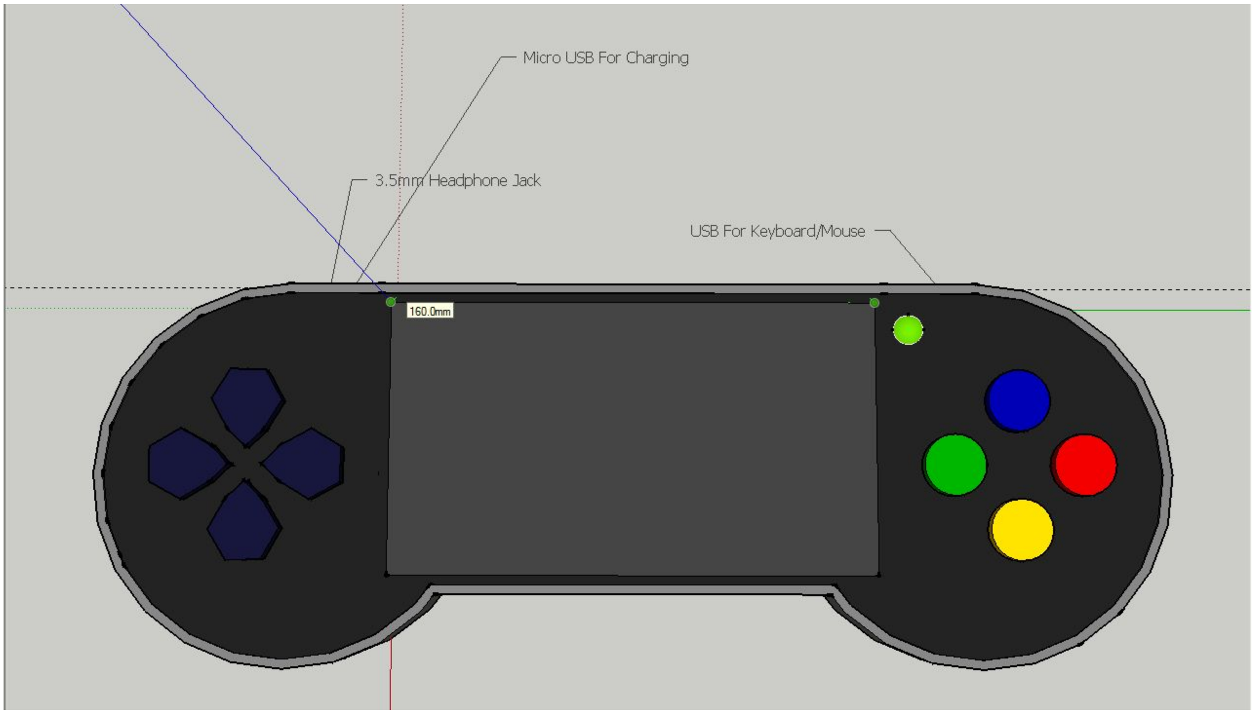


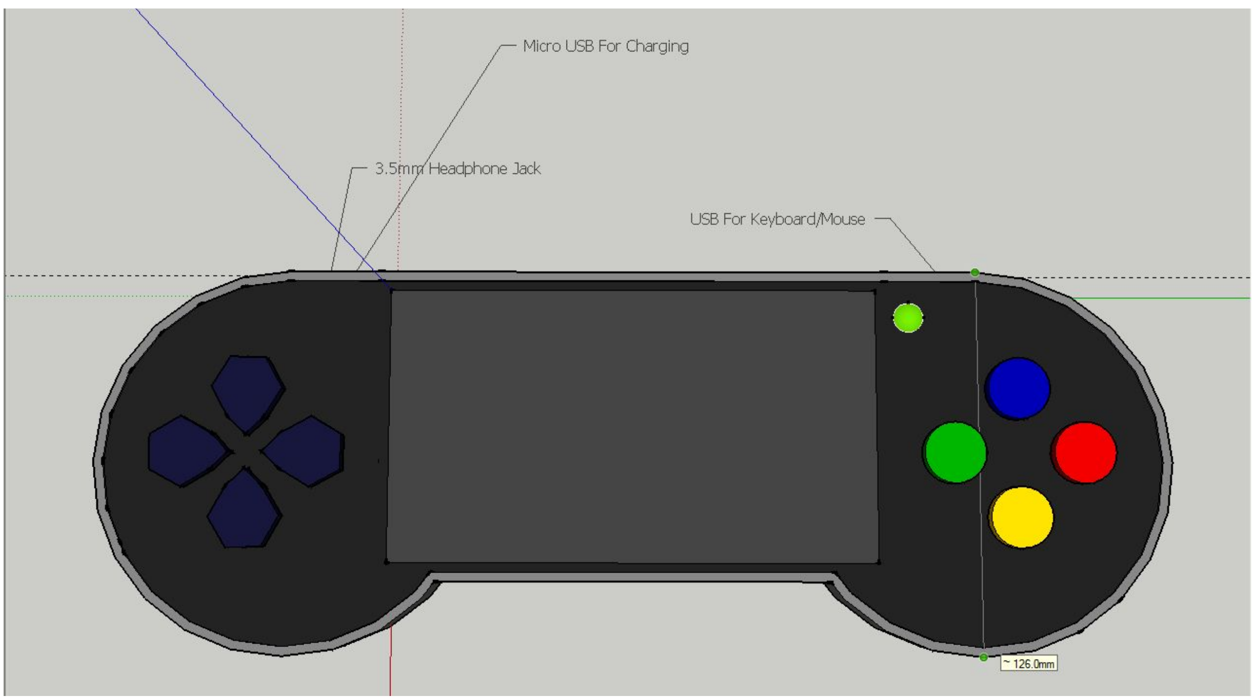
Appendix 2: CAD Screenshots

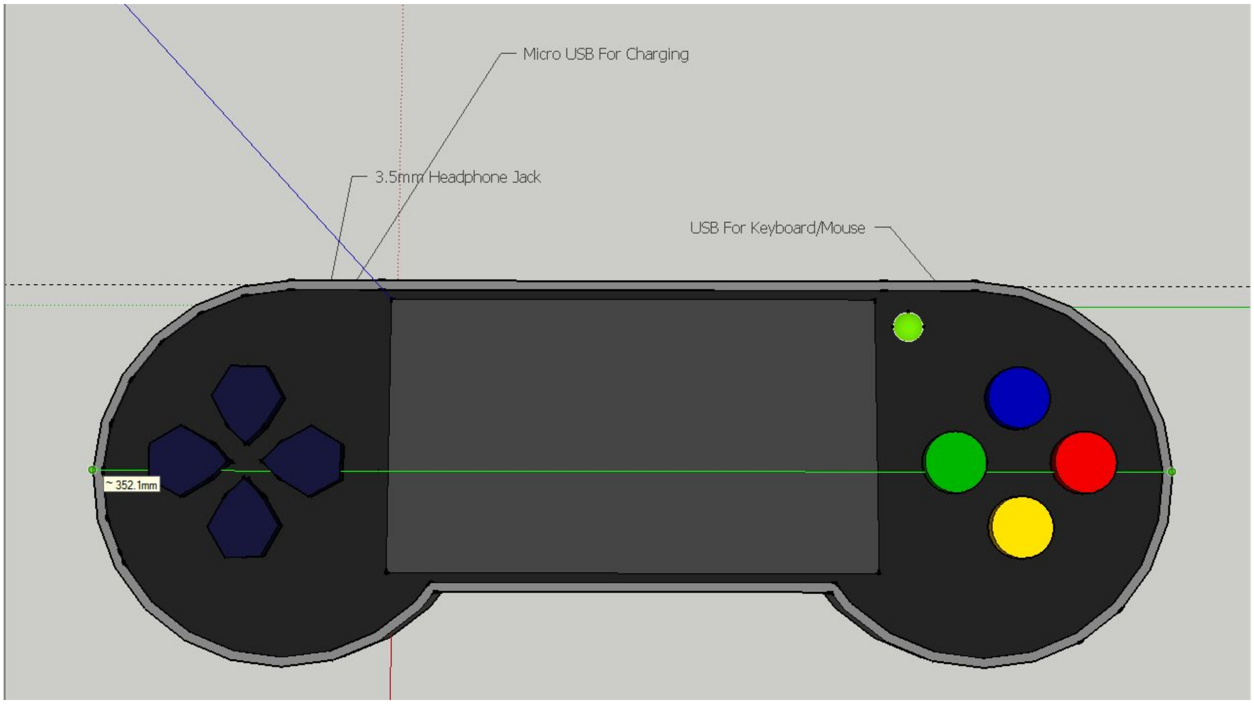


Console

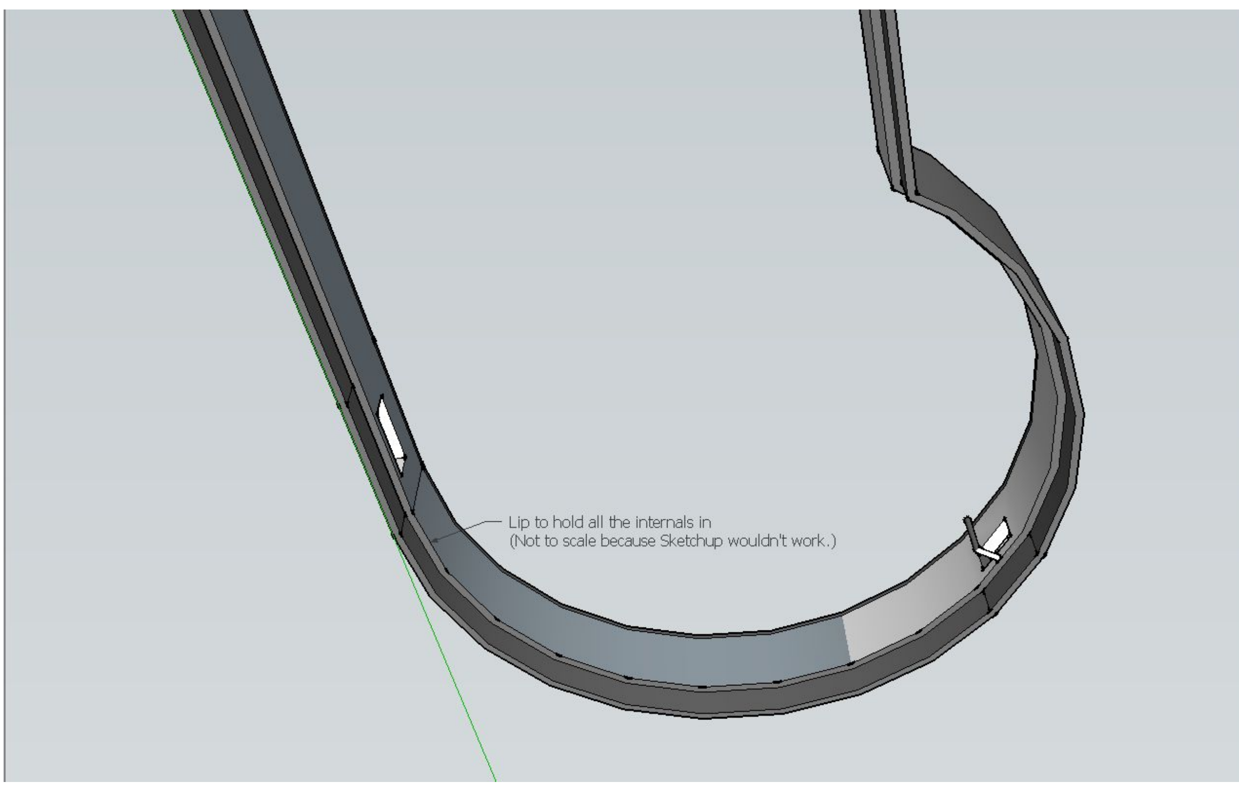


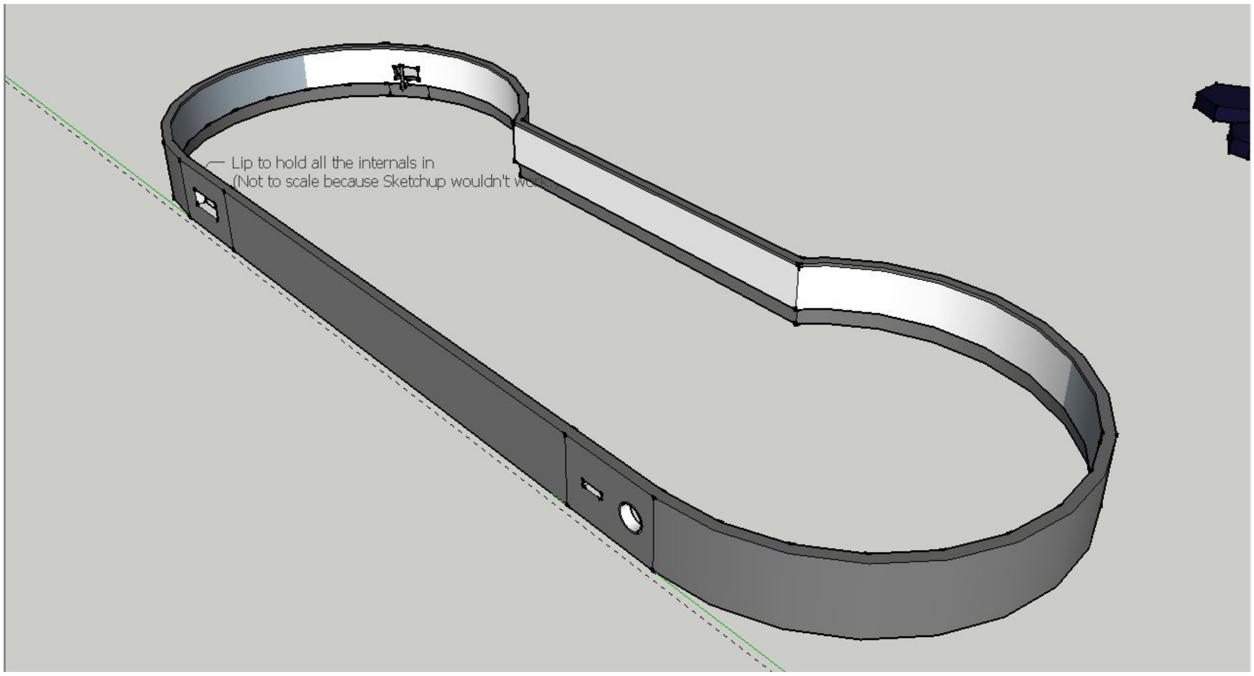

Micro USB For Charging
3.5mm Headphone Jack
USB For Keyboard/Mouse
160.0mm

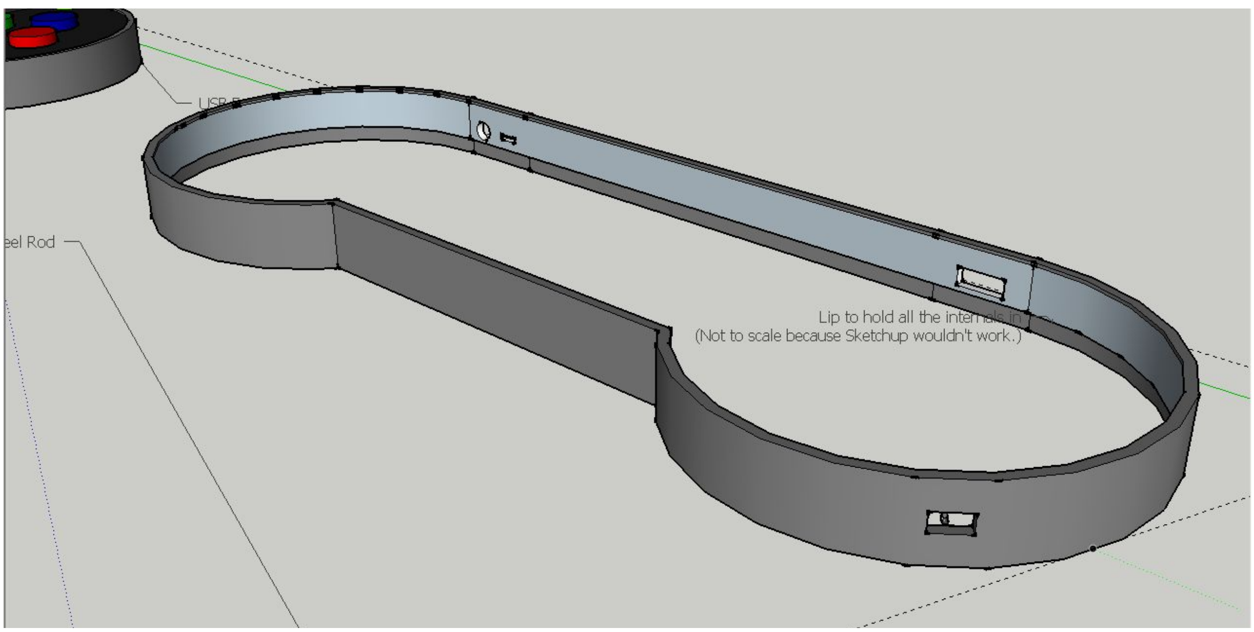

Micro USB For Charging
3.5mm Headphone Jack
USB For Keyboard/Mouse
~ 126.0mm


Micro USB For Charging
3.5mm Headphone Jack
USB For Keyboard/Mouse
~ 352.1mm

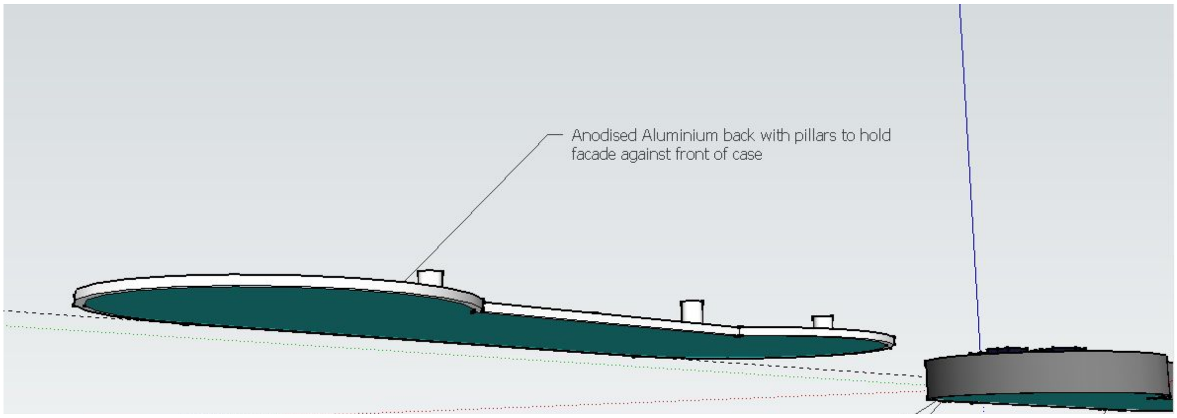
Surround

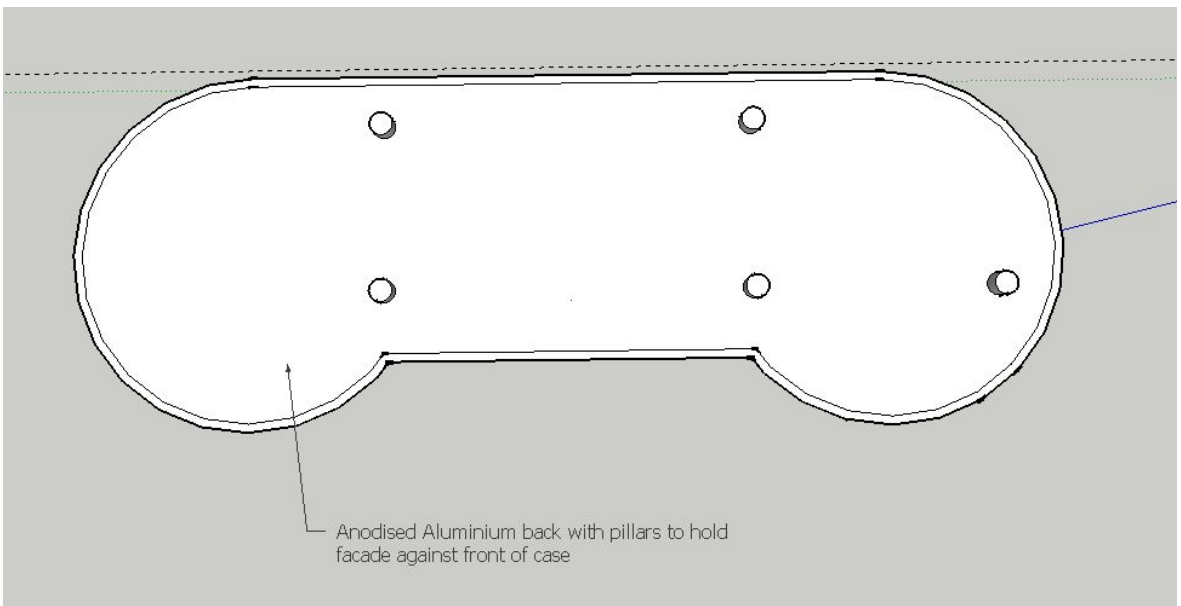

Lip to hold all the internals in
(Not to scale because Sketchup wouldn't work.)


Lip to hold all the internals in
(Not to scale because Sketchup wouldn't wo

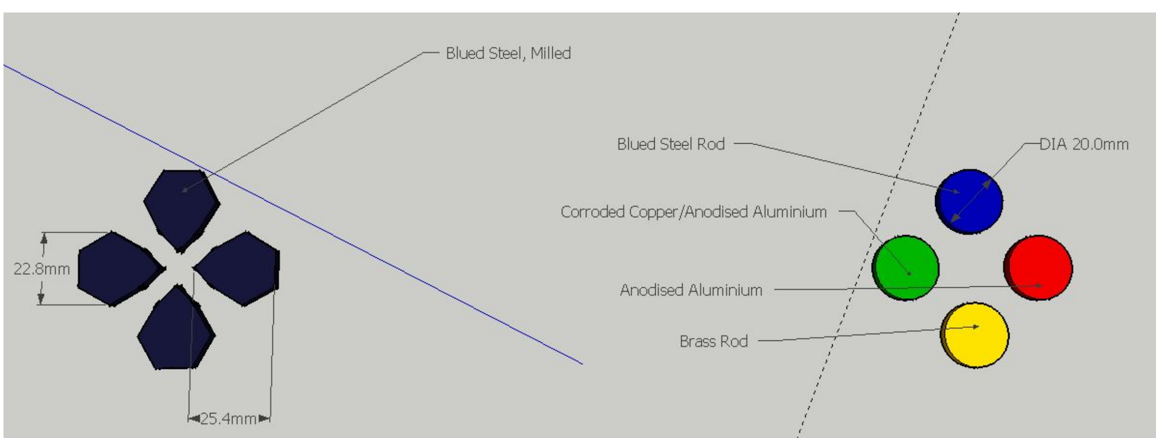

eel Rod
Lip to hold all the internals in
(Not to scale because Sketchup wouldn't work.)

Lid

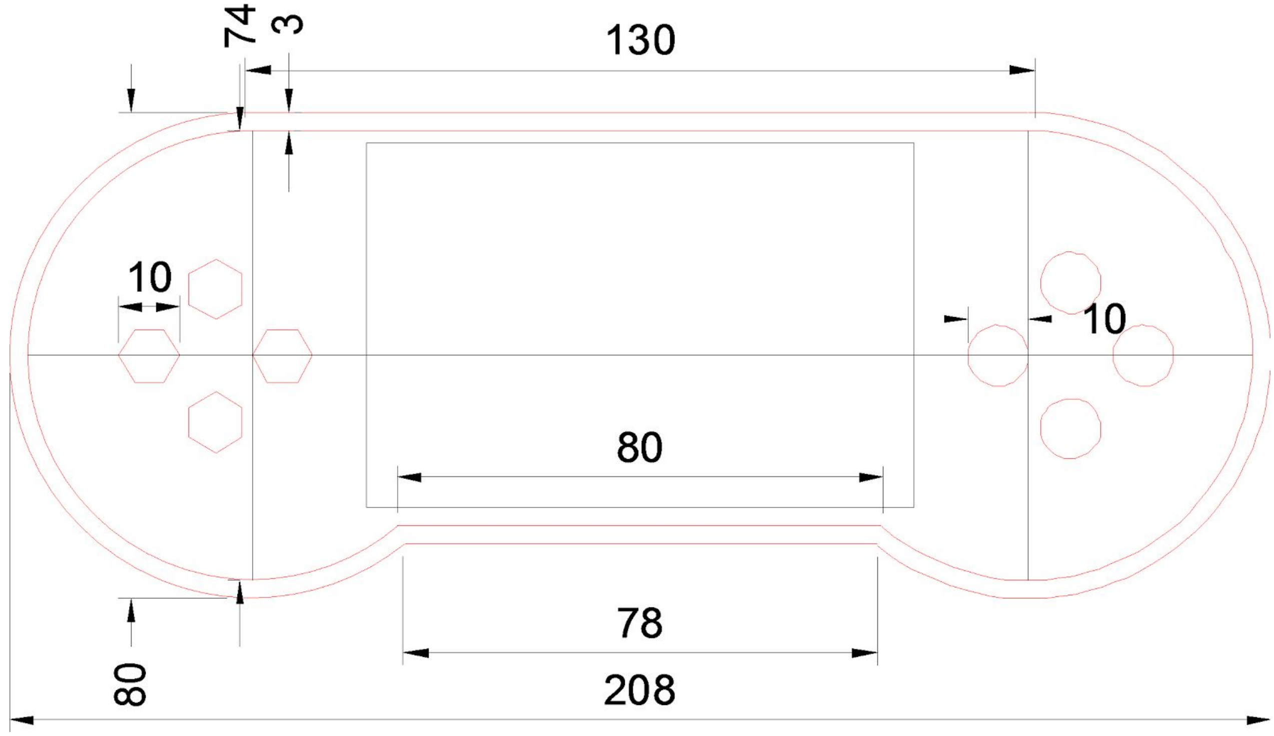

Anodised Aluminium back with pillars to hold
facade against front of case

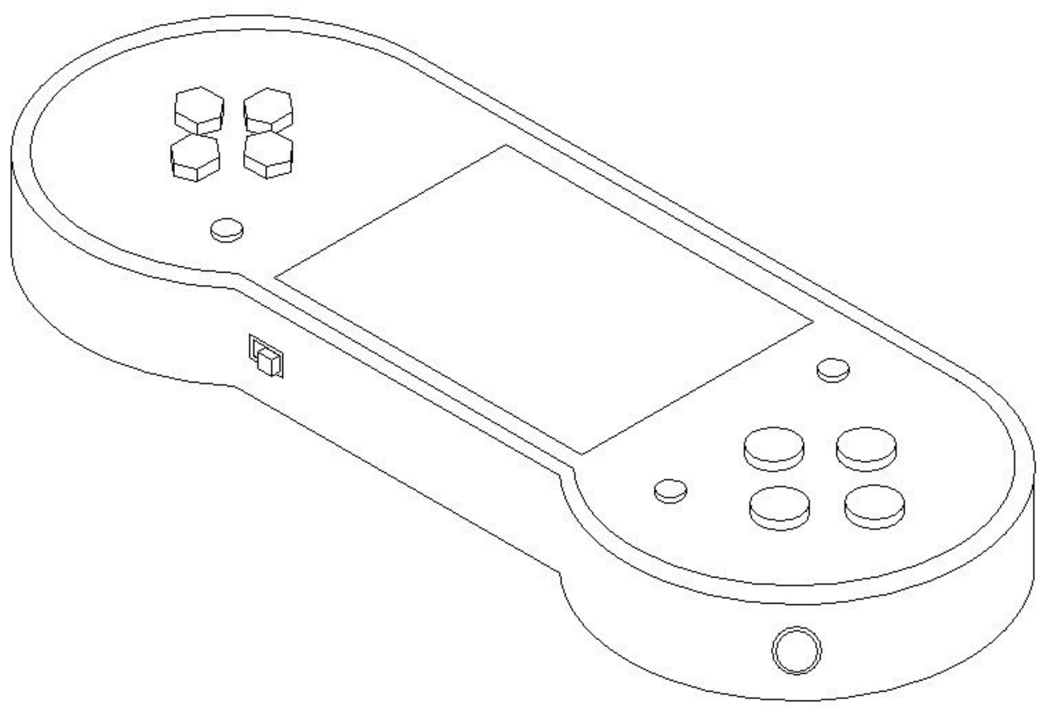

Anodised Aluminium back with pillars to hold
facade against front of case

Buttons


Blued Steel, Milled
22.8mm
25.4mm
Blued Steel Rod
DIA 20.0mm
Corroded Copper/Anodised Aluminium
Anodised Aluminium
Brass Rod

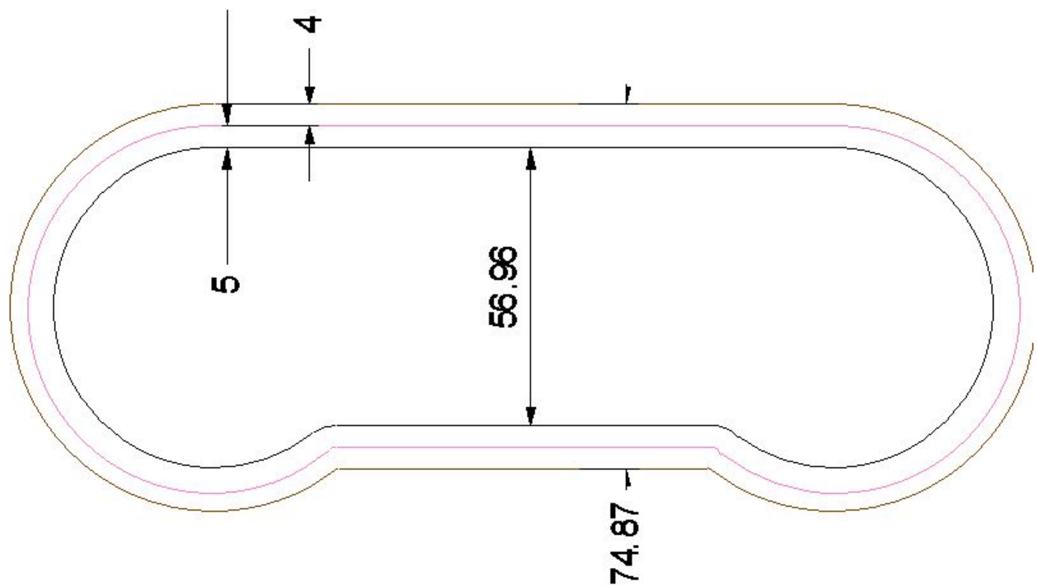
Appendix 3: Final Technical Drawing



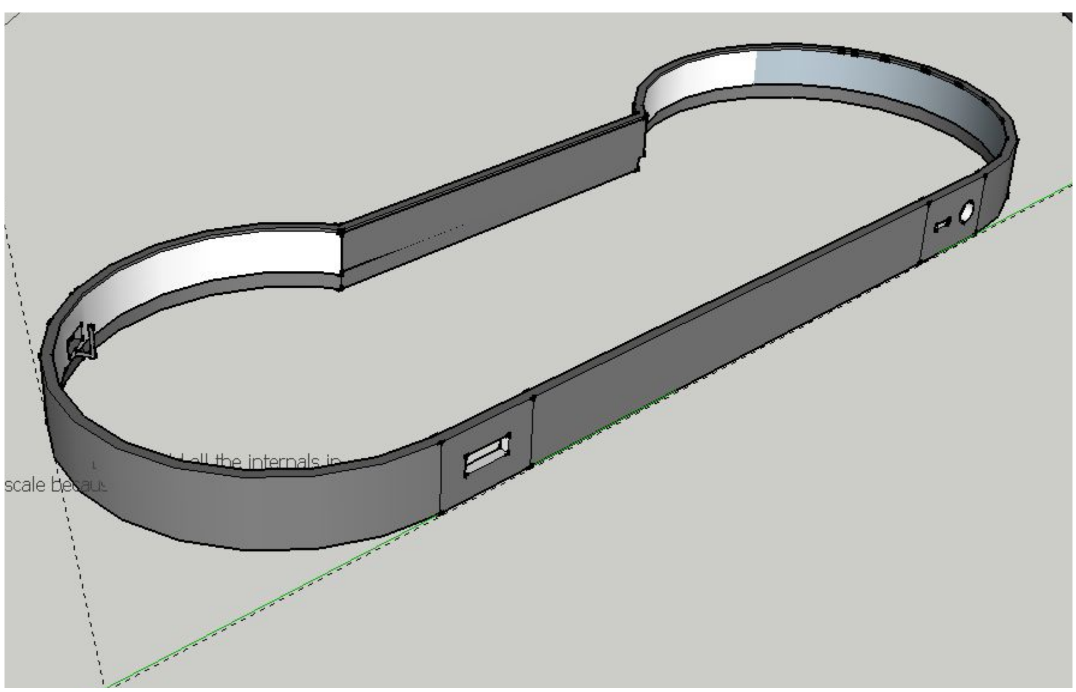


Appendix 4: Diagrams of Surround

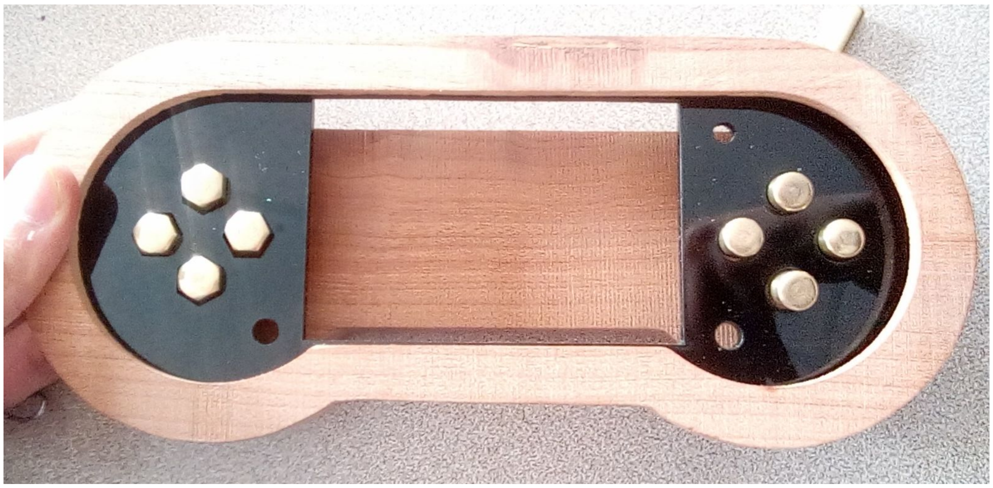
CAD CNC output:
Black and brown: 21mm depth, cut through.
Pink: 18mm depth



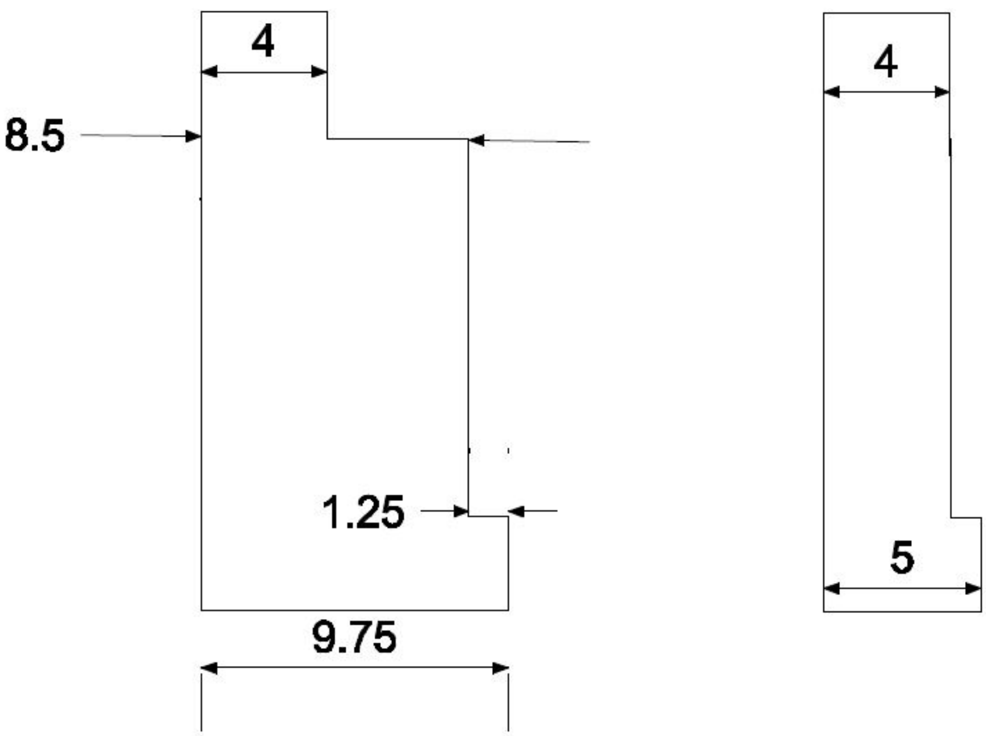
3D model of surround

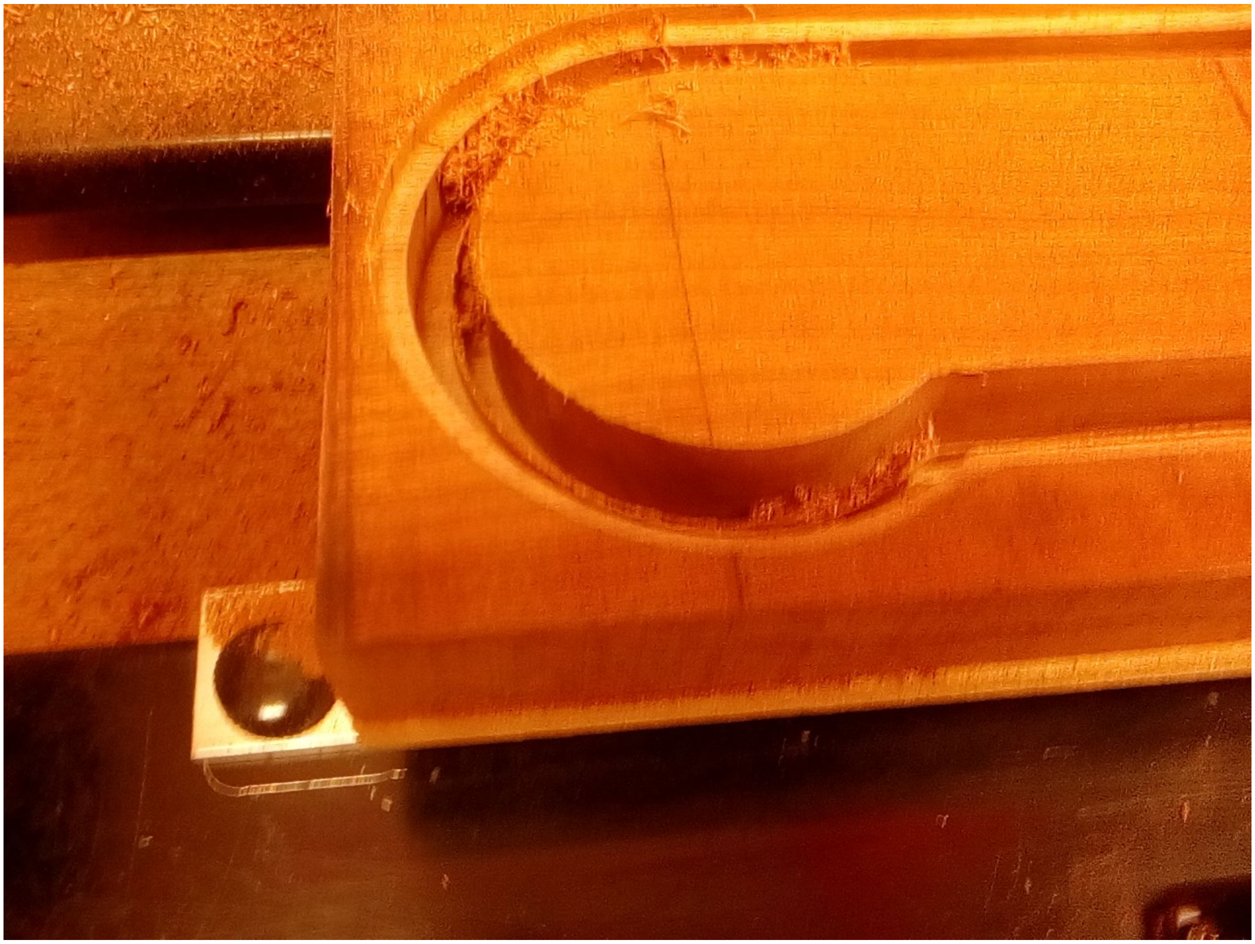


Appendix 5: CNC Error

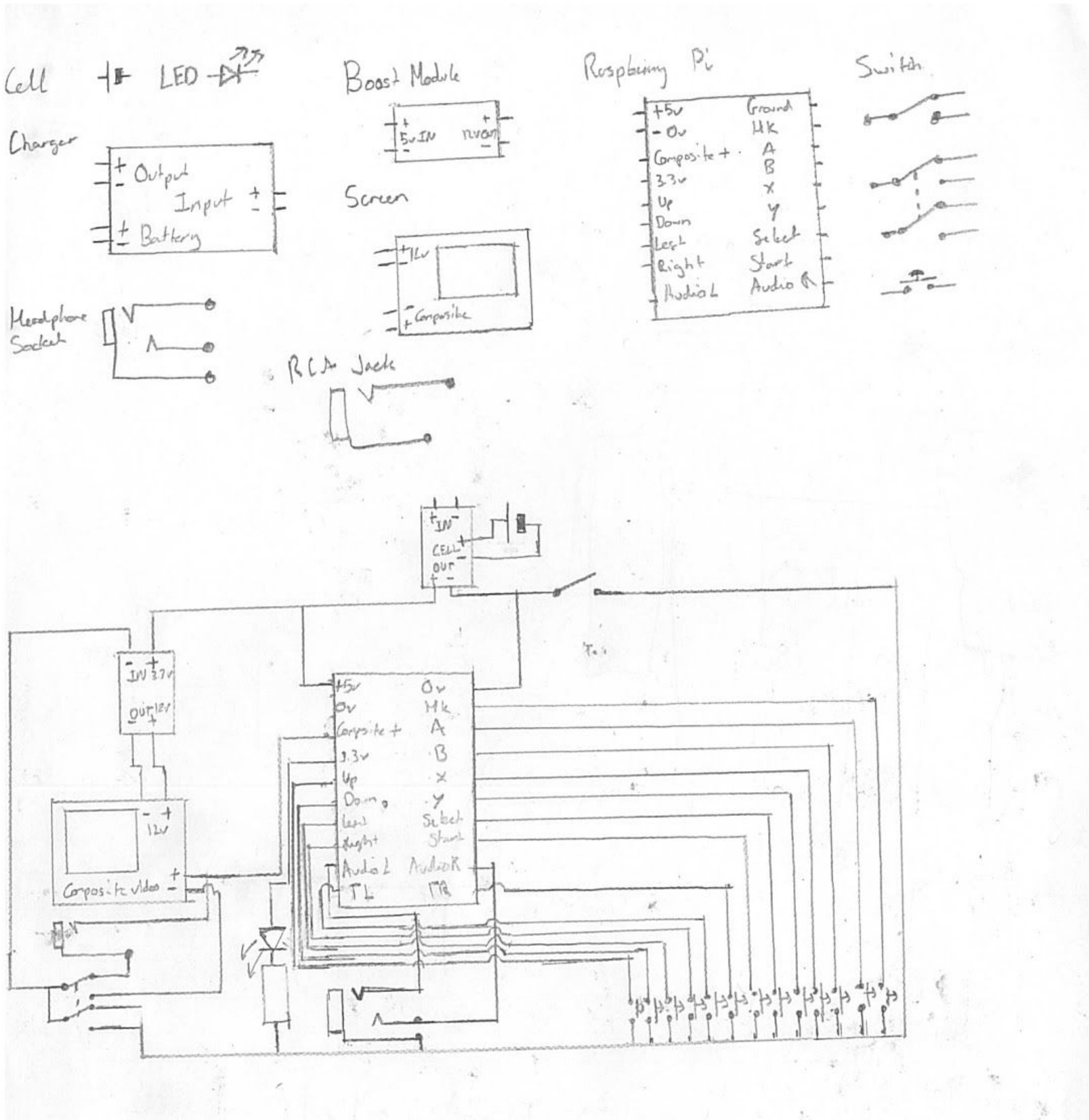


Produced cross section vs Intended Cross Section:





Appendix 6: Electronics Schematic



Appendix 7: Parts List

Physical

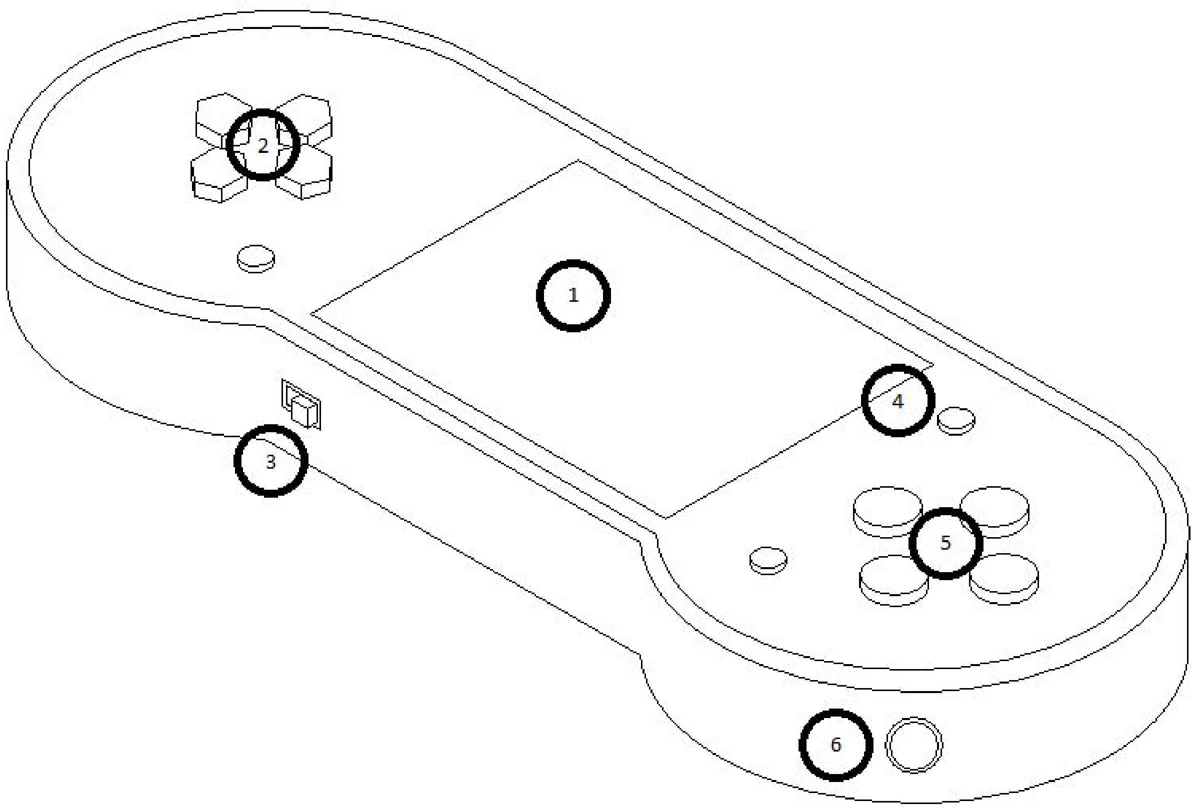
- CNC Routed Wooden Surround
- Laser Cut Perspex Front
- Laser Cut HIPS Mask
- Turned Brass Hex + Round buttons
- Brass bushing for strap hole
- Hand-cut shoulder buttons
- Leather Carrying Strap
- Laser Cut Acrylic Lid
- Hand cut and polished Aluminium back

Electronic

- Raspberry Pi Zero v1.3
- 3.5 inch Analogue TFT LCD Screen
- 3.7v to 12v Boost Converter
- 2000mAh Lithium Polymer Battery
- TP4056 Lithium Ion Charging and Protection Circuit
- 10x Tactile Buttons
- 5mm Green LED
- 2x Microswitches
- Female Composite Video port
- SPST Slider
- DPDT Slider
- PCB-Mounted Headphone Jack

Appendix 8: User Manual

About the device:



1. TFT Analogue Screen
2. Directional Buttons
3. Power Switch
4. Power LED
5. Action Buttons
6. Carrying Strap Retaining Hole

Turning on your device for the first time:

1. First, insert the provided SD Card into a computer and load your game ROMs into to relevant folder. There are folders for each emulator, simply insert your files into this folder
2. Open the back and mount the SD card in the Micro SD slot.
3. Charge the battery fully before closing the case.
4. Switch the leftmost switch to the right, “On” position to boot up the device.
5. Switch the rightmost “Screen Selector” switch to the right, “internal screen” position

Cleaning the device:

Wipe clean with a damp, lint free cloth. Do not use heat or excess water. Do not use strong solvents. Solvents will cause the plastics to cloud over and will reduce image clarity. Metal polish may be used RARELY in order to polish the buttons, but this must not touch any plastic surfaces as this will also cause clouding.

Charging the device:

- Use a Micro USB charger that meets the USB Specification ratings for voltage and current, else you risk severely damaging the device, possibly even damaging your device.
- Plug the charger into the Micro USB port on the top of the device. Then powered, a red light will light up to show that the battery is charging.
- It is not recommended that you use the device while it is charging as this can decrease the battery's lifespan, despite the device having this capability.
- The charging process from completely drained to full charge should take between 4 and 6 hours, depending on the charger used. During this process the aluminium back may warm slightly. This is normal to the operating of the device. Ensure that the device is not being heated externally during this process as this **will damage the device.**
- When the charging process has finished, the red light will turn to green, signalling that you should remove your charger and resume using your device.

Other:

- Do not drop, throw, heat or pierce the device.
- Please dispose of electronic goods responsibly.

Appendix 9: Final Pictures

Appendix 10: Guide to Mass Manufacture

To mass produce the device, the manufacturing process can be split up into multiple steps:

1. Sourcing Materials
2. CNC Machining
3. Laser Cutting
4. Electronics Assembly
5. Injection Moulding
6. Punching
7. Finishing
8. Material Recycling
9. Final Assembly
10. Printing and Packaging

Sourcing Materials

A sustainable, renewable source of wood would need to be found, preferably cut into 250mm x 100mm x 30mm blocks, but this could be done at the factory if it is more economical.

A source of Sheet Aluminium and Brass Rod would also need to be found, with materials ordered in bulk to reduce cost per item.

The electronics would also need to be sourced from a supplier, again leveraging economies of scale to minimise the per unit cost. The components would likely be assembled onto one board to minimise space required.

CNC Machining

The wood and brass shoulder buttons should be CNC Milled. This would require a CNC Milling Machine per part, or perhaps more, and an operator per machine to load and unload the Blanks. This would be a much faster method of manufacture, with a surround and two buttons produced in around 5 minutes. The operator would push the parts onto a conveyor where they would head for finishing, then assembly. The brass directional buttons would be loaded in a CNC Lathe, where they would be cut, polished and sent straight to assembly.

Laser Cutting

The laser cutting process would be almost identical to the techniques I employed in my manufacturing process. However, the machines used would be much faster, taking seconds to cut each piece, rather than minutes. The HIPS and Acrylic would both be cut on one machine, before being sent straight to assembly, as the Laser Cutting process leaves a very clean cut on plastics.

Electronics Assembly
The Electronics would be very different were this project mass manufactured - all of the components would be soldered by machine onto a single board which would be optimised to reduce the vertical space taken by the electronics, reducing the thickness of the system. This would be done on a conveyor system without direct human involvement for safety reasons, the process would however be moderated for quality at the end, in the event of a machine malfunctioning.

Injection Moulding
The lid of the device was made from multiple layers of laser-cut acrylic glued together This was difficult to manufacture as the acrylic was difficult to align exactly. The Lid could be made from Injection Molded ABS, a plastic which can be melted and recast and is often used in 3D Printing. LEGO Bricks are made by Injection Molding ABS [19], and the lid could be manufactured in the same way. This can, however leave **sprues** and other unwanted features which must be removed.

Punching
The Aluminium Backing could either be produced by laser cutting sheet aluminium, or punching out lid shapes using a punch and die. The punch and die would be more expensive to set up, but would take up much less room, and would be much cheaper in the long run [20]. The punched pieces would be sent for finishing and then assembly.

Finishing
All of the machined parts would be sent to be finished in order to protect them from wear and tear. The wood would be treated with a water-based polyurethane varnish, as my console was, and the metal parts would all be polished in a vibratory tumbling polisher, a machine that vibrates metal parts in a drum for a length of time to polish them [21]. The sheet metal would not need polishing, but may need to be **deburred**. This could be achieved with a team of workers manually removing the burrs with tools, or perhaps with an electrochemical solution which would dissolve the burr away [22]

Material Recycling
The machining process will produce waste material, such as wood shavings, Aluminium offcuts, Brass swarf, and waste plastic sheet. Wood shavings can be recycled to produce particleboard or MDF, or even used as animal bedding. It cannot however be reused within the manufacturing process and so would likely be sold as a waste product.

The Aluminium and Brass would most likely be sold back to the supplier at a lower price in order to recoup some of the costs of buying the raw materials. The scraps would be melted down and recast into sheet and rod stock.

The acrylic plastic sheets would also have to be sold to a plastic recycling firm as it is difficult to recycle. It is possible but requires much equipment and as such on-site recycling would not be cost efficient. This also applies to the HIPS sheeting. [23]

The only media that could be recycled on-site would be the ABS offcuts: The injection moulding procedure can leave sprues and other unwanted features that need to be removed. These can simply be put back into the machine and melted back down, which reduces the waste material to essentially none.

Final Assembly

The finished parts would be put onto separate conveyors and sent through a building, with a station for each stage of machining. The assembly would be split into the following steps:

1. Acrylic installation
2. HIPS Insertion
3. Shoulder button installation
4. Electronics Installation
5. Lid fitting
6. Button mounting
7. Testing

Each process would have a station, where a team of workers would receive the product from a previous step on one conveyor, and the parts required on their step on another, before the finished parts would be put onto an outbound conveyor which would head to the next step. Each step is very simple, The pieces need only to be placed into the correct position, however due to their shape, using humans to achieve this is much more useful.

Not all the units would be tested, perhaps 0.5 - 2% of units, as testing every unit would be impractical.

Printing and Packaging

The finished units would be sent to the packaging department, where they would be placed into open-cell die-cut urethane foam, which would protect the device in the box [24, 2:00]. This, along with a printed user manual and accessories, would be placed into a printed box which would most likely be ordered from a specialist firm.

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2. Design Specification
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Glossary

Analogue or **Composite** video is an old, but common video standard, commonly associated with a Yellow RCA cable. It can be found on almost all TVs, and in this case, was cheaper than the digital alternatives. It is lower quality than digital video, and as such is limited in its resolution, but this is not an issue with the games this device is designed to run.

Band-saws cut straight lines and curves in materials that are relatively soft, almost all plastics, and metals up to mild steel in hardness. They consist of two pulleys and a continuous blade that loops over these pulleys. This allows the blade to constantly cut, rather than having to oscillate like a regular saw would.

Battery Protection Circuits are circuits that manage how a battery is used and charged. They ensure that the battery isn't overcharged or over discharged and they regulate the current flow out of the battery. These are essential to use these batteries safely.

Belt Sanders are machines which have a large abrasive belt which can be used for removing material quickly. They leave a poor surface finish and can warp material due to heat, but this can be mitigated by cooling the workpiece.

Boost Converters are a type of circuit which increase a DC voltage, essentially like a DC transformer. I needed one as the screen required twelve volts (it was designed as a car rearview monitor, and as such was designed to run off a car battery, which delivers 12v). The **LiPo Battery** I was using, however, only outputs 3.7v.

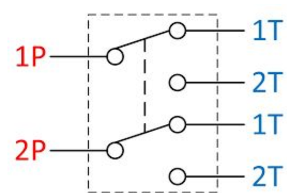
Boring Bars are steel cutters for use in a **Lathe** that can cut internal radii - they can make the hole in a pipe wider, essentially, to describe its simplest use.

CAD, or Computer Aided Design programs are programs that allow designs to be drawn on a machine, to an high degree of accuracy, and they can be easily modified and edited, and can often be outputted as data for computer-controlled (CNC) machines or laser cutters to use.
The **C.H.I.P.** is a $9 computer that I was going to use for this project. It has more features than the Raspberry Pi, but lacks power, and manufacturing issues caused delays which caused me to switch. Read more at getchip.com

CNC Routers are tools that are similar to the aforementioned milling machines: they have a small drill like cutter that can cut grooves in materials. However, these tools have much much less power, they can cut plastics and wood, with higher-end models able to cut aluminium. The cutting bit is also moved by motors which are controlled by a computer. This way, the machine gives reproducible results, and means the operator is able to work on other parts while the machine cuts.

Deburring is the process through which sharp edges (burrs) are removed from a piece.

DPDT switches are a special type of switch, composed of 6 electrically isolated contacts, which are connected in pairs to the central pair.



Drill presses are similar to drills in that a sharp cutter spins and is pushed into material to create a hole, but they only cut straight down. They cut with a lot of force.

Emulators are programs designed to run games from another system. Not only do they run games, but they programatically mimic the hardware of the machine and then run the game on the virtual copy of the console. They are very complex and as such, they really only exist for consoles up to around 2000, after which most consoles are too complex to emulate with current technology.

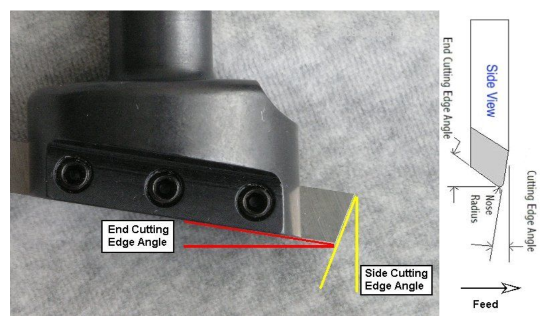
Endmills are steel cutters that are like drills but designed for the **Milling Machine**. They can be used to cut grooves or widen holes. They cannot drill holes as the entire bottom face is not a cutter, there is a small area that is left unsharpened for structural reasons. Combined with a drill to start the hole, they can be used to drill flat bottomed holes.

Files are steel bars which have many small teeth cut into them. They are very hard, and are used to remove material. Imagine a nail file, but bigger.

Feed rate is the speed and pressure at which a cutting tool is pushed into the work it is cutting. It should be proportional to turning speed.

A **Flush Trim Router Bit** is a cutting tool for a **woodworking router** that trims a surface to be flush(smooth) with another reference surface

Fly cutters are milling machine tools that hold a sharp knife like cutter and spin it in a circle, and can be used to cut circles of variable size. The further out the knife is held, the larger the circle cut. They can also cut surfaces flat by moving the cutter along them.



GPIO pins are used when creating circuits to interface with the circuit board. Essentially, the computer monitors the voltage on each of these pins, and when it detects a change, it does an action depending on what has changed. For example, when a button is pressed, the voltage on a pin will be 0 volts, and the computer will register this and tell the game that the specific button has been pressed.

Hacksaws are saws specialised for cutting metals, they are usually around 30cm long but 10cm “junior” hacksaws can be used for intricate work.

Headers are stiff wires sticking out of a circuit board, often used to interface with **GPIO** pins. You solder wires to the headers to interface with the GPIO pins.

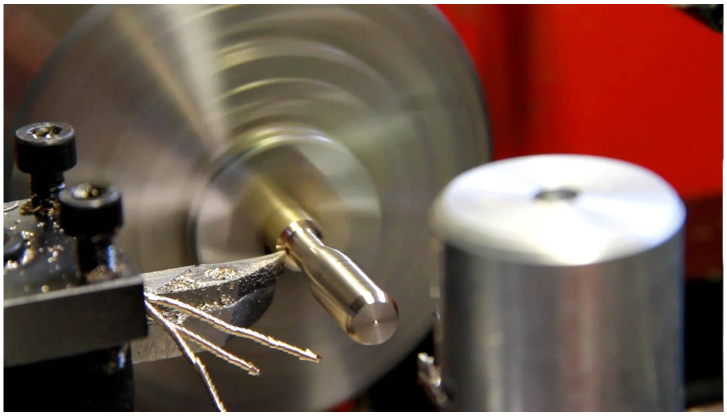
Hex Bar is the name for a rod which has a hexagonal profile. It usually refers to pieces of metal that are longer than they are wide. I used Brass Hex Rod for the Buttons of the controller.

HIPS, an acronym for High-Impact Polystyrene is a cheap **thermosoftening** plastic that is used widely in toys and signs. It can be **Laser Cut** or **Vacuum Formed.** I used HIPS for the black plastic layer that hid the electronics

Iterative Improvement is the process of reaching an optimum solution by progressively improving upon an initial approximation. For example, Polishing, wherein a surface is scratched with progressively finer scratches to the point where the scratches are no longer visible.

Laser Cutters are machines that use a high powered laser to cut material by burning/melting through it. They have a flat late on which material is places, and a laser "head" which moved to cut the path given by the data from the **CAD** package

Lathes are large machines cut shapes in spinning material, almost like a Potter's Wheel but rotated 90 degrees. They can machine almost all materials including High Carbon Steel, which is very hard and difficult to machine.



LCD Screens are the most common type of screen, they are composed of a white backlight, which passes through a colour filter, and a **L**iquid **C**rystal layer which blocks light where appropriate to form the image.

Lithium Polymer, or LiPo Batteries are a type of rechargeable battery, most commonly used in phones, but widespread in all wireless technology. They require **Battery Protection circuits** because if they are overcharged, over discharged, or if too much current is drawn then they can be damaged. In extreme cases they can explode and catch fire, as demonstrated by the infamous Samsung Galaxy Note 7.

Losing the Origin is an error where the entire design to be cut by a machine slips, as the machine “forgets” where the design is compared to the material to cut it from. This happens as the lower left corner, or the origin, moves and is “lost”.

Milling machines are like drill presses, however the work is attached to a bed and can move in the X and Y planes, and so paths can be cut in the material with a drill-like cutter

Operating Systems, or OS’s are complex programs which regulate the running of a computer, simplifying greatly. Windows, OS X, Android, and iOS are common examples. The OS I used was called Recalbox and is designed for running Game **Emulators**

Plywood is a manufactured type of wood which is made by gluing together thin layers of real wood at 90 degrees to each other for stability. It is cheap and can be laser cut

Power supplies, or more accurately, Voltage Regulators, are small circuits which make sure the sensitive components of a circuit board receive exactly the correct voltage to function correctly. For example my battery voltage varied from 4.2 to 3.6 volts, depending on charge, but the Voltage regulator ensures the CPU always receives a constant 3.3 volts.

Power Management Chips are circuits which regulate power, they can contain multiple voltage regulators, they may charge batteries, and they may monitor charge levels and shut down electronics in order to prevent damage to the circuit. The **C.H.I.P.** had all of these features, which is why I initially considered it the better choice.

The **Raspberry Pi Zero**, which I refer to as the **Pi** in this document, is a £4 computer. While faster and more versatile than the **C.H.I.P.** it requires more accessories and circuitry to perform the tasks I need it to.

Seizing occurs when a spinning cutter or workpiece stops spinning due to a significant **Torque** acting in the direction opposite to the direction of motion. This is most often seen when a car stalls, the resistance to motion opposes the direction of rotation of the engine.

Shorting, or short circuit, occurs when two wires are conducted when they should not be, this can in the best case mean that a component does not receive power, but in the worst care can damage components or even cause batteries to fail and ignite

A **Sprue** is a leftover piece of material from a casting process, they are usually unwanted and are cut off.

Thermosoftening plastics are plastics that become flexible and moldable when heated, and will set hard when they cool, similar to how glass behaves, though at a much lower temperature
Threads are the spirals that you have on screws and nuts, there are external and internal threads, which both fit into each other and let a fastener grip into an object very tightly.

Tinsnips are essentially metalworking scissors. They can cut through thin sheet metal (up to around 2mm in thickness). I used them when prototyping the lid for the console.

Torque is the term for "rotational force", as it were. It is the force that causes an object to turn, for example, you apply a torque on a nut when you undo it with a wrench.

A **Woodworking Router** is a tool used to cut grooves in wood, it is composed of a flat "bed" from which a rotating cutting bit protrudes. It can be used to cut structural or decorative grooves. I used it to thin the retaining lip of my surround.

Vacuum Formers are machines that form a rigid plastic over a solid mold by heating it until it is soft and sucking the air out, causing it to follow the profile of the mold. HIPS is the only plastic I could use with this process in school.