Mana Tohu Mātauranga o Aotearoa
New Zealand Qualifications Authority

Level 3 Technology 2024

91612 Demonstrate understanding of how technological modelling supports technological development and implementation

EXEMPLAR

Achievement

TOTAL 04

91612 Technological Modelling
For my robotics project this year, I worked with my school chess club to develop a chess-playing robotic arm. Because we train using chess computers, we spend hours playing and training chess on the computer. This is bad for our health looking at the computer for too long, and we lose the social connection of the club that would come with standard physical play. The stakeholders of my robot were five members of the chess club, as well as the chess club teacher, who were all interested in the development of the arm.

To ensure that my robotic arm is fit for purpose, technological modelling was important throughout its development.
Technological modelling can be divided into two stages: functional modelling and prototyping. My definitions are as follows:

1. Functional modelling – This is where the feasibility and practicality of design ideas are tested, to learn about whether they should be further developed.
2. Prototyping – This is where the model is tested in the intended social and physical environment to discover implications with the implementation of the robot.

Breaking the outcome down into competing and contestable factors was key to better analyse and improve the robotic arm.
Competing factors – these are factors in conflict with others, so I have to make tradeoffs:

- Time: The robot should be finished by the end of term 3 so the members can use it in term 4. This prevents me from iterating and improving indefinitely, so I have to use my development time wisely.
- Cost: More money can buy more powerful components, such as higher torque servos and a bigger battery pack. However, I have a budget of $75, so I need to choose components that have the most value in my robotic arm.
- Number of joints: More joints may make the robot more flexible giving the user more control, however needs more servos (and a more powerful battery to accommodate the servos) competing with the size and cost.
- Portability: The robot would need to be moved around a lot between chess games, so it is important I make an informed tradeoff. A more portable robot is easier to carry around, however there will be less space for components and have a less balanced structure.

Contestable factors – these factors I have to make a judgement on:

- Stakeholders' wants: I cannot meet everyone's wants in the arm, so I would have to make a judgement on how the robotic arm should interact with its social environment, such as the functionalities of the robot.
- Gripper: I need to design a gripper that to pick up and place pieces well, and also be safe and aesthetic. Since different gripper designs don't have tradeoffs with other factors, this is not a competing factor and is instead a contestable factor.
- Interface: There are many decisions to be made, for example some people prefer a minimal and aesthetic interface while others prefer more complex interfaces with more control. I need to make a judgement on the design and functionalities of the interface so that it is usable for all end users, and since different interfaces decisions don't affect other factors, this is a contestable factor instead of competing.
- Sustainability: This is a judgement on how important future-proofing is for my robotic arm. For example, if I value it highly, I might make it easier to disassemble or change the code on my robotic arm.

Functional modelling – Researching ideas and discussing with stakeholders

[redacted]

I always start with researching and brainstorming as it gives me a broad overview of possible design ideas. Discussing ideas with stakeholders allow for fast and responsive evaluation on the spot. I started by researching ideas on the website [redacted] as authors often provide comments about their tech experience that I can learn from. One competing factor I tested was the number of joints on each leg, and I saw that it commonly ranged from 2 to 6. The issue with two joints is that the robot is only able to move in two-dimensions, which will not meet the required functionality as it will not allow moving chess pieces across the board. The issue with five or six joints is that not only will the servos cost more themselves, it also requires a larger battery pack and chassis further increasing the cost. I learnt this from [redacted] on [redacted] which commented that his 5 joint design cost $75 USD, compared to $40 for smaller four joint designs and from videos of 5+ joint designs I did not notice any worthwhile increase in functionality compared to four joint designs for my robot.

[redacted]

Figure 1: [redacted] design has 5 joints, competing with cost and portability as he needs more input buttons, two Arduinos instead of the usual one to wire everything, and a large power supply.

The trade-offs between three and four servos were interesting – from the videos on [redacted] four servos allowed for much more flexible movement and thus more easy-to-use, however didn't affect where the gripper could be positioned. Three servos designs, on the other hand, will be about $10 cheaper. To resolve this, I discussed this decision with two stakeholders. Both of them commented that they are willing to invest more money in order to get better control over the robot. We went back and forth on how the robot would pick up pieces, and saw that sometimes the robot would need to make complex movements like picking up a piece carefully without knocking over neighboring pieces. We concluded that four servos would provide a far better experience for ensuring that the pieces are picked up and placed where the user expected it to be. Speaking with the users themselves ensured that I further developed ideas that the end users truly want.

Functional modelling – testing with 2D modelling

There were many requirements and constraints of the base of the arm, so I undertook 2D modelling to effectively synthesise these. I chose AutoCAD to do 2D modelling (instead of, say, sketching) as it defines shapes through relationships and properties (e.g. length, coincidence, tangency). When I change one property/relationship the whole design will update to accommodate it. This allowed for responsive decision-making as it is quick and easy to modify specific properties of the model. One constraint that I realized after some discussion with my club members was that the footprint of the robot must be small enough to fit on a school desk that already has a chessboard on it, which measured to about 50 cm long but just 14 cm inwards. So, I simply decreased the width to 8 cm. Then, after some further measurements of the [redacted] I discovered that I needed an extra inch of clearance to accommodate the cable, so I increased the width to 10 cm.

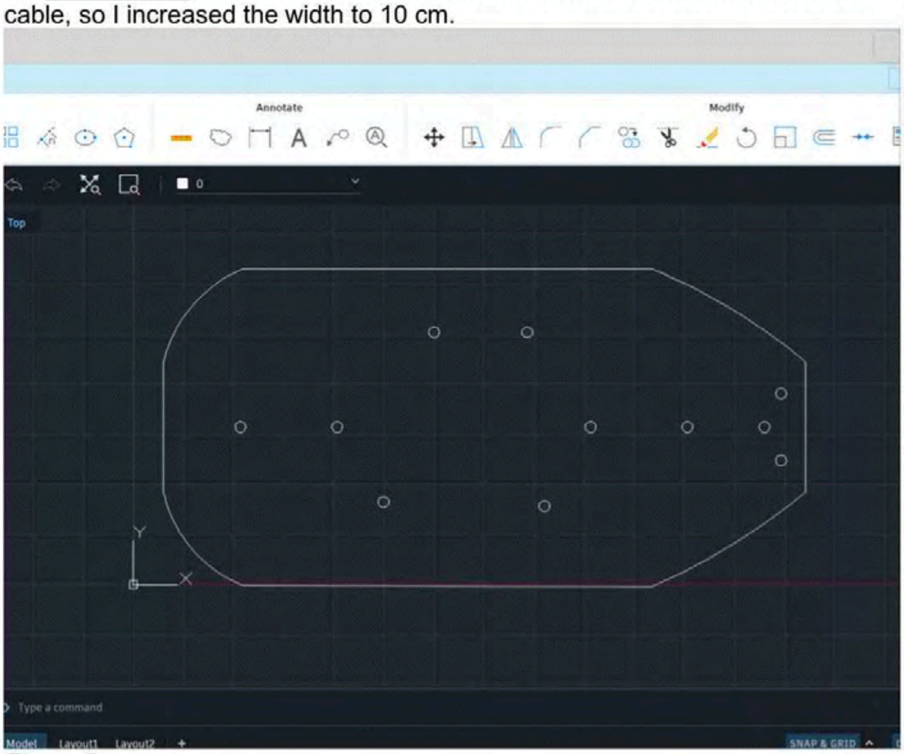


Figure 2

[redacted]

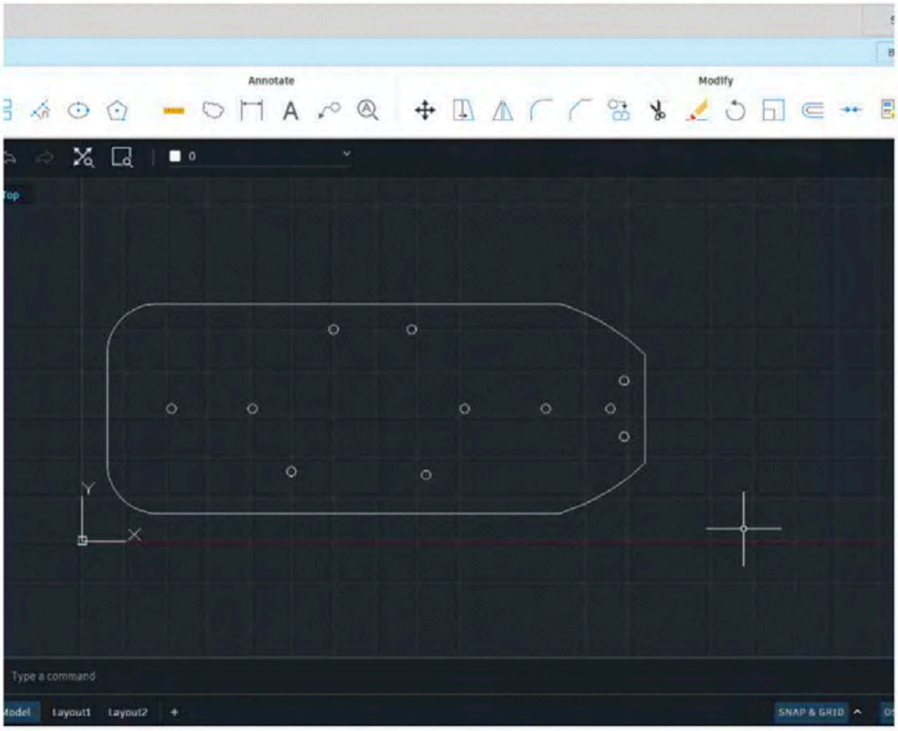


Figure 3 – These two images show responsive modelling as changing one variable (the width) updates the whole model accordingly, allowing me to quickly see the feasibility of new decisions.

2D modelling in [redacted] allowed me to adapt to new information to best optimize competing factors, as I had to choose a size large enough that will comfortably fit all the components, while making a good trade-off with portability as school desks can be quite small.

Functional modelling – testing and trialling with 3D modelling
An important contestable factor was the gripper, which needed to be safe, functional, reliable (i.e., strong grip), and aesthetic. This was modelled in a 3D CAD website called [redacted]. I undertook trialling by creating three drastically different models, and then simulating the gripper models using [redacted] assembly features to gain evidence on the functionality and reliability of each trial. I found that the claw design was quite difficult to get a good clasp on round chess pieces, such as the pawn. The round design worked well with round pieces due to the groove where the pieces sat in, however struggles with the flat chess knight; the flat gripper was the opposite, contacting the knight well but not the round chess pawn.

[redacted]

Figure 4: This is an image of be 3D modelling and simulating the claw grippers. I saw that the contact between the gripper and the chess pawn was small, making the pawn easy to slip out.

Thanks to trialling, I was able to test a wide range of design ideas instead of being tunnel-visioned into one, giving me a better view on the gripper that best meets the requirements of the end user: I synthesized these observations to create a flat design but added a central groove for better contact.

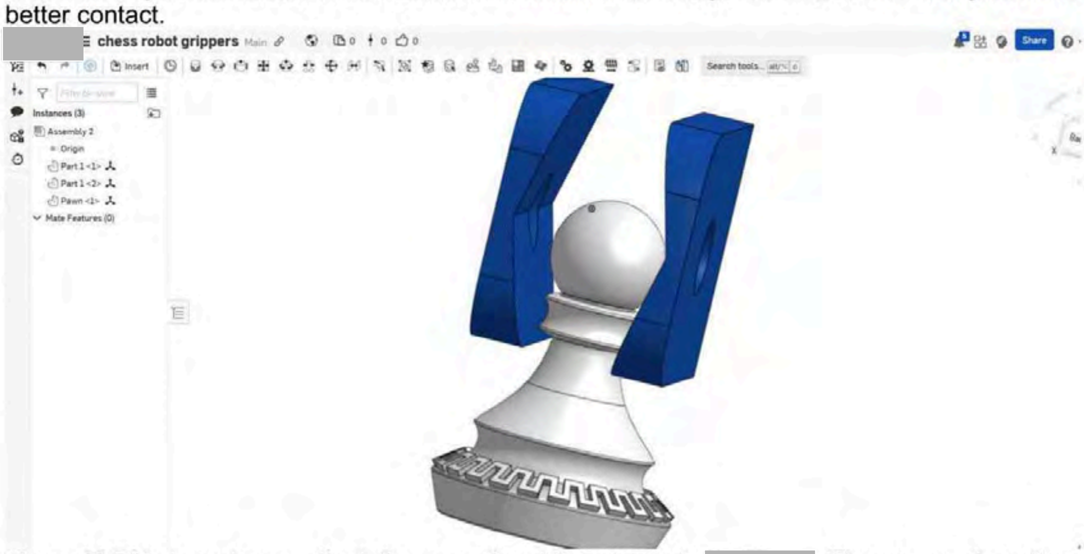


Figure 5: This is an image simulating my refined flat gripper in [redacted] *The groove along the surface makes the surface better contact all chess pieces such as this pawn. This makes the piece harder to slip out.*

I reflect that 3D modelling spotted issues in the grippers early before I waste time 3D printing poor designs for further development.

Functional modelling – testing the electronic circuit, with discussion with specialists.

[redacted]

I discussed with my physics teacher about the circuit of my robotic arm. I undertook this discussion before testing my circuits physically because there is a cost risk if I damage components, especially if the component in question is an [redacted] or a servo. A new piece of knowledge I learnt was that new AA batteries will drop from 1.5V to around 1.2V after some use.

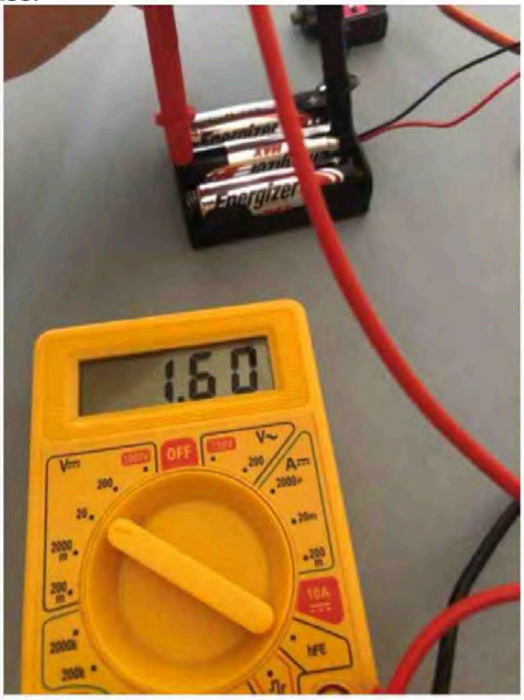


Figure 6

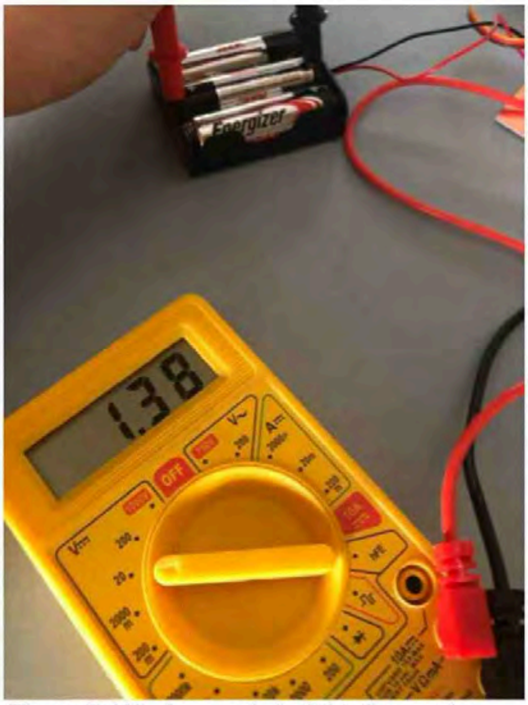


Figure 7: We demonstrated this happening using a multimeter to read the voltage on new vs used batteries, and saw a drop in voltage for the used ones.

Previously my circuit used 3 AA batteries in series (1.5*3=4.5V total) as I knew that the voltage required for a micro servo to function properly is between 4.5V and 6.0V. I had tried to minimize the number of batteries in order to lower the cost and waste (batteries are difficult to recycle) from my robotic arm. Thanks to her advice, to ensure the components functioned reliably over time, I made the decision to use 4 batteries so the supply voltage will be at 4.8V after long-term use. Having a mentor made my decision-making far more responsive, as if I hadn't learnt this, I would probably only find out after hours of testing the robot physically until servos began to jitter due to not having enough voltage across it. Looking back, I reflect that by discussing with a specialist, my physics teacher, I have better optimized competing factors as though it now costs slightly more and is more wasteful (batteries are difficult to recycle), the functionality trade-off is worth it to ensure that I don't waste time developing circuits that would not work reliably.

Prototyping - Testing and trialling in situ

Most of my prototyping was testing and trialling in situ, meaning I used it on a school desk, with a school chess set and gave a club member to control the robot. I first tested the gripper, a contestable factor, and one issue I discovered was when the gripper was closing, often the piece simply tipped over. Testing in situ was key to discovering this issue, as the school chess sets were lighter and smaller than a standard set so it would have more chance of tipping. The next week, I returned with three solutions to trial: attaching a rubber band to prevent wobbling, increasing the notch of the gripper, and increase the closing speed of the gripper. By explicitly trialling (instead of testing just one and choosing it if it's good enough), I was able to learn a lot about the gripper by comparing information gained across the trials: Adding the rubber band prevented wobbling which effectively solved the problem, however I also learnt that increasing the closing speed made the minor improvement that the pieces had less time being pushed by the gripper, leading to being more centred. Making the decision to add both these solutions to the arm made the movement of the pieces much more controlled, so the user could pick up and place pieces without getting frustrated on wonky movement, thus giving a stronger case for the implementation of the robotic arm in our chess club environment.

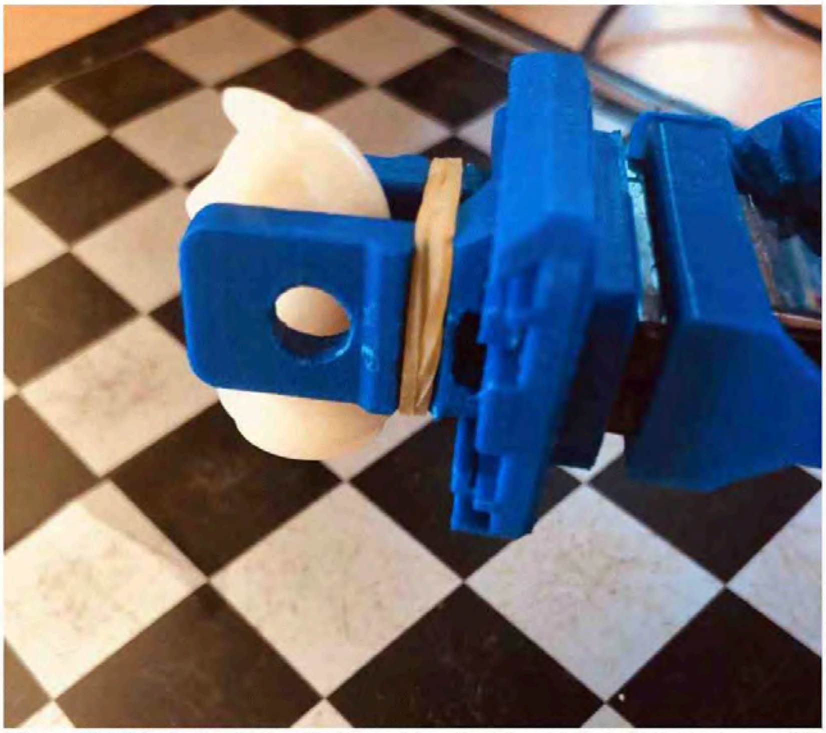


Figure 8: This is the trial with the rubber band, which definitely clasped the knight a lot better than without the band which is shown in the image below.

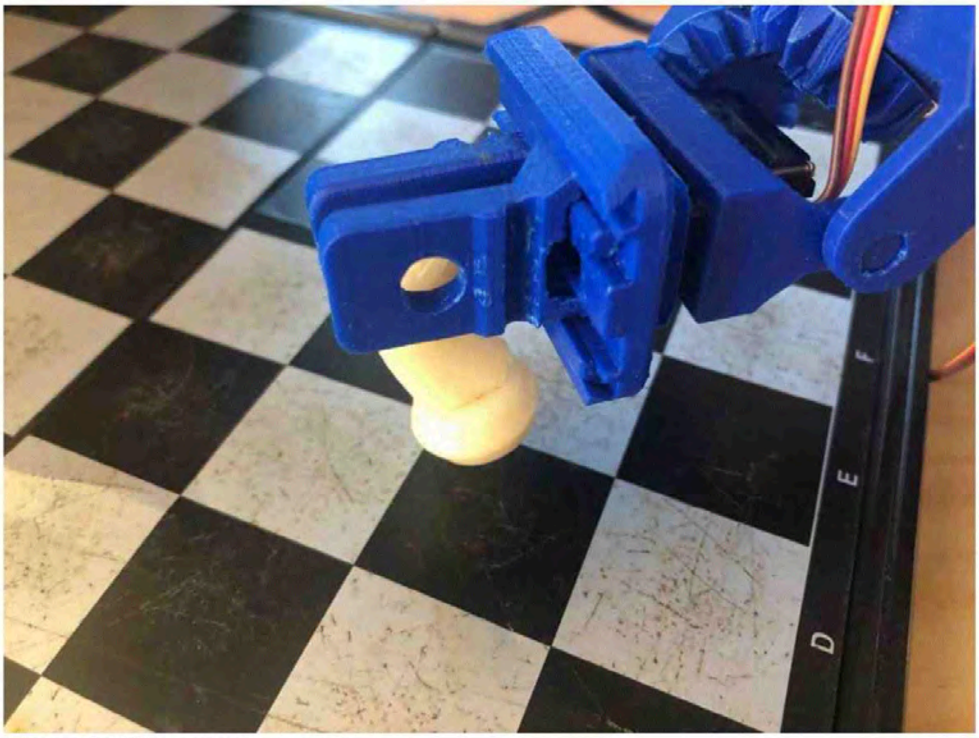


Figure 9: Without rubber band

Another issue that I discovered was when a club member quickly dragged the slider from one side to another, and the arm quickly spun from one side to the other which was a great hazard. In situ testing was key to finding this problem, as I, being the developer, already developed the muscle memory to slowly drag the slider from one side to the other. Actual end users, especially new ones, do not have this knowledge. The great thing about testing directly with the end users was that I could make a change then and there and get immediate and responsive feedback. I first limited the maximum speed of the robot's rotation, gave it to a club member, who commented “the limited speed feels like it's lagging”. To solve this, I replaced the slider with a joystick so the visual interface represented speed rather than position.

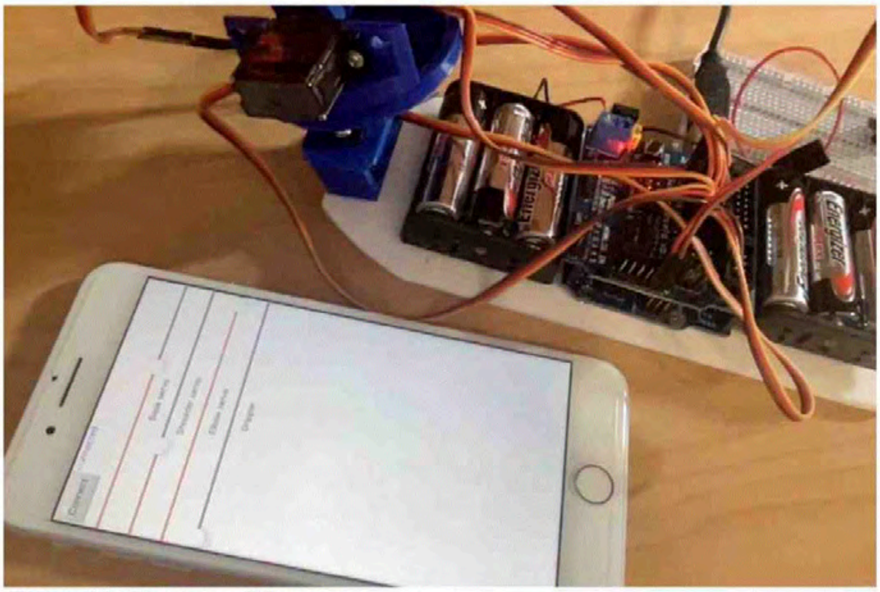


Figure 10: Previous slider app

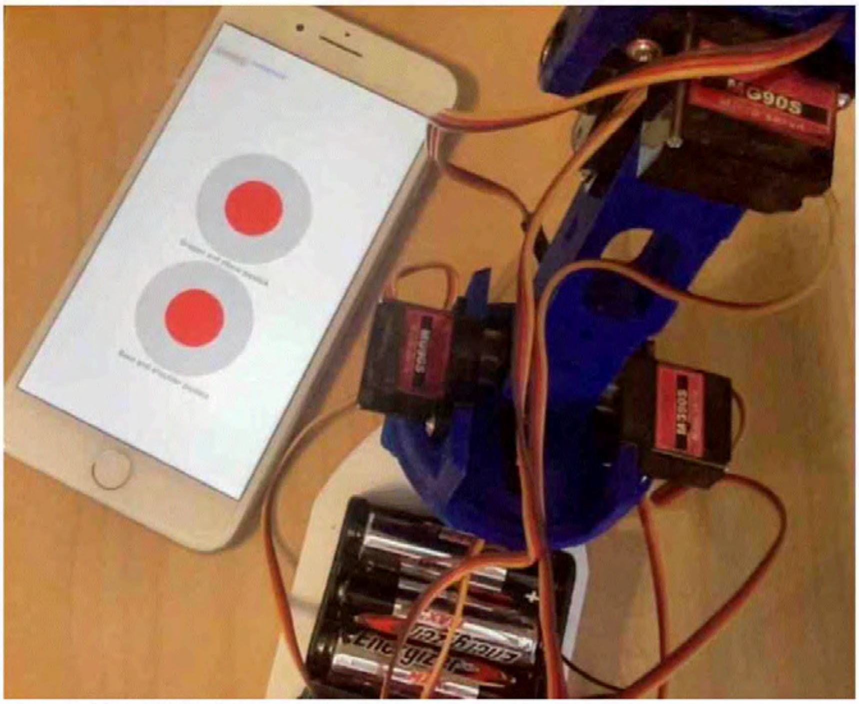
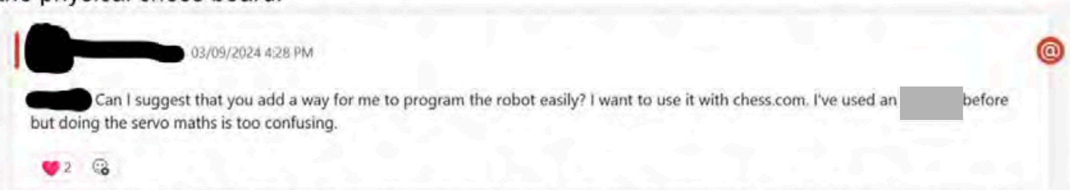


Figure 11: Modified to a joystick app

[redacted]

Both club members I talked to found the new interface easy-to-use and they felt like that they were in control of the robot. These positive comments justified this decision to use a joystick, thus prototyping has helped me make a judgement on the contestable factor of the interface. Having real end users enjoying the robot in the intended environment meant I could better defend the implementation of my robotic arm in my chess club.

Prototyping – Thinking and discussion with stakeholders
It was key that discussing with stakeholders continues into the prototyping stage as they get a better idea of their requirements. This is because can base their comments on the physical prototype model rather than ideas and digital models alone. After playing with the current app, one of the club members messaged me. He told me that he was an avid programmer and, in the future, he would love to create custom software beyond what was needed right now, such as integration with online chess (e.g. with sites like chess.com) that would update automatically on the physical chess board.



In our next chess club meeting, we went back and forth discussing that if the end users can create custom interfaces to the robot, then end users could design apps that create customized experiences in the future. I learnt that future-proofing, a contestable factor, should be highly valued. I hence made the decision to create a document that contained easy-to-understand instructions on how end users themselves can program the robot, and in the [redacted] code, I created a range of functions that the programmer can use. To ensure that the functions I chose would be most useful to the future programmer, I discussed with different club members what they would add to the chess robot. Many wanted to play online chess, and some wanted integration with other chess software, so I created a function that allowed the user to input a move that would update on the board, allowing for easy integration with any sort of website. Both these discussions had allowed me to pinpoint the exact needs of the end user (i.e., online chess integration). This led to the decision to add instructions to modify the robotic arm which ensures that it would be fit for purpose in its implementation even in the future.

In conclusion, technological modelling has been essential to ensure that my robotic arm is developed and implemented successfully and in a way that best meets the requirements the chess club members. In Term 4, I gave the chess club my robot which went smoothly thanks to technologically modelling, especially in situ prototyping. The chess club members where very satisfied with the outcome and found it fun, easy-to-use and met their needs. I found the experience building the robot enjoyable and learnt a lot about robotics (batteries, servos and Arduino code) and how to discuss ideas with stakeholders and end users throughout development. The development of this robot helped me develop my modelling skills which I would use in future projects, whether that is in robotics or other technology fields.

Achievement

Subject: Technology

Standard: 91612

Total score: 04

Q	Grade score	Marker commentary
One	A4	The candidate has correctly defined and differentiated between functional modelling and prototyping. The competing and contestable factors were identified and briefly explained. The candidate explained how different modelling stages were used to test competing and contestable factors as well how prototyping was used to inform decisions for implementation of their technological outcome. The use of photographs should have been kept minimal and only used relevant images.