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A Microworld to Explore Controlling the National Carbon Footprint

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of the requirements for the degree of

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Declaration

I, the undersigned, declare that this work has not previously been submitted as an exercise for a degree at this, or any other University, and that unless otherwise stated, is my own work.

Sarah Dolan

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Abstract

Climate Change is one of the greatest challenges facing the world at present. It is caused by the release of greenhouse gases, such as carbon dioxide and methane, into the atmosphere, which traps heat causing the Earth's temperature to rise. This leads to a variety of negative effects, including the rise of sea levels, severe weather events and changes in the patterns and amount of precipitation. These changes can have devastating consequences for human societies and natural ecosystems, including flooding, drought, and the extinction of plant and animal species.

The Carbon Footprint is a measure of the amount of greenhouse gases produced. The unit used is carbon dioxide equivalents. Currently, Ireland has a Carbon Footprint of 61 million tonnes. This is approximately 50% higher than the EU (European Union) average per capita. As per the Paris Agreement, Ireland has agreed to the 2030 goal of a 51% reduction in the National Carbon Footprint.

Our carbon footprint is of relevance to young people as they are the future leaders and decision-makers who will inherit the consequences of our actions today. Through education, we can empower them to make informed decisions and take action to mitigate the impacts of Climate Change. An array of techniques are used to educate this demographic on the complexities and importance of the factors at play. These vary from visualisations and calculators to simulators and games. More important than the technology used, is the underlying approach to teaching and learning which varies from direct instruction to problem-solving.

The tool described in this report is aimed for use in a university outreach program – Bridge2College (B2C) – aimed at 15-17-year-old secondary school students. The B2C workshops follow constructivist and constructionist pedagogical approaches (Kevin Sullivan, 2021). Microworlds align well with such pedagogical approaches so the report details the design, implementation, and evaluation of the efficiency of a Microworld tool that can be used to investigate the key concepts and factors involved in controlling Ireland's carbon footprint.

The software is designed to serve as a low-fidelity simulation, with the goal of highlighting the essential issues involved in the government's decision-making processes surrounding mitigation techniques to lower the Carbon Footprint of Ireland. The tool allows users to make decisions and witness the effects of these decisions, over time, on Ireland's Carbon Footprint. The Microworld is challenge-based setting out two key challenges to stimulate the learner and illustrate the essential dynamics and trade-offs involved in reducing Ireland's Carbon Footprint.

The principal technical challenges encountered during the tool's development are discussed, as well as how these challenges were overcome and how this influenced the Microworld design.

The efficiency of the tool was tested following the B2C workshop by a cohort of (N=23) students. A survey was performed to assess the tool's usability and effectiveness from a pedagogical perspective. The aim of the survey was to see how effectively the students responded to active participation in their learning. The quantitative and qualitative feedback indicated that it was successful in its main aim of developing a Microworld with pedagogical and constructionist characteristics to enhance the learner's understanding of how to control the national carbon footprint. Although designed with B2C in mind, the tool should be useable in any Transition Year setting which uses a similar pedagogical approach.

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1 Introduction

Climate Change is one of the greatest challenges we face today (Clarkson, 2018). The long-term shifts in temperatures and weather patterns we are experiencing are primarily the result of human activity, particularly the use of fossil fuels and deforestation, both of which emit large amounts of greenhouse gases into the atmosphere (IPCC, 2001b). Greenhouse gases absorb thermal radiation emitted from the Earth's surface, acting as a "blanket" to keep the planet warm (Houghton, 2004). The release of these gases contributes to global warming.

The effects of global warming can be measured on a social, economic, and environmental scale, including rising of sea levels, floodings which can lead to homelessness, droughts, extinction of species and impacts on agriculture and human health (IPCC, 2014). Not only does this effect society, but it specifically effects young people aged 15-17 years of age, as this demographic are the next generation of decision-makers who will inherit the planet and face the consequences of our actions towards the environment.

The future of Climate Change is a multifaceted issue that has been extensively studied by the scientific community. Society plays an important role in the future of Climate Change as a variety of factors are reliant on society's willingness to act, including the extent to which greenhouse gas emissions and the global carbon footprint are reduced, and how efficiently and successfully adaptation and mitigation measures can be established. Education and the exploration of how to control Climate Change and Carbon Footprint can play a critical role in addressing the problems by raising awareness, promoting sustainable practices, empowering individuals to take action, and fostering innovation and technology development. The Microworld tool this author has designed aims to show the next generation the positive consequences of their actions in the simulation and hopefully foster an understanding in future societies.

Carbon footprint is the measure of the impact that human activities have on the environment in terms of the number of greenhouse gases produced, measured in units of carbon dioxide equivalents (CO2EQ). Carbon Footprint is one of the important indexes to evaluate the sustainable development of society and most countries are trying to reduce their Carbon Footprint as part of their efforts to combat Climate Change (Minx, 2008). Therefore, Carbon Footprint was an obvious candidate for this Microworld as it is a vital indicator whilst simultaneously mitigatable.

On both a personal and societal level, Carbon Footprints and Carbon Budgets are frequently covered in the media, although it is unclear to what extent people are cognisant of the trade-offs involved. As of 2021, according to the Irish Environmental Protection Agency, Ireland has a Carbon Footprint of 61.53 million tonnes of CO2EQ (EPA, 2021). Furthermore, as of 2015, Ireland has the third highest emissions of Carbon Footprint per capita in Europe at 13.2 tonnes of CO2eq per capita. As Ireland faces challenges to address the issue of a high Carbon Footprint and emissions, mitigation strategies such as promoting renewable energy sources and improving energy efficiency are crucial.

Mitigation refers to the act of reducing or minimizing the negative impacts of any particular issue. In terms of Climate Change and carbon footprint modelling, the UN Intergovernmental Panel on Climate Change (IPCC) defines mitigation as "a human intervention to reduce the sources or enhance the sinks of greenhouse gases" (IPCC, 2014). For the purposes of this project, mitigation involves implementing strategies to prevent or minimize potential harm caused by Climate Change. This consists of reducing emissions from industry and transportation, improving energy efficiency, and promoting renewable energy sources. Mitigation techniques used when referring to Climate Change and controlling the National Carbon Footprint can include the use of solar panels, wind turbines, hydropower, tree planting and nuclear power, all of which will be discussed at length. When implemented properly, these techniques have the potential to decrease Ireland's Carbon Footprint which is crucial considering Ireland’s current CO2EQ.

1.1 Project Goal

It is imperative that young people understand the complexity of controlling the National Carbon Footprint. Some factors to consider include cost, land mass, and time. These constraints are of relevance to young people, and therefore this project as they are the future leaders and decision-makers who will have to make realistic choices to combat the effect of our actions today. By educating young people through a constructionist approach, we can empower them to make informed decisions and take action to mitigate the impacts of Climate Change. By gaining awareness of the National Carbon Footprint and the 2030 goal, young people can become more environmentally conscious and become advocates for sustainable practices in their communities pushing for change on a larger scale. In addition to this, using a Microworld will show young people the consequences of their decisions, developing important skills such as decision-making, critical thinking and problem-solving.

The primary goal of the project is to provide Transition Year students with an interesting learning environment to investigate and gain an understanding of different methods the government can implement when controlling the National Carbon Footprint by utilizing computer science data visualization methodologies and technologies. The project will help students to investigate the trade-offs involved in the decision-making process when it comes to controlling the National Carbon Footprint.

The project will also be guided by practices from Human-Computer Interaction (HCI). Studies show technological advancements have had a profound impact on human behaviour (Bristol, 2002). It is evident that these advancements have also revolutionised the way in which we educate. Computer-Based Learning Environments (CBLEs) are being increasingly utilized in classrooms to facilitate the learning of complex subject matters (Azevedo, 2005). This project employs a Microworld to enable learners to explore, navigate, and test embedded concepts and ideas about real-world processes (Hoyles, 2002).

An effective Microworld must allow users to explore how to control the National Carbon Footprint is controlled in order to develop an understanding of the complex factors at play. A key goal for this project was to create a microworld where students could instantly see the consequences of their actions in a simulated environment in the hopes that it would inform their ideas throughout their lives. In order to achieve such a goal a basic comprehension of mitigation techniques and an understanding of the 2030 goal detailed in section 2 is required.

A cohort of students in the B2C Transition Year program will interact with the Microworld and should regard it as an educational and enjoyable experience. The tool should be suitable for any educational setting that employs a similar teaching environment. The tool's design should strive to combine compelling visual stimulation and a high level of user interaction to create an experience that engages the learner both visually and cognitively.

The tool is a Microworld primarily created using Hypertext Mark-up Language (HTML), Cascading Style Sheets (CSS) and JavaScript (JS) in the form of a web application. Other CSS and JS libraries are also used, which will be later explored in the “Project Specification” chapter.

This project's final objective is to select a suitable strategy for evaluating the simulator's efficiency and usefulness. The testing conducted should analyse the tool's learning objective and collect feedback on how well it can engage young people and influence their understanding of the National Carbon Footprint and how to influence it.

This study will begin by conducting a thorough investigation into the relevant background research as a prelude to the project. It will subsequently examine the key design considerations and choices made to develop the Microworld. A comprehensive overview of the significant technical challenges encountered, and the approach undertaken for implementing the simulation will then be presented. Finally, the study will provide an in-depth analysis of the testing and evaluation conducted on the tool.

The tool was used by (N=23) TY students for a period of 2 hours as part of a two-day workshop, within the B2C program, exploring different aspects of Climate Change. Ethical approval for researching different aspects of the Bridge2College program has been granted by the School of Computer Science & Statistics.

1.2 Roadmap

This report provides an account of this author's background research conducted for the purpose of constructing a Microworld. The report is comprised of several sections, including an explanation of the 2030 Goal, Mitigation Techniques, a Summary of Ireland's Budget, Pedagogy and Microworlds, HCI, and Current Carbon Footprint Data Visualisation Techniques. The subsequent section of the report presents the project specifications, outlining the Project's Scope, Requirements, and Technological Choices. The implementation of the simulation will then be described, focusing on the execution of certain aspects of the simulation. The testing and evaluation chapter follows, detailing the methods used by this author to assess the effectiveness of the Microworld. Finally, the report concludes with a summary of the project and a discussion of potential future work, including a written piece by this author.

2 Background

This chapter includes the review of research and literature that this author has conducted. This author has assessed nine factors on their relevance and contribution to an effective Microworld representing the National Carbon Footprint. The findings from this analysis form the body of this chapter and is crucial this study. The Background chapter will be divided into nine subsections.

An essential contributor to literature about Ireland's Carbon Footprint is the 2030 Climate Change Goal. Researching this goal informed this author on how best to design this project and will be discussed at length. Following on from this, an in-depth comparison of renewable and non-renewable energy will be provided. This is relevant as it then informed this author on the best mitigations techniques which will also be analysed. Understanding potential constraints such as Ireland's Budget was important in constructing this Microworld for reasons that will also be discussed. Perhaps the most pivotal factor in this project is the relationship between pedagogy and Microworlds, which is why it too will be discussed. Assessing the various resources and predecessors draws this chapter to a close along with some closing thoughts.

2.1 2030 Climate Change Goal

Ireland currently has a Carbon Footprint of 61.53 million tonnes (Enviromental Protection Agency, 2022). According to the Climate Action Plan 2021 (CAP21), Ireland is striving for a 51% reduction from 2021-2030. This plan aims to put Ireland on a more sustainable path. The terms of the 2030 Goal are legally binding objectives that are set out in the Climate Action and Low Carbon Development Act 2021. This goal seeks to decrease emissions, creating a cleaner, greener environment and society. In doing this, it will have great economic benefits such as generating employment and developing new businesses. Other benefits will also emerge such as improving public health by reducing air pollution (CAP, 2021). Ireland's CAP works alongside the Sustainable Development Goals and the Paris Agreement trying to mitigate the grave threat that Climate Change poses. Meeting the 2030 emission reduction targets is an essential step towards achieving the long-term goal of the Paris Agreement (United Nations, 2015).

The 2030 goal will support Ireland's transition to net-zero (the cutting of greenhouse gas emissions to as close to zero as possible (IPCC, 2014)) and the achievement of a carbon-neutral economy by 2050. Therefore, having resources for learners to explore ways of meeting the 2030 goal and managing Ireland's Carbon Footprint is vital.

2.2 Renewable vs Non-Renewable Energy

Energy production and consumption are major sources of carbon emissions that contribute to Ireland's Carbon Footprint. To effectively allow learners to explore how to control the National Carbon Footprint, it is crucial to have a background knowledge of the two types of energy and their effects on carbon footprints.

<u>Renewable Energy:</u>

The term "renewable energy" refers to self-replenishing sources of energy, such as solar radiation, wind and hydropower. These resources have the potential to generate electricity for various economic sectors, provide fuels for transportation, and supply heat for buildings and industrial processes (Energy U. D., 1997) . These produce little to no carbon dioxide emissions and are thus environmentally friendly alternatives to harmful forms of energy (Change, 1996). A focus on a shift towards renewable energy sources can have a significant impact on the amount of greenhouse gases Ireland produces. A prior knowledge of renewable energy and their benefits can better inform the young people who will use this project.

Non-Renewable Energy:

Non-Renewable energy refers to energy that is derived from sources that are finite and will eventually be depleted (IEA, 2022). These energy sources contribute to a significant portion of the world's energy supply. Fossil fuels account for the majority of global energy consumption (IEA, 2022). Their use comes with a range of environmental, social, and economic challenges, including greenhouse gas emissions, air and water pollution, rising costs of these fuels as their resources become more finite and the risk of accidents and disasters.

2.3 Mitigation Techniques

When referring to our Carbon Footprint, the Intergovernmental Panel on Climate Change (IPCC) defines mitigation as "a human intervention to reduce the sources or enhance the sinks of greenhouse gases" (IPCC, 2014). They advocate for clean sustainable solutions to Ireland's energy problem and recommend the aforementioned renewable energies as an alternative to fossil fuel to reduce CO2 emissions while still generating electricity.

Mitigation techniques were needed when making this Microworld as it educated the young people in a constructionist way of the alternative and sustainable energy sources available at present, that perhaps are not being used to their maximum potential. By incorporating mitigation techniques into a simulation, it is possible to model the potential results of different strategies and determine which ones are likely to be most effective in reducing carbon emissions. Within the context of the Microworld, students can reduce the CO2EQ with this author's chosen mitigation techniques to control the Carbon Footprint at a national level.

Understanding this author's chosen mitigation techniques will help students make informed decisions about how to control the Carbon Footprint in the Microworld. This demonstrates the educational methods of constructionism, where learners can experiment with various situations and evaluate their effects on Carbon Footprint levels in real-time, leading to a stimulating and contemplative learning experience which is becoming more popular in today's classroom.

Of all the mitigation techniques at this author's disposal, methods concerning energy were selected as there is a lot of potential in this field and at present renewable energy generation is underutilised. Therefore, the following subsections will briefly introduce the energy-focused mitigation techniques and their relevance to this project.

2.3.1 Solar Panels

Figure 2-1: Solar panel (Ireland, 2019)

Solar panels are devices that convert solar energy into electricity. When sunlight strikes the solar cells, an electrical current is generated that can be used to power homes, businesses, and other structures (SEAI, 2017). Solar panels have grown in popularity in recent years as a source of clean, renewable energy. They can be installed in any locations where sunlight is available. Solar panels are frequently used in tandem with energy storage systems such as batteries to ensure a continuous supply of electricity even when the sun is not shining (BordGais, 2023).

Solar panels have the potential to meet a significant portion of the world's electricity demands while at the same time reducing greenhouse gas emissions and mitigate Climate Change (Shah et al., 2020) (Alam et al., 2019).

2.3.2 Micro-Hydropower

Figure 2-2: Micro-hydropower (GE, 2022)

Micro-hydropower is a form of renewable energy that generates electricity by harnessing the energy of falling or flowing water. Unlike its macro-equivalent hydropower, micro-hydropower refers to small-scale hydroelectric systems typically producing less than 100 kW of power. Using water to generate electricity, hydropower in general, is a clean, dependable, and renewable energy source that has the potential to meet a significant portion of the world's electricity needs.

According to the IEA, hydropower currently accounts for approximately 16% of global electricity generation, making it the world's largest source of renewable energy (IEA, 2020). However, data shows, only 2.5% of Ireland's electricity is generated by hydropower (Teagasc, 2017).

2.3.3 Wind Turbines

Wind turbines are devices that convert the kinetic energy of wind into electrical power. They are becoming a more popular form of renewable energy, particularly in locations with strong winds (Teagasc, teagasc - Wind energy, 2017). As of 2022, there are approximately 300 wind farms in the Republic of Ireland and just under 400 wind farms on the island of Ireland (WindEnergyIreland, 2022).

Wind turbines are separated into two categories: onshore turbines and offshore turbines.

<u>Onshore Turbines:</u>

Figure 2-3: Onshore wind farm - Galway wind park Connemara (Renewables, 2023)

Onshore wind power refers to wind turbines situated on land. They are often found in locations with low population density and conservation value. Onshore turbines in comparison to offshore turbines are cheaper. Onshore wind farms are the most popular type of wind farm in today's world. Galway Wind Park is currently the largest onshore wind farm in Ireland, consisting of 58 turbines (Renewables, 2023).

<u>Offshore Turbines:</u>

Figure 2-4: Ireland`s first floating offshore wind farm (off the coast of cork) (Kaldellis, 2013)

Offshore wind power refers to wind farms built on shallow bodies of water, usually in the ocean. In comparison to their onshore counterparts, offshore turbines have the potential to generate more electricity at a steadier rate, due to the higher, more consistent wind speeds at sea (Kaldellis, 2013). At present, Ireland has 69 offshore wind farm projects, of which 1 is currently operating (4COffshore, 2023).

2.3.4 Tree Planting

Figure 2-5: Newly planted trees in a forest near Grange Crag in County Tipperary (Alamy, 2021)

Carbon sequestration refers to the process of capturing and storing atmospheric carbon dioxide (Lal, 2008). This helps to either mitigate the dangerous effects of Climate Change. A fully grown evergreen tree captures approximately 0.14kg CO2EQ from the atmosphere per year (TreeCouncil, 2023) . One way to absorb more CO2 from the atmosphere is to plant more trees. This can be done in two ways:

Afforestation:

According to the Food and Agriculture Organization (FAO), afforestation refers to the "planted or naturally regenerated forest on lands that have not been forested for a long time, usually for more than 50 years" (FAO, 2021). The process of afforestation involves planting trees or encouraging natural regeneration in areas where forests have been depleted or destroyed due to deforestation, urbanization, or other land use changes.

Reforestation:

Reforestation refers to the "establishment of forest on lands that, until recently, have either contained no forest or have been subject to deforestation" (FAO, 2021). The process of reforestation involves planting trees or allowing natural regeneration in areas where forests have been depleted or destroyed.

2.3.5 Nuclear Power

Figure 2-6: Nuclear Power Plant

Nuclear Power is a form of non-renewable energy which refers to energy generated by splitting atoms of radioactive materials. This process releases a significant amount of heat energy that is used to produce steam, which then drives turbines that generate electricity (Robledo, 2016). Nuclear Power results in no direct CO_2 emissions, and it is said to be a promising technology option for Climate Change mitigation (Bauer, 2012). Nevertheless, the negative effects of Nuclear Power is widely known to be devastating as seen in Fukushima-Daiichi and Chernobyl. Furthermore, as of 1999, the use of Nuclear Power is prohibited in Ireland (Ryan, 2007). According to Ryan, the Irish government believes that Nuclear Power is neither sustainable nor the answer to Ireland's energy needs. However, the possibility of implementing Nuclear Power as an energy source in Ireland has sparked discussions, with some advocating for its utilization and others raising concerns about its safety and environmental consequences (Grimes, 2015). For the purposes of this Microworld, Nuclear Power will be a suitable mitigation technique to provide a well-rounded representation of the dilemma currently facing Ireland's government.

2.3.6 Comparison of the Mitigation Techniques

Below is a table of showing a comparison of the key information found in each of the aforementioned mitigation techniques.

Mitigation Technique	Cost in Euros	How much C02EQ does it mitigate	How long do they last	How long does it take to see reductions?	Comments
Solar Panel – 8400 Watt	€1,250	900 kg per year	20 – 30 Years	Less than 1 year	There are currently 2,123,590 permanent homes in Ireland [1]. 8 per house.
Wind turbines	€1.8 million	1000 Tonnes per year	20 – 30 Years	2 years	In 2019, 24 wind farms were built with an average of 10 turbines per farm.
Micro-hydropower	€4000 - €6000	7 Tonnes per year	80 –100 years	2 years	Presently 2.5% of Ireland's electricity generated is in the form of hydropower (not solely micro-hydropower) [3]
Tree planting	€2	0.14kg	80+ years	8 years	20,000 HA a year is being made available in the Climate Action Plan for tree planting [4]. 20 trees can be planted per HA.
Nuclear Power	€22 billion	51 million Tonnes per year	20-40 years	8 years	Currently banned in Ireland [7].

Table 1: Comparison of Mitigation Techniques

[1] (Census, 2022)

[2] (Association, 2023)

[3] (Teagasc, Small Scale Hydro Generation, 2017)

[4] (Environment, 12 June 2020)

[5] (Ryan, 2007)

Some mitigation techniques are significantly more expensive than others, however so are the rewards. This should prompt students to think critically about how best to maximise the reduction in CO2EQ. The economic prinicple of opportunity cost will effect students when faced with constraints like money. For example, which will reap more rewards, €22 billion worth of trees or 1 Nuclear Power Plant? When students are faced with these dilemmas within the simulation it will encourage them to think critically about their choices which is something a contructionist methos of teaching should strive to do.

There are some conditions that students will have to abide by when running the simulation for example, the average amountr of solar panels per house is 8 as seen in Table 1 above. This will be further expanded on when discussing this authors design of the code and the differences between Challenge 1 and Challenge 2.

2.4 Ireland's Budget

As seen in Table 1, implementing these techniques can be expensive and requires significant investment and money. The main source of financing for carbon mitigation techniques is the annual budget of a country. The Government allocate funds to various programs and projects, including those aimed at reducing greenhouse gas emissions.

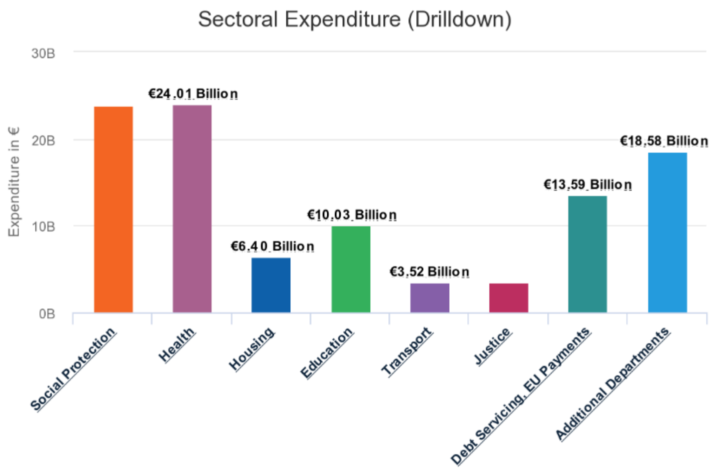

Figure 2-7 : Breakdown of Irish Budget 2023

Ireland currently has a budget of €103.5 billion (Reform, 2023). The budget details how income will be generated and spent in 2023 as seen in Figure 2-7 (Expenditure, 2023). The figure shown in is taken from "whereyourmoneygoes.gov.ie". This website effectively presents the breakdown of the National Budget using various interactive graphs, with the bar charts standing out for their simplicity and remarkable impact. As seen in Figure 2-7, climate change initiatives are accounted for in "Additional Departments" meaning when students encounter fiscal constraints in the Microworld, their decisions should be influenced accordingly.

2.5 Pedagogy and Microworlds

Microworlds refer to computer-based environments that allow individuals to engage in exploratory activities, where they can see the consequences of their actions. These environments provide individuals with opportunities to learn and gain insights through active participation and experimentation.

These twin roles for the learner lead directly to the idea of constructionism, which argues that effective learning "will not come from finding better ways for the teacher to instruct but from giving the learner better opportunities to construct" (Harel, 1991). Constructionism is an approach to learning that requires the creation of an artefact during the learning activity which can subsequently be shared with others (Harel, 1991).This aids in constructing a foundation upon which subsequent knowledge can be incorporated.

By giving students an environment that allows both free discovery as well as experimentation given certain constraints, it encourages the students to think for themselves. In the context of this Microworld, the author has created two challenges that align with the ideas associated with pedagogical teaching practises.

The adoption of a student-centred pedagogical approach that fosters active learning has been demonstrated to result in enhanced engagement in the field of science (Handelsman, 2005). Allowing learners to discuss and contemplate their learning leads to increased student motivation (Handelsman, 2005). This literature is important to remember when designing a Microworld as it should foster creativity and scrutiny to keep its audience engaged.

Therefore, a Microworld should have its own set of tools and operations that are open for interpretation and change. In essence, learners are in the position simultaneously of user and designer (Ableson, 1985). Microworlds offer various features and abilities that can encourage cognitive dissonance, which is crucial for the development of conceptual comprehension.

2.6 Human-Computer Interaction

Human-Computer Interaction (HCI) is an interdisciplinary domain of research that focuses on the conceptualization, evaluation, and execution of interactive computing systems intended for human utilization (Te'eni, 2007). The primary objective of HCI is to develop computer-based systems and technologies that are user-friendly and effective, enhancing human activities and experiences.

The usability of a system is critiqued by the extent to which it can be used efficiently and adequately to accomplish certain goals for certain users. However, the actual effectiveness of it is achieved when there is a balance between the functionality and usability of a system (Plaisan, 2004). The HCI design should consider many aspects of human behaviours and needs to be useful. Therefore, the degree of activity that involves a user with a machine should be thoroughly thought out. The user activity consists of three different aspects:

- Physical: Determines the mechanics of the interaction between human and computer (Chapanis, 1965).
- Cognitive: Deals with the way that users can understand the system and interact with it (Norman, 1986).
- Affective: Tries to make the interactive a pleasurable experience for the user but also affect them in a way that makes them continue to use the machine. (D. Te'eni, 2007) (Picard, 1997).

HCI involves the comprehension of how individuals interact with computers and other digital technologies and how these technologies can purposefully be designed to enhance and improve this interaction (D. Te'eni, 2007). As HCI simultaneously studies a human and a computer, it draws from research on both aspects. With respect to the computer aspect of HCI, the focus is on various techniques such as programming, graphics, and data visualizations. These techniques are essential for creating user-friendly interfaces that promote efficient communication and interaction between humans and computers (Hewett T.T., 1992). Regarding the human aspect, HCI directs its attention towards incorporating knowledge from cognitive psychology, human factors, and communications theory (Karray, 2008).

HCI is an important part of the Microworld's system design. The quality of the system depends on how it is represented and used by the users. Therefore, enormous amounts of attention will need to be placed on this when designing this Microworld.

2.7 Carbon Footprint Data Visualisation Techniques

This section examines some standard methods for data visualization in exploring the themes surrounding the Carbon Footprint and evaluates their applicability to the project. This author examined a range of available resources with the aim of critically assessing the tools to incorporate the best features of each into their Microworld. In this section, the author has focused on the relevant aspects to the Microworld they designed.

2.7.1 Calculators

A Carbon Footprint Calculator is an interactive tool designed to provide an estimate of the amount of greenhouse gas emissions that an individual produces from their daily activities or operations. The tool is typically web-based and enables users to input data related to several factors. The calculator employs complex algorithms to generate a comprehensive carbon footprint estimate. The output is usually measured in terms of tonnes of CO2EQ, which can help users to identify areas where they can reduce their carbon emissions. The pedagogical approach of the carbon footprint calculator is aimed at raising awareness about Climate Change. By providing users with personalized carbon footprint estimates, the calculator encourages individuals to consider their impact on the environment and take steps towards reducing their carbon footprint.

Carbon Footprint Calculator- Carbon Footprint ltd.

URL: https://www.carbonfootprint.com/calculator.aspx

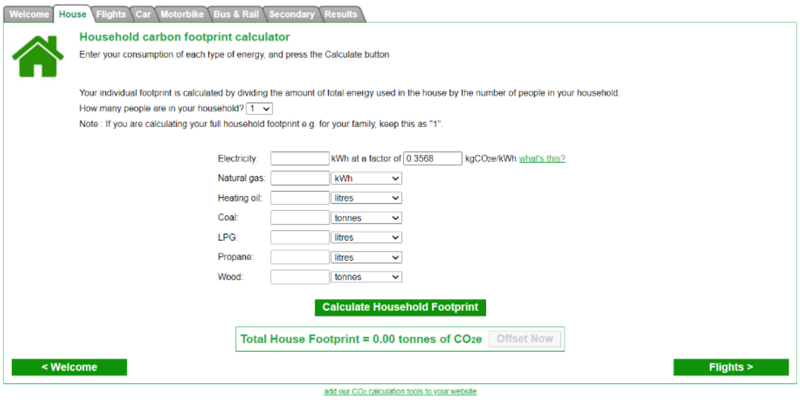

Figure 2-8: Carbon Footprint Calculator

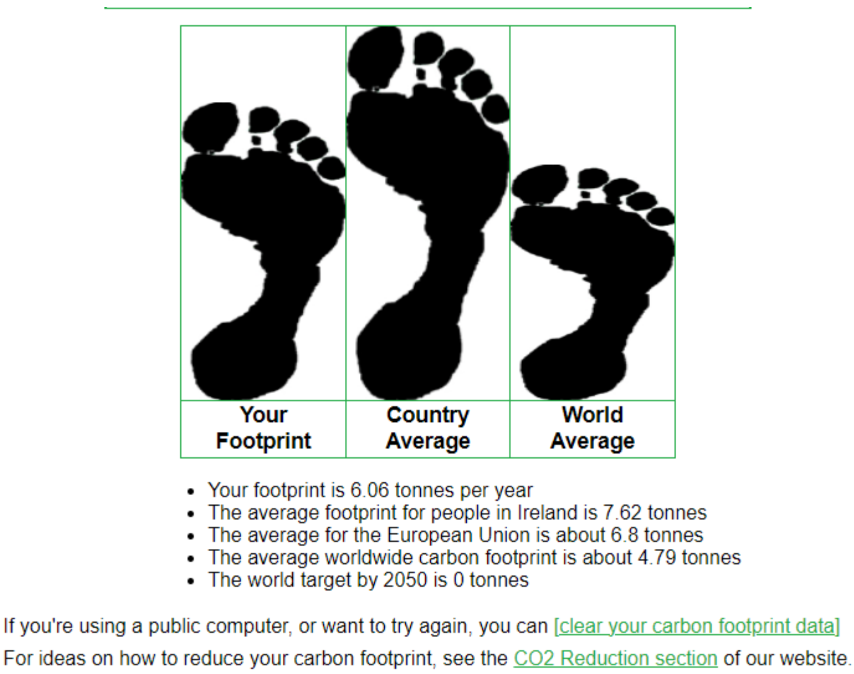

Figure 2-9: Carbon Footprint Calculator Results

This is an informative website, which calculates the carbon footprint of a user, based on their input. The calculator asks questions about topics which influence a person's carbon footprint, for instance, Home, Flights, Transport, food, and recreation. Ultimately, after answering the questions, the user will receive their carbon footprint emission number. Overall, the Calculator tool is both informative and educational. It allows users to gain a deeper understanding of how their choices affect Carbon emissions. However, the data visualisation techniques lack innovation and are monotonous. The calculator is also rather limiting in the sense that you are restricted to a certain number of entries per field, for instance, the users are only allowed to enter a maximum of 3 return flights a year and you must have precise measurements of a plethora of things such as household electricity in kWhs.

2.7.2 Simulators

Simulators are programs or devices designed to mimic the behaviour of a system or process, enabling users to practice operating them without any real-world consequences. Simulators are used extensively in training and education, as well as in research, design (Taneja, 2015). Simulators are used across a broad range of subjects and play a critical role in a range of industries when emulating new practices. When considering a Microworld simulating the National Carbon Footprint, simulations gives students the opportunity to see the result of their actions without having to conform to the real-life timeframes.

<u>My 2050 Simulator</u>

URL = http://2050-calculator-tool.decc.gov.uk/#/calculator

Figure 2-10: My 2050

This is an interactive simulation tool created by the UK Government to allow users to build their own low-carbon scenarios with the aim of meeting the 2050 EU Climate Change Plan. This simulator aims to encourage a debate with all UK citizens on how they can make their society evolve towards a low-carbon society by 2050. The user is given several choices to try and reduce the CO2EQ emissions, whilst showing a visualisation of the world the user is creating. This is an interesting and educational simulation that implements several novel concepts for demonstrating how to control a national carbon footprint. This tool has an extremely interesting concept. It allows users to recognise how different trade-offs affect levels of CO2EQ in the UK, whilst displaying simple visual aids. Perhaps, the visualizations could be more intriguing and eye-catching.

2.7.3 Visualisations

This section analyses some of the interesting educational videos discovered by this author which provided interesting visualisation techniques but provided no element of interactivity for the user. In terms of the National Carbon Footprint, it could be an interesting concept for users to see the effects of their Carbon Footprint.

Meet your Carbon Footprint

URL: Virtual Reality/360 video: Meet your carbon footprint

Figure 2-11: Meet Your Carbon Footprint Video

This is an educational YouTube video developed by 'UN Environment Programme' which allows users to explore through an immersive virtual reality video how their daily choices can feed or fight Climate Change. Initially, the viewer is confronted by their Carbon Footprint in "real size." The outcome of many habitual daily choices are shown. The viewer can see their impact on the planet in terms of rise of sea levels and wildfires. Finally, the learner is shown choices they can make to live a climate-friendly lifestyle. This is a fascinating and pedagogical video that demonstrates the effects of one's daily choices regarding Climate Change and visualises the outcomes of those choices. While being a useful tool to visualise carbon footprint modelling, it could be argued that the video may be a bit introductory and without an interactive element the user is subjected to a generic representation, leaving no room for autonomy. The animations and general look of the simulations are highly captivating.

Climate Time Machine - NASA

URL= https://climate.nasa.gov/interactives/climate-time-machine/

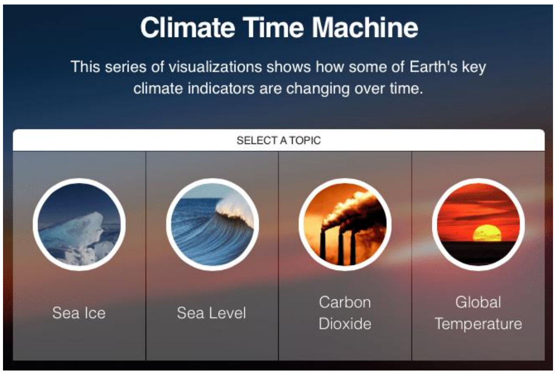

Figure 2-12: Climate Time Machine image 1

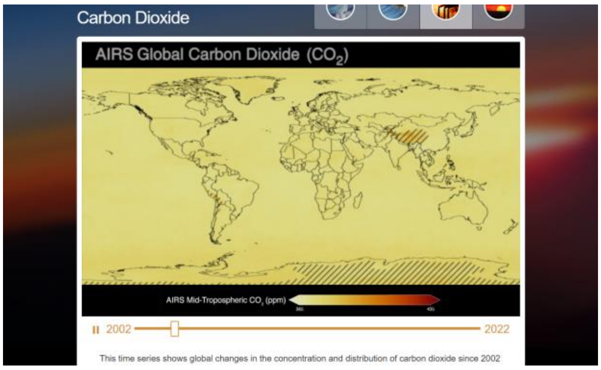

Figure 2-13: Climate Time Machine image 2

The Climate Time Machine is a series of visualizations that demonstrate how some of Earth's key climate indicators are changing over time. This quartet of animations demonstrates how recent changes in the average global temperature, sea level, sea ice extent, and carbon emissions are indicative of Climate Change in recent years. The web application is a component of NASA's Global Climate Change initiative and was created to give users a visual overview of the recent changes the planet has undergone so they can learn more about Climate Change and the potential effects it may have on the rest of the world. Overall, this web application is simple, informative, and comes from a very authoritative source. This is an impactful tool in terms of dramatizing some of the well-known Climate Change concepts. Each page offers a limited amount of involvement using sliders that advance the changes on a sizable timeline. To further understand the visualisation, a short paragraph is included. However more context is needed, and a higher level of interactivity would provide for a more cognitively enhancing learning experience. Alongside this, although relatively easy to follow, no initial instructions are included to run the visualisations.

2.7.4 Games

Ducky Game

URL: https://app.ducky.eco/footprint

Figure 2-14: Carbon Footprint Ducky Game

This is a challenge by a Norwegian start-up and is used by students in Norway which allows the user to learn about their daily eco-choices. 'Ducky' is a digital behaviour challenge that aims to help people track and reduce their carbon emissions. This gamified climate challenge app allows participants to compete with their peers to change their habits and reduce their footprint. This game encourages students to actively participate in their learning to yield the results, which is fundamental in constructionist methods of teaching. This is a unique and bespoke educational tool that has accounted for the reduction of over 273 tonnes of CO2EQ in just 3 weeks (Fortuna, 2019). Although the game is no longer running, it had a great educational impact. The tool could benefit from having an online initiative to play seen as it is no longer supported by local governments. This game has the potential impact students all over the world rather than Norway alone.

The Climate Game - Financial Times

URL: https://ig.ft.com/climate-game/

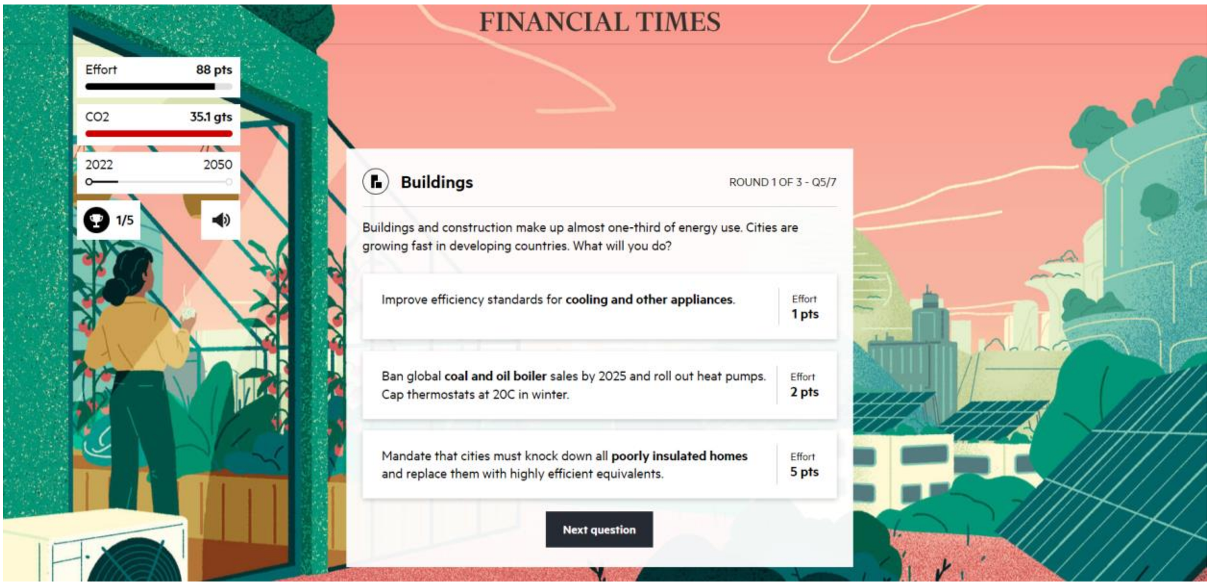

Figure 2-15: The Climate Game - Financial Times

The main aim of this educational game made by the Financial Times is to reduce carbon dioxide emissions from 36 billion tonnes to the goal of net zero by 2050. At the beginning of the game, the player is prompted to choose an advisor who will help them and give them feedback throughout the game. Each question has a series of choices the user has to make and a certain amount of "Effort" tokens are assigned to each answer. The user's response to these questions have a direct impact on both the emissions and global temperature in the game. Feedback is given in several ways throughout the game, allowing the user to reflect on the choices they have made. Upon finishing the game, an assessment of the player's overall performance is shown on screen.

This game is an interesting way to demonstrate to users the effect their choices can have on Climate Change. It allows users to explore different options and make choices regarding to contributing factors of Climate Change. The player's overall performance of the game is shown following the completion of the game. An aspect of this game which greatly adds to the pedagogical value, is that the choices made by the users are meaningfully reflected in the feedback given. This gives the learners opportunity to reflect on the decisions they have made. Despite this, the game consists nearly entirely of text and basic images which isn't cognitively engaging for the given demographic and perhaps a greater visualisation of the changing of the CO2 levels would improve the learning experience for the user.

2.8 Comparison of Similar Applications

	Interactivity	Engaging Visual Aid	Explanation of Logic	Challenged Based Learning	Replay ability	Catered towards target demographic
Calculator	✓	X	✓	X	✓	✓
"Meet Your Carbon Footprint"	X	✓	X	X	X	X
"Climate Time Machine"	✓	✓	X	X	X	X
"My 2050"	✓	✓	✓	✓	✓	X
"Ducky Game"	✓	X	X	✓	X	X
"The Climate Game"	✓	X	X	✓	X	✓

Table 2: comparison of similar applications

In this table, the applications that have been previously analysed by the author have been compared based on a few key factors. The outcome of this analysis was used to inform the development of the author's systems, drawing inspiration from the most useful features, and building upon those that could be improved. The author has identified the useful functionality, as well as the shortcomings and limitations of the systems that are currently available.

2.9 Discussion

It is evident that the process of creating a tool that explores Carbon Footprint on a national scale is a complex endeavour, and it may pose challenges to comprehend the concept initially. However, the utilization of technology, specifically Microworlds, presents a significant potential to foster learning and promote an understanding of the subject matter. While several systems have proven informative and encompassed crucial features, some lack essential elements, such as captivating visual aids and interactive features. Nonetheless, the key features identified in the tools mentioned previously serve as inspiration and generate ideas for the project. Additionally, it is apparent that the integration of pedagogical theory and data visualization techniques may yield a dynamic synergy. Microworlds emphasize the development of robust thinking tools, and can significantly benefit from the cognitive loop created through data visualization techniques, thereby enabling the application to become a seamless part of the thought process. Through testing the various tools, this author then came to the conclusion that a Microworld would be the most effective for meeting this projects brief.

3 Project Specification

3.1 Project Considerations

The Microworld should be accessible and usable for Irish Transition Year students, but it should also be valuable to other demographics. Keeping this in mind, certain considerations were made during the design process.

- As part of the Junior Cycle curriculum, Transition Year students will normally have completed 100 hours of C.S.P.E over the course of three years (NCCA, 2021). This course explores rights and responsibilities, global citizenship and democracy.
  Students learn about Climate Change, sustainable development, and sustainable living strategies as part of this curriculum (NCCA, 2021).
  Additionally, Climate Change, sustainability and carbon footprint modelling can also be seen in other subjects in the Junior Cycle including Home Economics and Geography.
  Students who have opted to take geography will have learned about Climate Change, and explored mitigation techniques (NCCA, 2017).
  Students who have chosen to take Home Economics will have learned about sustainable living and therefore global warming, and fossil fuels (NCCA, 2017). This means that the students will have been exposed to exploring Climate Change in typical classroom settings and should have a basic understanding prior to testing the simulation. This should influence how complex the information should be.

- Learning Environment: The Microworld will typically be used within a group-based, technology-mediated learning environment. Nevertheless, the tool must be self-explanatory because it may still be utilized by individuals outside the setting of a dedicated class.

- Accessibility: It is crucial that the tool is useable and accessible for all users regardless of their level of technical literacy. It should be designed to offer a system that the learner can easily comprehend and manage. The tool should enable learners to participate completely and help them reach their full academic potential.

- Ethics: This tool should take caution not to misinform students about carbon footprint at a national level. The simulation ought to refrain from expressing political opinions and concentrate on actively involving students, with the aim of fostering knowledge and developing their capacity to become more discerning and educated members of society. In this regard, it is crucial that the tool explicitly states that the model contains assumptions and simplifications and that it is not meant to perfectly represent or forecast actual carbon footprint mitigation plans in a scientific manner. All activities surrounding, and including, this tool should be of educational benefit to the learners.

3.2 Project Scope

Given the constraints and overall project objectives and considering the intricacy of exploring the Carbon Footprint as described in the previous chapter, some limitations had to be placed on the project's scope.

- In order to make the tool as cognitively engaging for learners several assumptions and simplifications have been imposed.
- The tool should be easily accessible on laptops and PCs and should work on a variety of sized screens. However, this application is not suitable for small mobile devices to encourage its use in classroom environments.
- Constraints were placed on resources with the intention of providing a critical thinking element to the Microworld.

3.3 Functional Requirements

- The user must be able to clearly explore different mitigation options (Solar Panels, Micro-Hydropower, Wind Turbines etc).
- The user must be able to witness the effect the mitigation techniques have on the National Carbon Footprint.
- The user must be able to configure certain variables in real time, which have a clear visual impact on the outcome of the simulation.
- To make the Microworld as realistic as possible, the user must have financial constraints or must make decisions in order to account for the money they spend.
- The simulation should run across 8 years, signifying the years between now and 2030 as the challenge of the simulator is to achieve a 51% carbon emission reduction in line with the 2030 Climate Change Goal.
- The mitigation techniques should be shown in relative real time e.g., if you buy trees on year 1, the carbon footprint should not go down until year 8.
- The user should be able to clearly visualise and easily understand the task and information on the screen.
- The simulations must have stochastic elements so that the outcome of the simulations vary with each run.
- The tool should set a series of challenges for the user but should also have a sandbox version available for experimentation.

Microworld Results:

- When the Microworld simulation is finished, the results should be displayed and the users should be told if they have met the 2030 Goal.
- The user should be able to see the reduction in Ireland Carbon Footprint, as well as the amount of money that they have spent throughout the simulation, teaching them about trade-offs and consequences

3.4 Non-Functional Requirements

Documentation

- The tool should provide an introductory guide giving a brief outline of what the purpose of the tool is and how it works.
- The tool should be accompanied with a fact sheet and PowerPoint, giving users a brief background on the Carbon Footprint and how to influence it on a National Level.

- The simulation should gradually add more elements, and the tool should describe each one as it is introduced.

Usability

- To accommodate a variety of users, the system should follow the universal design principles meaning relying on users' intuition to understand the simulation and having indicators to keep users in line with the brief therefore, eliminating possibility to fail.
- The tool should be suitable for Transition Year pupils.
- The tool should make use of compelling data-visualisation techniques to enable learners to easily visualize the effect of the changes they have made.
- The system should enable learners to develop opinions and generate conversations about different techniques used to mitigate carbon emissions.
- The tool should be of use to individual learners as well as in a collaborative learning environment.
- The tool should be intuitive and not present a steep initial learning curve.

Availability and Reliability

- The tool should be accessible on a standard PC or laptop device.
- The system should support as least the 4 most used modern browsers (Google Chrome, Mozilla Firefox, Safari, and Microsoft Edge).
- The system should be scalable and capable of supporting multiple groups of students using it concurrently.

Overall Design of the Project:

Considering the previously discussed requirements and the literature discussed in section 2. It was decided to create two challenges which are explained in detail in subsequent sections. Brief introductions are given to each of the challenges outlining the main goal of them with "Start" buttons prompting the user to begin the Microworld. The simulator gives the learners the opportunity to explore 5 mitigation techniques including, Solar Panels, Micro-Hydropower, Wind Turbines, Tree Planting and Nuclear Power. Challenge depending different constraints were placed on each mitigation technique considering the data in Table 1. The purpose of implementing these restrictions is to create a simulation that closely mirrors real-life scenarios, enabling learners to encounter the actual challenges that the government faces while dealing with the National Carbon Footprint. In addition to this, the Microworld permits users to make decisions and observe the consequences of their actions every year from now until 2030, enabling them to witness the impact of their concepts and strategies throughout this time period. The applications with similar features, mentioned in section 2, also served as sources of inspiration and in turn helped to create a tool in which ticks all of the boxes in Table 2, making it a highly engaging, interactive tool that has captivating visual aids. In terms of education surrounding the Carbon Footprint at a National Level, the tool is catered towards the targeted demographic and implements challenged based learning techniques.

Below are some key screens of the Microworld.

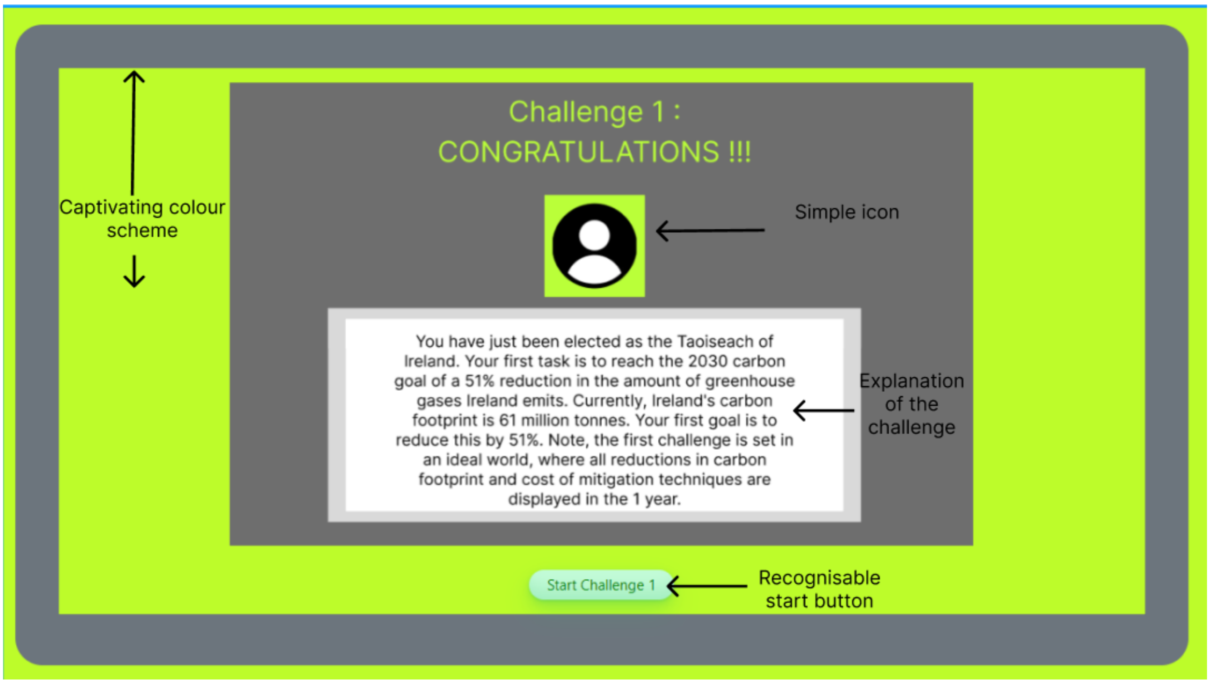

Figure 3-1: Challenge 1 introduction screen

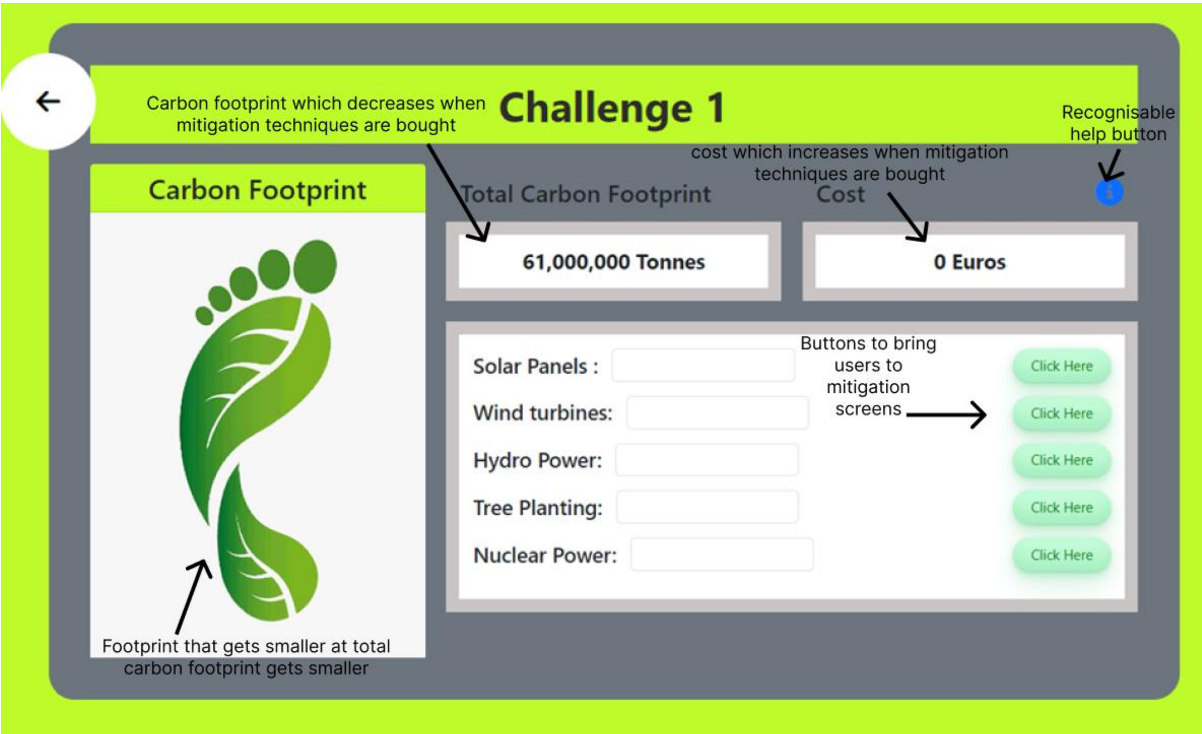

Figure 3-2: Challenge 1 Microworld

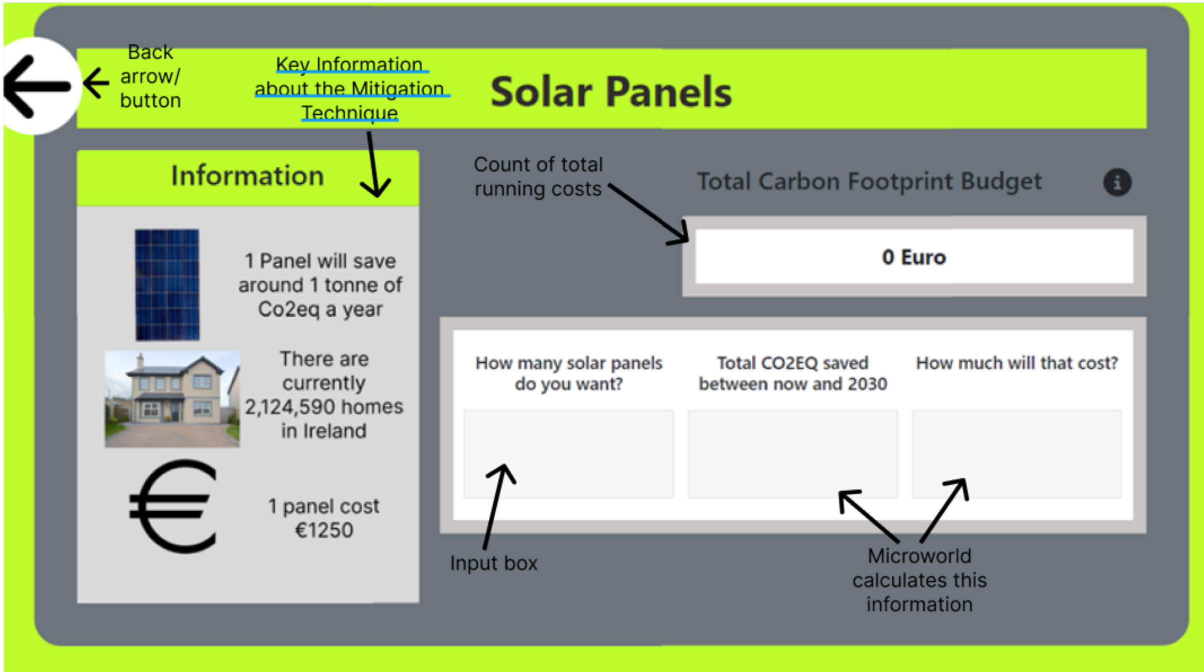

Figure 3-3: Challenge 1 Mitigation technique (Solar Panel)

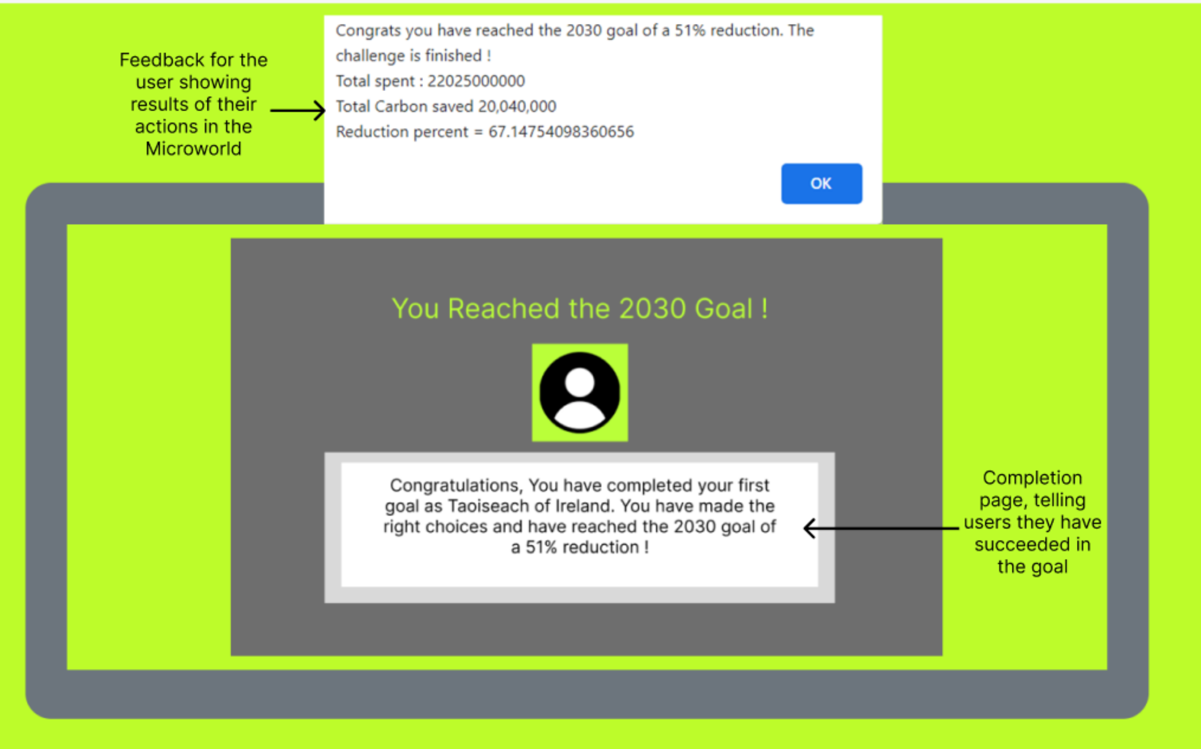

Figure 3-4: Challenge 1 Completion Screen

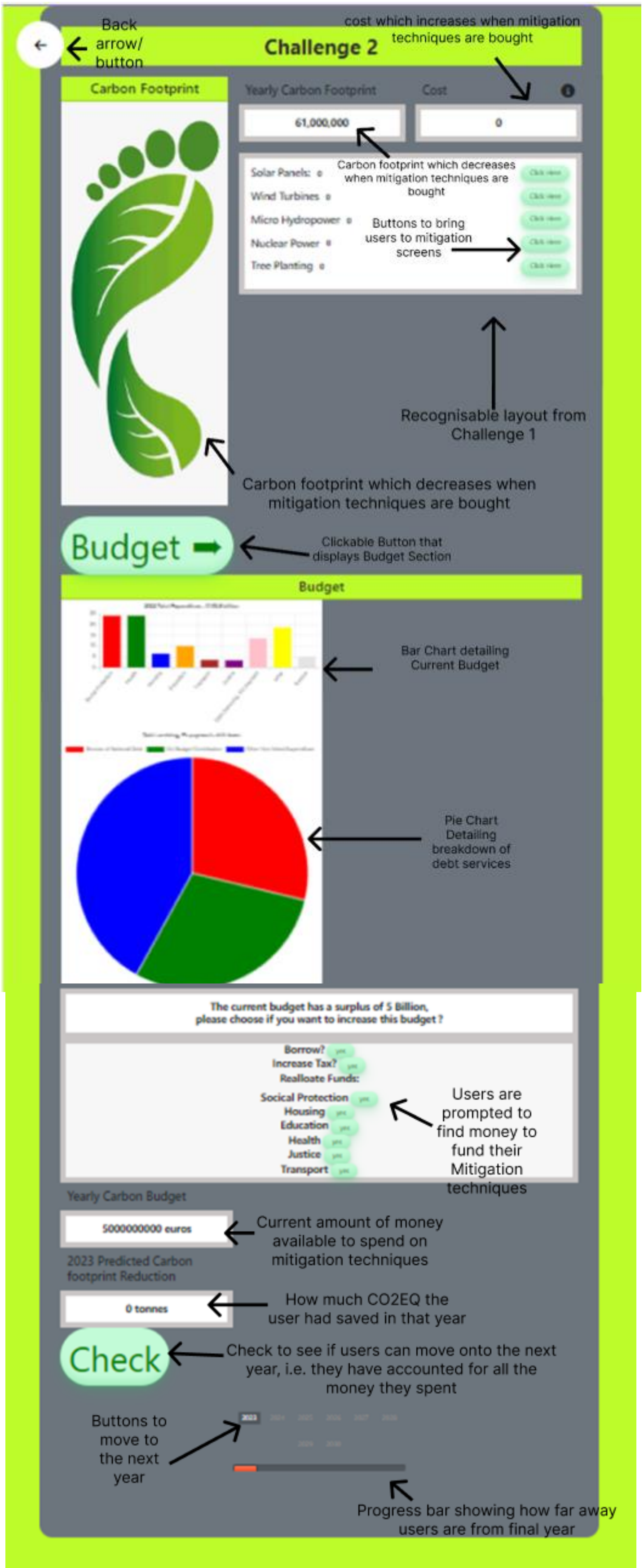

Figure 3-5: Challenge 2 Microworld

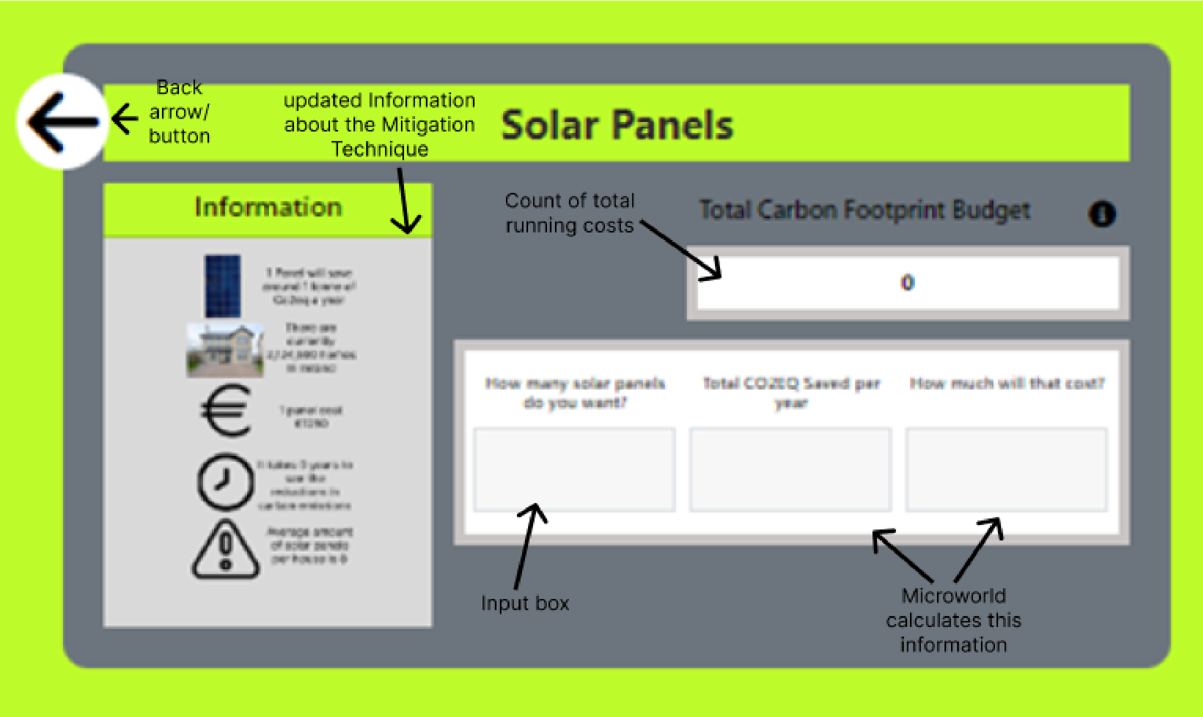

Figure 3-6: Challenge 2 Mitigation Technique Screen (Solar Panel)

3.5 Initial Technology Choices

After analysing both the functional and non-functional requirements of the tool, it was determined that a web application would be the most appropriate host for the Microworld. The primary access requirement is a device equipped with an internet connection, with the possibility of poor internet connectivity being a potential obstacle. The recent trend towards web applications and away from desktop applications has been favourable, as it permits more rapid development of applications such as this one. Furthermore, much of the advancement in the development of new data visualization and graphical user interface technologies has focused on web applications, making it an obvious and fitting choice for this project.

3.5.1 HTML & CSS

HTML (Hypertext Markup Language) and CSS (Cascading Style Sheets) are widely used technologies in the field of web development. HTML serves as the foundation for the content and structure of a web page, while CSS is responsible for the design and styling of the web application. These two technologies, in conjunction with graphics and scripting, form the fundamental building blocks for the development of websites and web applications. Alongside this, CSS can be used to optimize the design, reduce page load times, and improve the overall performance of the simulation. Their universal nature highlights their critical importance in the modern digital landscape, allowing this author to create engaging and effective simulation.

3.5.2 JavaScript

JavaScript functions in tandem with HTML and CSS to offer scripting capabilities to web pages. As an object-oriented programming language, JavaScript empowers the incorporation of intricate features and interactivity into web pages. It is the most prevalently utilized language for programming web page behaviour and interactivity, consequently enjoying extensive support across numerous platforms. Additionally, JavaScript possesses a vast array of frameworks and libraries that can augment its functionality and furnish highly beneficial visualization and interactive technologies for the tool's advancement.

3.6 Cloud Hosting Platform

To facilitate the exploration of National Carbon Footprint control by Transition year students during the B2C workshop, it is important to ensure easy accessibility of the Microworld through a cloud hosting platform that enables seamless interaction.

3.6.1 Google Firebase

Google's Firebase is a production-grade platform that offers hosting, storage, and analytics. It is widely used in web development. It offers robust web content hosting, ensuring scalability and accessibility. Firebase is particularly useful in fast-paced development scenarios, such as the project at hand, as it facilitates easy deployment and rollback of new versions through a single command. It also allows for the integration of user feedback, thereby enabling the rollout of new versions. Moreover, Firebase seamlessly integrates with Google Analytics, providing essential data on devices and browsers used to access the tool, which is beneficial for prioritizing testing.

3.6.2 Fleek

Fleek is an open source, blockchain agnostic, extensible web3 development platform which provides web services (e.g. hosting, storage, gateways, and domains) to developers that are built with the technologies that form the foundation of the open web. It is a popular platform for hosting applications. As it is deployed on a decentralized system, the network is scalable and autonomous as well as transparent and secure, as there is no single point of failure or control. Due to Fleek deploying the websites on the decentralized web, it means faster loading times than the traditional web hosting solutions as it allows users to retrieve content from the nearest node instead of having to wait for a centralized server to respond. Fleek is also developer friendly allowing for seamless integration for several popular frameworks and its easy deployment makes it more enticing. It is a simple-to-use platform for building apps for the decentralised web, hosting websites, and storing and delivering content (DWeb) making it ideal for projects such as the project at hand.

3.6.3 Choice Cloud Hosting Platforms

Both cloud hosting platforms are popular with web developers and possess several advantages and disadvantages which were thoroughly considered however the author ultimately choose to host the Microworld on Fleek for several reasons. Mainly as they were already familiar with this platform, and because of its advantageous integrated GitHub capabilities such as its simplicity of committing and pushing changes to the server. This platform is particularly suited for utilization within classroom-based settings by students due to its automatic scaling of any deployed website to handle traffic spikes.

3.7 Data Visualisation Technology Choices

A plethora of JavaScript and CSS libraries and frameworks are available for data visualization purposes. This section entails an analysis of a subset of these libraries, which are evaluated based on their appropriateness for meeting the project requirements. The selection process considers several criteria, including the compatibility of the library with diverse devices and browsers, the degree of flexibility it offers for designing and personalizing visualizations, and the extent of documentation and support available for the library.

3.7.1 Bootstrap

Bootstrap is a widely recognized front-end framework that is extensively used to create responsive and mobile-first web applications in conjunction with HTML, CSS, and JavaScript. The framework is favoured for its reusable CSS and JavaScript components that can be easily integrated into a HTML document, making it simple for developers to create consistent and high-quality user interfaces. Bootstrap's components provide developers with mundane but critical functionality such as buttons, forms, etc., allowing them to concentrate their efforts on the unique functionality of the web application. Bootstrap has comprehensive documentation and a large active community of developers that provide resources and guidance, making it easy for developers to receive assistance when needed and find solutions to common design challenges.

3.7.2 Bulma

Bulma, similarly to bootstrap is a framework that is both open source and free, offering front-end components that can be readily utilized to create responsive web interfaces by effortlessly combining them. It is a lightweight, customizable framework which provides good support and documentation. It is easy to learn and use. It is compatible with most modern browsers and has a large community which provide help and insights.

3.7.3 Charts.js

Chart.js is another framework used to create stimulating visualisations. It is an open-source data visualisation library that is freely available for JavaScript. It enables the seamless integration of interactive, animated charts into web pages, thereby facilitating the communication of complex data in an intuitive and engaging manner. The library is compatible with all modern browsers and is equipped with dynamic resizing capabilities that ensure optimal presentation of graphs on different screen sizes. Furthermore, Chart.js offers a wide range of pre-configured graphs that can be easily customised and tailored to suit the user's specific needs. The library's charts are animated and interactive, heightening user engagement and retention of information. Overall, Chart.js is a powerful tool for enhancing data visualisation on the web.

3.8 Comparison and Choice of Visualisation Technology

Below is a table of the libraries in which the author considered and a comparison under a range of selected criteria.

Library	Visualisations	Learning Curve	Extensibility	Compatibility
Bootstrap	Popular, powerful, and extensible frontend toolkit	Easy	High	Compatible with all modern browsers
Bulma	Free open-source framework with ready to use frontend components	Easy	High	Compatible with most major modern browsers
Chart.js	Limited availability for customisable unique visualisations. However easily integrated charts available	Easy, little background knowledge is needed	Low	Compatible with all modern browsers
D3.JS	Allows for unique visualisations and a wide range of customizable examples available	Steep	High	Compatible with all modern browsers
P5.JS	Allows for unique visualisations which are customisable and can be tailored easily.	Easy to get started, but can get tricky when working with complex systems	Medium	Compatible with all modern browsers

Table 3: Comparison of choice visualisation technology

The libraries that were examined earlier are well-known for their ability to display data visually. After conducting and presenting the analysis, Chart.js and Bootstrap were chosen as the preferred frameworks for creating this Microworld, as they possess numerous advantages specific to this project. Bootstrap triumphs as the most suitable framework for this Microworld as it made designing features such as the Carbon footprint that gets bigger or smaller depending on the user's actions easy to incorporate. Chart.js was chosen for similar reasons. Charts.js allows developers to create interactive charts that respond to user input, such as hovering over data points or clicking on elements. This interactivity can help engage users and make things such as budget data more meaningful, allowing them to explore and develop a greater understanding, which is why this author choose to use this framework.

3.9 System Architecture

This section delves into a diverse range of system architecture alternatives aimed at facilitating the rendering of the tool. Notable factors considered during the selection process include responsiveness, load times, and compatibility with modern technological options. The objective of this section is to meticulously evaluate the available alternatives and settle on the optimal system architecture option that would yield the desired outcomes.

3.9.1 Client-side rendering (CSR)

Client-Side Rendering (CSR) infers rendering pages directly in the browser using JavaScript. When rendering on the client side, a server sends the browser a basic HTML document (with the relevant styles and scripts), and JavaScript generates the rest of the web application dynamically. CSR can be used to build interactive applications with quick response times. Initial load time can be slow, but the application generally runs quickly after that. To boost load times, a static front-end can be hosted on a content delivery network reducing the amount of work that the server must do.

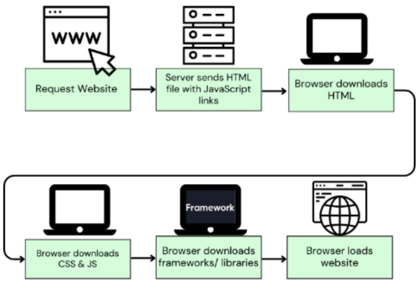

Figure 3-7: Client-side Rendering (Made in Canva)

3.9.2 Server-side rendering (SSR)

Server-side rendering (SSR) is a widely adopted technique for rendering information on the screen. This technique involves the conversion of HTML files on the server into a format that is compatible with web browsers. When a user visits a website, the browser sends a request to the server that contains the website's content. The speed at which the request is processed by the server depends on numerous factors such as internet speed, the location of the server, and the number of users attempting to access the site. Upon completion of the request, the browser receives the fully rendered HTML and displays it on the user's screen.

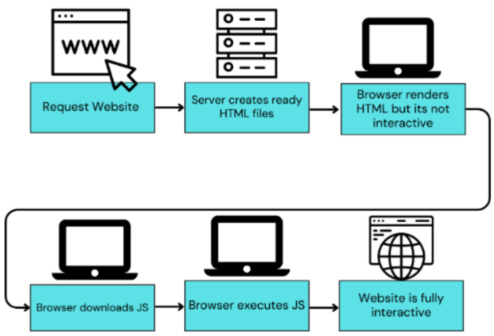

Figure 3-8: Server-Side Rendering (Made in Canva)

3.9.3 Hybrid Rendering (HR)

Hybrid rendering is a technique that combines multiple different rendering methods. This popular technique involves using a mixture of client and server-side approaches. Here, the server sends a complete page that has been rendered to the client, allowing the client's JavaScript bundle to take control thereafter. This technique requires code to be integrated into both a client-side and server-side framework, which can be complex to set up. It also creates a bigger load on the server.

3.9.4 System Architecture Comparison

System Architecture	Performance	User Experience	Development
Client-Side Rendering	Initial load time can be slow, but the application generally runs quickly after that.	-Highly interactive -Highly Responsive -Less scalable -Ideal for web apps	-Simple to implement -Flexible -Easily maintainable
Server-Side Rendering	Initial load time can be fast, but the application can run slowly after that.	-Ideal for static sights -Scalable -More consistent user experience	-Complex to implement -less flexible
Hybrid Rendering	Initial load time can be fast, and the application generally runs quickly after that.	-Responsive -Interactive -Scalable	- Difficult to implement -Difficult to maintain

Table 4: System Architecture Comparison

3.9.5 System Architecture Choice

After analysing various system architecture approaches, the client-side rendering approach was selected for this system due to the following reasons:

- The adoption of CSR enables users to enjoy a more interactive experience, as opposed to SSR and HR. This aligns with the project's objective of providing learners with a highly engaging and mentally stimulating experience.
- Although the implementation of a hybrid rendering system could potentially reduce the initial load times, it is not considered a functional requirement for this project. Moreover, the level of complexity required for its implementation may not significantly enhance the usability of the system, as the responsive interactions would still be rendered at the same speed with CSR.
- Fleek, the chosen hosting and deployment platform allows for the seamless integration of CSR.

- CSR works well with web applications, and as the Microworld is in the form of a website this is ideal.
- Client-side rendering is easy to implement and easily maintainable.

While the other system architectures may possess some advantages over CSR, due to the reasons stated above this Author decided to implement CSR.

3.10 Challenge Based Learning

Expanding upon the aforementioned concepts of challenges-based learning, it is essential to design activities that engage the learner's cognitive processes, prompting them to analyse and evaluate information, solve problems, and make informed decisions. As a result, a set of challenges were designed that utilize the Microworld simulator to actively engage learners, facilitate desired learning outcomes such as critical thinking and problem-solving, and provide educational value to the tool. The challenges include:

- Challenge 1: In this challenge, the user is given the title of “Taoiseach of Ireland” and they have to explore how to control Irelands Carbon Footprint without the constraints of influencing factors such as time or money. The primary objective of this introductory challenge is to familiarize the user with the layout and functioning of the simulator, while avoiding the initial cognitive overload that may arise from an excessive influx of information.

- Challenge 2: In this challenge, like its predecessor, the user is given the title of “Taoiseach of Ireland”, and they must explore how to control Ireland’s Carbon Footprint. However, in this challenge, they must abide by the constraints of time and money as the simulation will be ran over the course of 8 years and the user must decipher where in the budget they are getting the money from to pay for their choices.

3.11 Screen design

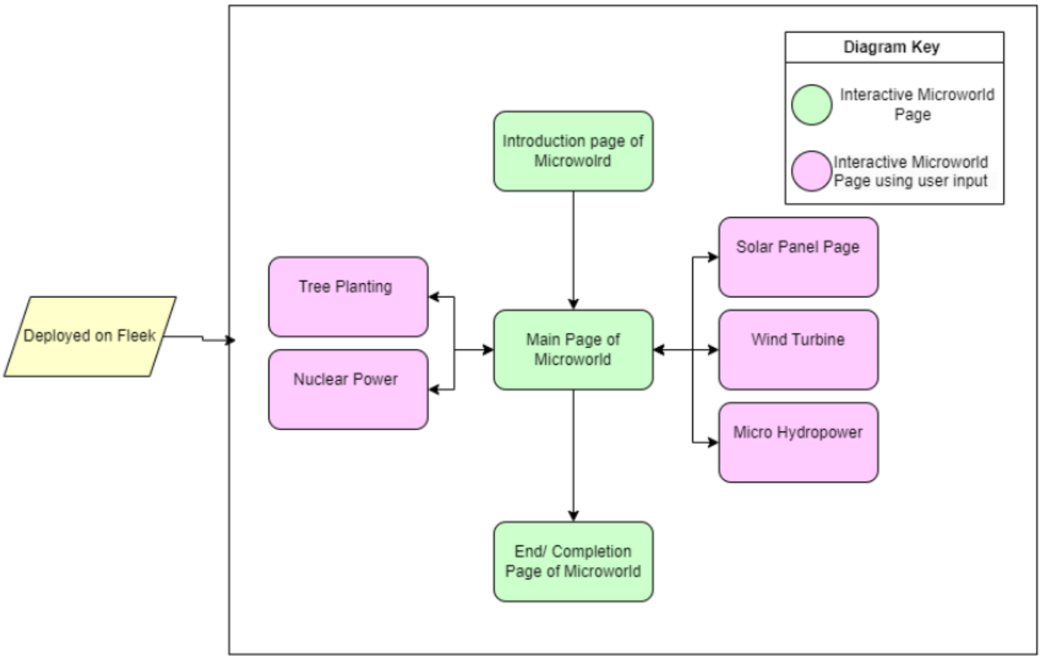

Figure 3-9: Visual Representation of Microworld

The utilization of mock designs during the design phase is imperative, as it provides the author with the opportunity to thoroughly test and refine their ideas prior to finalizing the design. By scrutinizing the functionality and aesthetics of the simulation, potential issues or areas for improvement can be identified, and necessary adjustments can be made. This process facilitates a more effective design process, which lends itself to a higher quality product, as demonstrated in this project. The figure above, is a visual representation of the authors template of the Microworld. Presented below is a mock design created for the Microworld simulation. Older Mock ups can be found in APPENDIX C. The initial prototype was formulated to guide the design and development of the simulator, considering the visualization techniques examined in Chapter 2, along with the project's prerequisite to integrate an immersive visualization with a substantial level of interactivity.

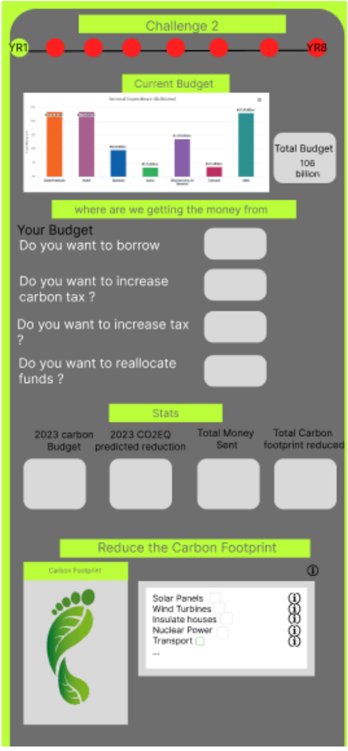

Figure 3-10: Final Mock-up of Microworld Design

This Mock-up details the basic layout for this project. As seen in Figure 3-10 a progress bar is situated at the top of the screen. Here users can see what year they are in in the simulation. Each circle represents a year between 2023 and 2030. It is imperative for the learning experience to be able to explore the carbon footprint and budget across the eight years between 2023 and 2030. This gives the user a realistic view on how to explore the national carbon footprint. A simulator that covers the eight years leading up to 2030 can provide a more accurate representation of the progress towards the 2030 goal. It can help people understand the subsequent steps needed to reach their goal of a 51% reduction in carbon emissions and track progress more effectively. It can also help the learners plan more successfully. It can help them understand what actions need to be taken in the short, medium, and long term to achieve the 2030 goal.

Following that, a bar chart containing the breakdown of the Irish budget for 2023 is shown. This allows the user to interact with the current budget of Ireland and helps the learner conceptualize how the Irish budget is currently split up. Bar charts allow for quick visual comparisons between different sectors. They present information in a simple and intuitive manner that can be easily grasped and interpreted by learners.

The user is then prompted to make choices based on how they want to fund their mitigation techniques, prompting users to further develop their critical thinking skills. Information such as 2023 Carbon Budget, 2023 CO2EQ Predicted Reduction, Total Money Spent, and Total Carbon Footprint Reduced is then shown on screen. This reiterates the information to users.

Below each prompt, users get to explore the mitigation techniques by clicking on the information buttons. When the user clicks on the mitigation technique they want to explore, they are shown more information about that technique e.g., Costs, how much CO2EQ it mitigates and other viable information (See Figure 3-11). This allows the user to make more informed decisions when trying to explore how to control the national Carbon Footprint given certain constraints.

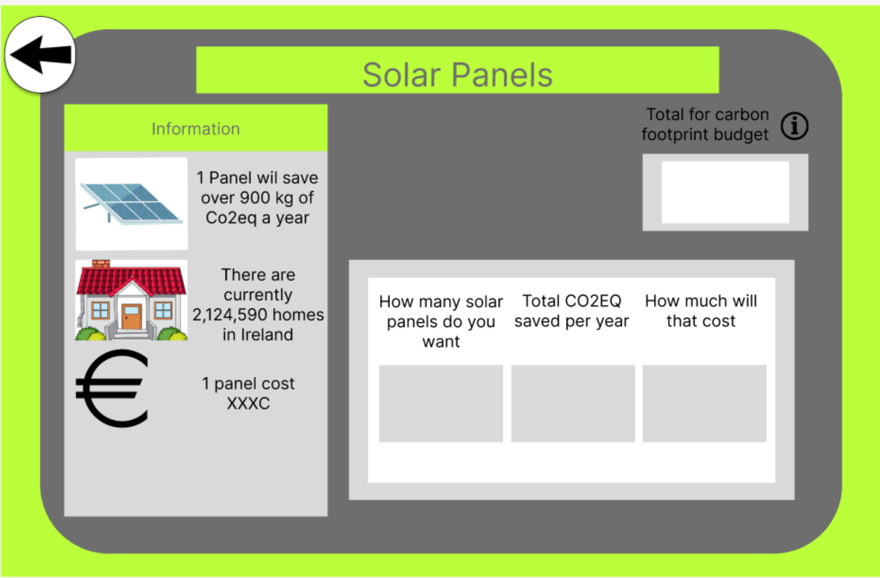

Figure 3-11: Mock Design for Mitigation Techniques

Here, the user will input how many solar panels they want to buy, then the total CO2EQ saved per year and Cost will be calculated.

Upon returning to the main screen, the size of the footprint displayed in Figure 3-10 will reduce proportionally based on the users chosen mitigation technique. This helps the user understand the impact of their actions. By presenting the footprint as a dynamic and interactive visual, users can see how their choices affect the size of the Carbon Footprint. This can be a powerful motivator for users to keep acting and implement more mitigation techniques to reduce their Carbon Footprint. It also provides a sense of accountability, as users can see the direct impact of their actions on the environment.

This author believes that the Microworld's initial design offered a compelling and efficient visual that learners could use to experiment and construct knowledge based on controlling the National Carbon Footprint.

3.12 Design Summary

In essence, the design of the tool is based on thorough background research aimed at identifying the most appropriate techniques for modelling and visualising the Carbon Footprint, mitigation techniques, and budgeting. The design was influenced by the relative merits and demerits of similar applications, with the ultimate objective of producing a tool that would possess both practical significance and distinctive features. The most fitting technologies were scrutinized and ultimately selected for this tool's creation.

4 Implementation

This chapter delves into the intricacies of the implementation of the proposed Microworld allows users to explore how to control the National Carbon Footprint. This implementation has been developed in accordance with the design requirements considered in the preceding chapter. The present discussion of the implementation has played a pivotal role in appraising the efficacy and constraints of the design. The goal of this chapter is to provide the reader with a comprehensive understanding of the development process of the Microworld.

4.1 The Challenges

Active learning prompts learners to participate in meaningful learning activities that encourage them to think about what they are doing. Therefore, it is pertinent to implement a variety of challenges that capture a range of desired learning outcomes and allow users to gain value from the Microworld.

Challenge 1: Reach the 2030 Goal with little to no constraints.

As the newly elected Taoiseach of Ireland, the first challenge is to make decisions on what mitigation techniques you are going to implement to reach the 2030 goal of a 51% reduction in carbon emissions. This challenge allows users to freely explore how to control the National Carbon Footprint without limitations.

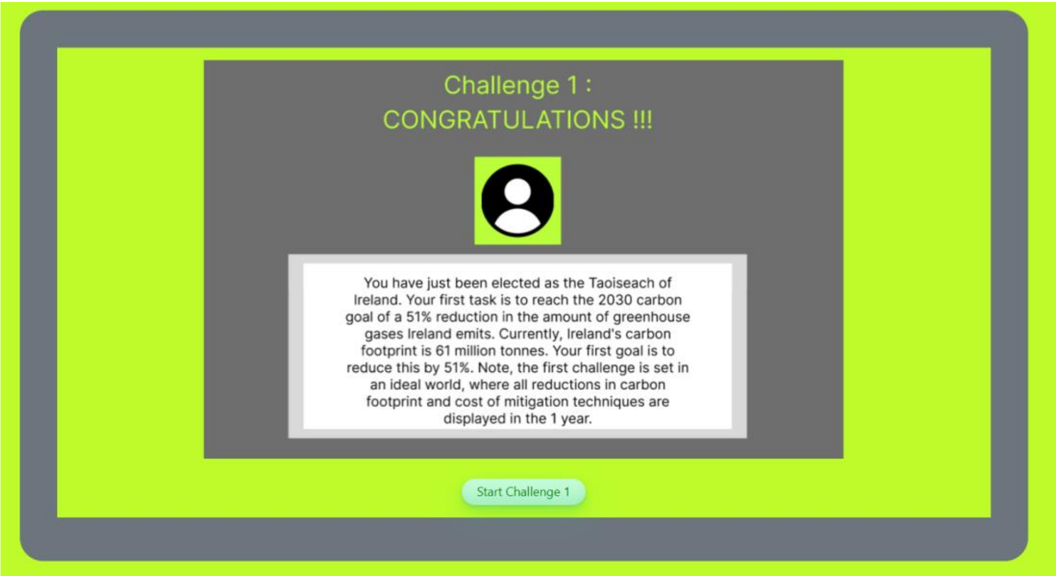

Figure 4-1: Challenge 1 Goal

Challenge 2: Reach the 2030 Goal with constraints e.g., Time and Money.

Like challenge 1, the user must make decisions as Taoiseach of Ireland to reach the 2030 goal. However, this time they must budget for money that they spend, and be aware of extra constraints such as time, space, and reality.

To make this project as effective as possible a "low floor, high ceiling" approach was taken when setting the challenges. This means that new learners, should find it easy to get started regardless of their background knowledge and it shouldn't be limiting for advanced users (Maiorana, 2019). The first challenge depicts the "low floor", the students are free to implement whatever strategies they believe to be most useful to meet the 2030 goal without having to worry about constraints. The "High Ceiling" ensures that advanced or returning learners still gain educational value from the Microworld as id seen in challenge 2. Here the users are more constricted in what they can do.

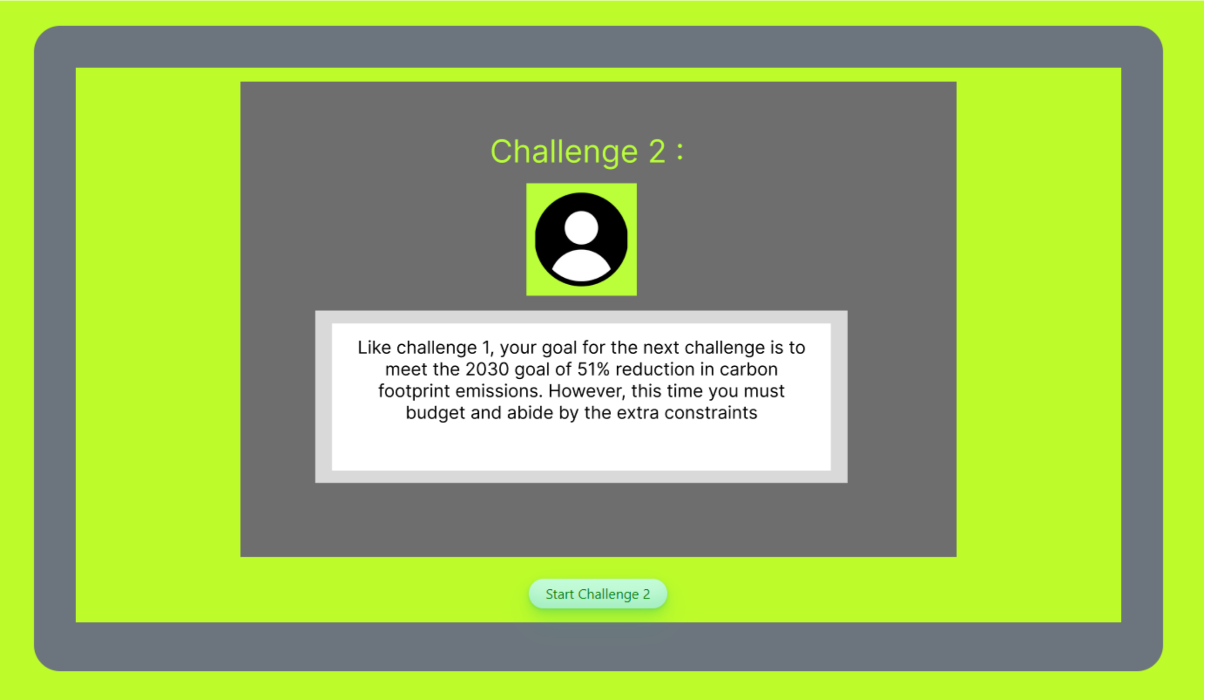

Figure 4-2: Challenge 2 Goal

4.2 The Mitigation Techniques

Building on the decisions to focus on exploring the National Carbon Footprint, this simulation utilised five different mitigation techniques, including Solar panels, Wind Turbines, Micro-Hydropower, Tree Planting, and Nuclear Power as discussed in previous sections. Each technique was developed with careful consideration of the unique characteristics of the technology and the environmental context in which it would be implemented. The creation of each mitigation technique varies, depending on the information explained in previous sections.

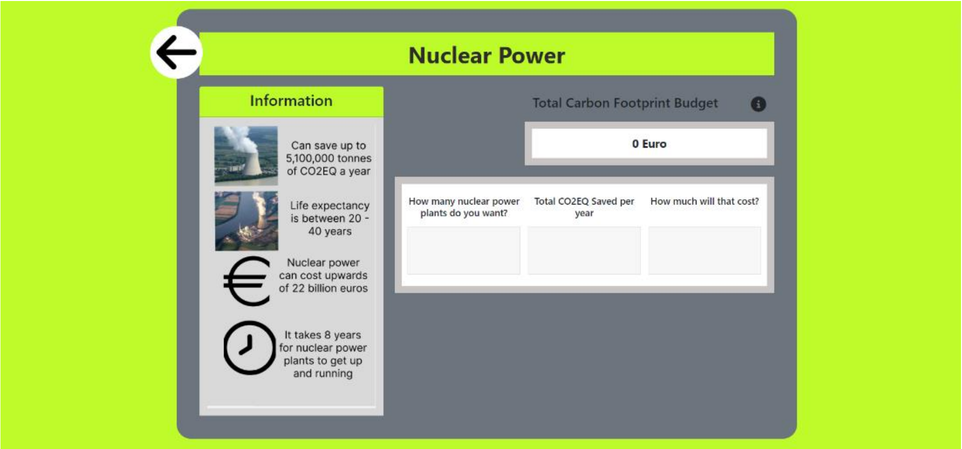

Figure 4-3: Mitigation Technique Page - Nuclear Power

In Challenge1, the learners are free to test any theory they believe will help the government to reach the 2030 Goal however, Challenge 2, shows makes the users abide by real life constrictions. For instance, the second challenge shows it is not feasible to plant over 400,000 trees per year due to the current governments plans for setting aside 20,000 HA per year. The table below taking inspiration from the Table 1 in section 3.3.6, below is a table showing the constraints for each technique implemented.

	How much CO2EQ does it mitigate per year	Cost in Euros	When in the Microworld will you see the reduction in CO2EQ	How many can be bought in the Microworld per year?	Discussion
Solar Panel	900kg	1,250	Same year	1,840,000 (total across 8 years)	Total no. of houses = 2.1 million and average number of Solar Panels per house is 8
Wind Turbines	1000 Tonnes	1,800,000	In 2 years	582	In 2019, 24 wind farms were built with an average of 10 turbines per farm. This number was planned to be doubled over the next couple of years.
Micro-hydropower	7 Tonnes	5,500	In 2 years	Unlimited, if cost is accounted for	Micro-hydropower as easily implemented therefore once the cost is accounted for students can plan to implement as they see fit.
Tree Planting	0.14 Kg	2	In 8 years	400,000	Government has set aside 20,000 HA per year for the next 8 years for tree planting and an average of 400,000 trees can be planted in this space.
Nuclear Power	51,000,000 Tonnes	22,000,000,000	In 8 years	1	Nuclear power is expensive and difficult to build therefore its constricted to 1.

Table 4 – Comparison of mitigation techniques constraints used in Challenge 2

Considering the complexities of each mitigation technique to implement this successfully each one was created having their own HTML and JS scripts which pushed the key information to local storage so it can be used throughout the Simulation. This allowed users to freely explore and decipher each mitigation technique. Event listeners are set in the code for each mitigation, listening for user input detailing the number of each mitigation technique they want to buy. Things such as the number of the technique bought, how much CO2EQ it mitigates and the target year are stored in local storage, therefore being accessible to read in all parts of the microworld see Figure 4-4. The target year of the mitigation technique is set, by getting the current year and adding the amount of time it takes for the technique to come into effect.

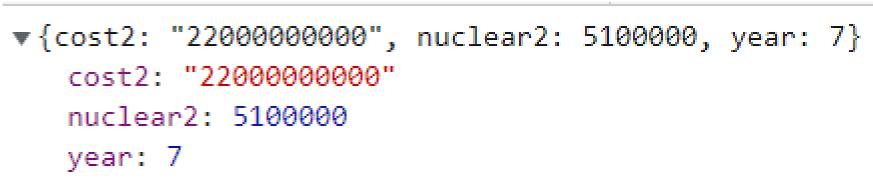

Figure 4-4: Example of Local Storage storing Nuclear Information

To provide feedback to the user, in case they input a number that exceeds the limit of the amount they can buy of each mitigation technique,a message is displayed to the user. For example, if a user inputs a request to buy 2 nuclear power plants, feedback such as Figure 4-5 is shown. This way, the user is provided with more context and guidance to make more informed decisions.

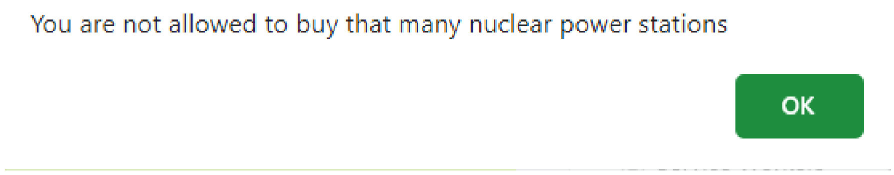

Figure 4-5: On screen Alert due to wrong input

Overall, this code allows users to input a number of each technique they wish to purchase and calculates the associated costs and carbon savings. The code also stored data in local storage for future use.

4.3 The Footprint

Once the user develops a plan and begins purchasing the mitigation techniques, as decided in the design stage, and stated in the design chapter the National Footprint will decrease in size depending on the Carbon Footprint of the technique and how many they have bought. It is crucial for the learner to be able to explore and witness the effects of their decisions in the Microworld. Therefore, the visual implementation of the carbon footprint getting smaller, as the total Carbon Footprint decreases is pertinent to the learners understanding. How, often the size of the footprint is changed depends on how often the function is called. It is set up to be called whenever the learner buys a new mitigation technique. This is done using event listeners and the Onblur() function.

Figure 4-6: Carbon Footprint IMG initially

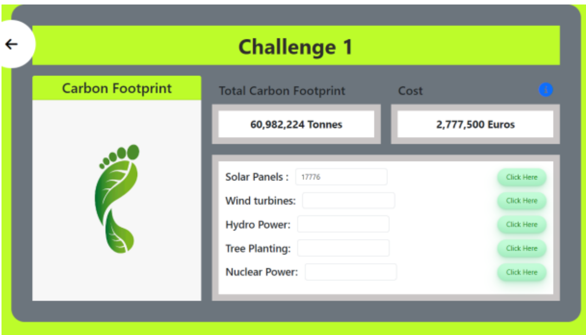

Figure 4-7: Carbon Footprint IMG after decreasing in size

This feature is implemented using the formula **(totalAvailable / 61,000,000) * 30**. Where totalAvailable is the sum of CO2EQ mitigated from all the purchased techniques. The graphical display is then updated in the simulation to show the user the relative impact of the mitigation technique has on the total carbon footprint, see Figure 4-6. Hence making the learning experience more cognitively engaging and achieving a key goal of this project in creating a Microworld where students could instantly see the consequences of their actions in a simulated environment in the hopes that it would cause discussion of their ideas.

4.4 Accounting for Costs

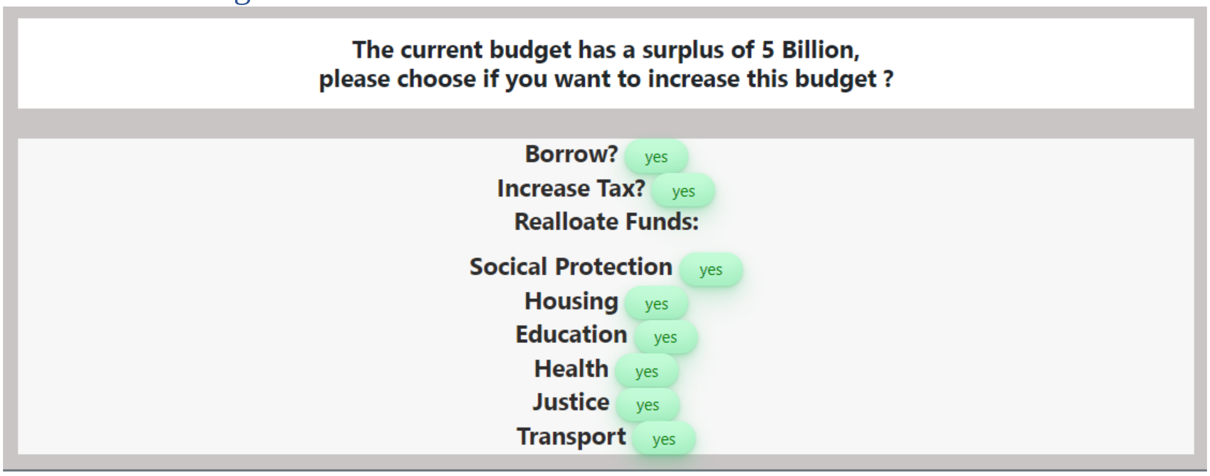

Figure 4-8: Reallocating Budget

To foster the user's cognitive engagement and simulate the real-life consequences of their decisions, a cost function was incorporated into the simulator. This integration of resource allocation requires the user to make thoughtful and deliberate choices when exploring the National Carbon Footprint. Furthermore, implementing the cost function facilitated the integration of challenge-based learning, a fundamental objective of this project.

A cost was assigned to each of the mitigation technique which is explained in Table 3. The costs for the mitigation techniques bought is accumulated and shown in screen. These techniques can be costly therefore, each year in the Microworld the learners must account for the cost of their purchases. To introduce the cost of this spending, the user was given a surplus in the budget of 5 billion euros and had the option Borrow, Increase Tax or Reallocate the current budget.

These choices were presented to the user on screen and have buttons beside them. These buttons were made using css styling. For example, if the user wants to reallocate the budget, they click the ‘yes’ button. Here the Microworld takes a predefined pro-rata amount from whichever area of the budget they choose.

Each section of the budget is assigned a function which takes the form of an event handler that is triggered by a user action (i.e. clicking a button) as seen below.

```
function ReallocatesocialProtectionHandeler() {
    alert('you`re borrowing 3 billion ')
    let reallocate = 3000000000;
    setData('reallocate', reallocate);
    yearBudget.innerText = Number(yearBudget.innerText) + Number(getData('reallocate'));


}
```

Figure 4-9: Reallocate budget function

Borrow Money is another option users have, to account for money they have spent. Similarly, to the reallocation of the budget, it was decided in the design stage that implementing a feature where users could borrow money from the EU to fund what they bought in terms of mitigation techniques was necessary to make the simulation as realistic as possible.

If the users choose to borrow money, an alert comes on screen prompting the user to enter how much they would like to borrow as shown in Figure 4-10. If the user chooses to borrow money, they also agree to repay 3% back each year thereafter. This is to emulate real world choices the government are faced with and allows for a thought-provoking learning experience.

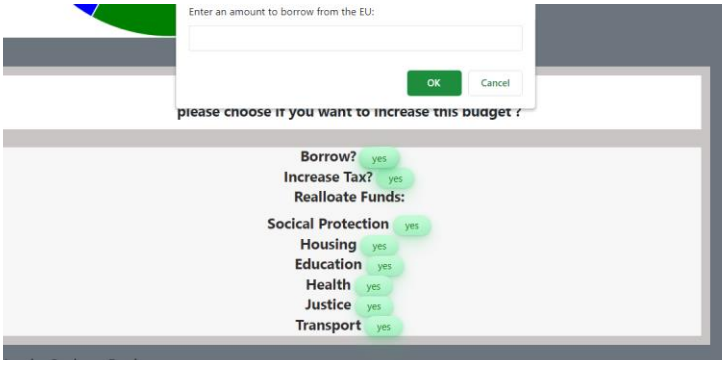

Figure 4-10: On Screen Borrow Money

The interest is calculated using the following formula: **Interest = ((borrowInterest / 100) * Number(getData('borrow1')));** where borrow interest is 3% and Number(getData('borrow1')) is the how much the user has selected to borrow.

The final option user has to account for the money they have spent is to increase tax

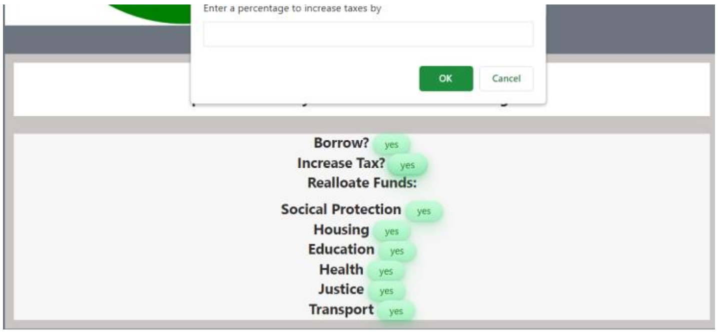

Figure 4-11: On screen Tax

If the user chooses to increase tax, and click the "yes" button, an alert appears on screen prompting the user to enter a percentage to increase the taxes by. The tax function is used to calculate a tax amount based on a given year and add it to a budget value stored in an HTML element, assuming certain conditions are met.

If their accumulated spend exceeded this new budget, they would not be permitted to move onto the next year, forcing them to re-evaluate their choices that year and make them think more cautiously about how they spend their budget.

The costings and reallocation of the budget acted as an educational feature, giving the users a more insightful and realistic experience when exploring decisions surrounding the National Carbon Footprint.

4.5 Simulating The Years Between Now and 2030.

As decided in the design phase of the project, it would be of educational benefit for users to be able to interact with the tool over the course of the 8 years between 2023 and 2030. This allows for a more comprehensive and accurate representation of the factors involved in exploring how to control the national carbon footprint. Shown below are how the years 2023 – 2030 are represented in the Microworld.

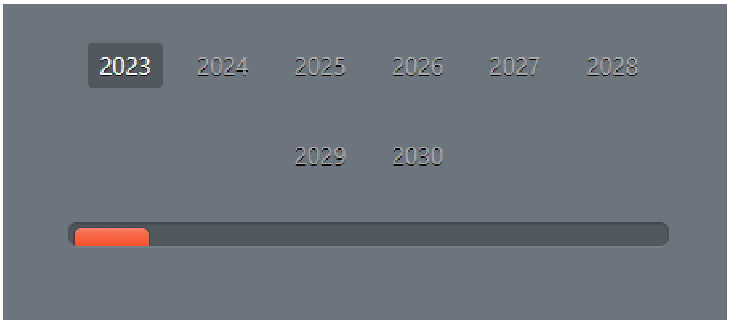

Figure 4-12: How the years 2023 – 2030 are represented in the Microworld.

This feature was implemented using a radio button element, whereby the radio is listening to see if the user has moved onto the next year. Initially the year is set as year 1. As the user progressed through the years the progress bar increments accordingly and changes in colour depending on how far away the learners are from the final year. This was of importance as the users could visualise how far away, they are from 2030, provoking them to assess their current plans and re-evaluate the choices they are making.

```html
<button class="button-34" onclick="finYear1()" role="button">Check </button>

<div class="containerdots">
    <input type="radio" class="radio" name="progress" value="one" id="one" checked>
    <label for="one" class="label"> 2023 </label>
    <input type="radio" class="radio" name="progress" value="two" id="two">
    <label for="two" class="label">2024</label>
    <input type="radio" class="radio" name="progress" value="three" id="three">
    <label for="three" class="label">2025</label>
    <input type="radio" class="radio" name="progress" value="four" id="four">
    <label for="four" class="label">2026</label>
    <input type="radio" class="radio" name="progress" value="five" id="five">
    <label for="five" class="label">2027</label>
    <input type="radio" class="radio" name="progress" value="six" id="six">
    <label for="six" class="label">2028 </label>
    <input type="radio" class="radio" name="progress" value="seven" id="seven">
    <label for="seven" class="label">2029</label>
    <input type="radio" class="radio" name="progress" value="eight" id="eight">
    <label for="eight" class="label">2030 </label>



    <div class="progress">

        <div class="progress-bar"></div>
    </div>
</div>
```

Figure 4-13: Radio to show years 2023 -2030

The Microworld also keeps track of the current year and checks if the current year in the simulation is equal to the target year of any previously bought mitigation techniques and deals with them accordingly. For instance, if a user in year 1 opts to buy 20,000 trees, as trees take 8 years to grow to mitigate 0.14kg a year, the amount of CO2EQ these trees have mitigated should be taken out on the 8th year. Alongside this when the YearChange() function is called, components of the code are reset for instance the number of each mitigation technique purchased in that year and the current amount spent, the previous values are stored in local storage. The simulation closely mimics real-life situations, making it a highly valuable educational tool. Students can observe the consequences of their choices over an extended period of eight years, enhancing their learning experience.

4.6 Creating Charts for Budget

Bar Chart

The bar chart is a commonly employed visualisation tool for demonstrating budgets due to its ease of comprehension and simplicity. This type of chart is used to display the distribution of data points or to compare metric values across various subgroups of the data. Pie charts and stacked-column charts were also considered for this however, due to its familiarity with users and intuitive nature, the bar chart was chosen as the accompanying chart during the design stage. Interactivity was a crucial requirement for the graph, as it facilitated the visual representation of each section of the Irish budget throughout the simulation. The Chart.js library was utilised to construct this graph.

```
var xValues = ["Social Protection", "Health", "Housing", "Education", "Transport", "Justice", "Debt Servicing, EU payment",
"other", "Surplus"];
var yValues = [23.9, 24.0, 6.4, 10, 3.5, 3.4, 13.6, 18.6, 5];
var barColors = ["red", "green", "blue", "orange", "brown", "purple", "pink", "yellow"];

var mychart = new Chart("myChart", {
    type: "bar",
    data: {
        labels: xValues,
        datasets: [{
            backgroundColor: barColors,
            data: yValues
        }]
    },
    options: {
        legend: {
            display: false
        },
        title: {
            display: true,
            text: "2022 Total Expenditure : €103.5 billion "
        }
    }
});
```

Figure 4-14: Total Expenditure Bar chart Code

This created a singular bar chart, which when a user hovers over a bar within the chart the allocation of the Irish budget for that section is shown.

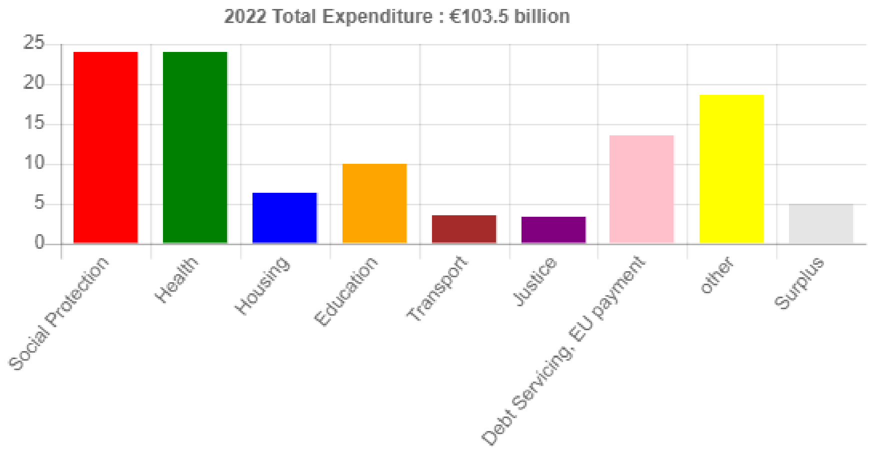

Figure 4-15: 2022 Total Expenditure budget (Ireland)

Pie Chart

It was important to further emphasise the breakdown of Debt servicing and Eu payments, so a pie chart was also used to show this. This was also implemented using the Charts.js method. The pie chart allows for easy, yet effective interpretation of the given data.

```
var xValues = ["Service of National Debt", "EU Budget Contribution", "Other Von Voted Expenditure"];
var yValues = [3.91, 3.98, 5.71];
var barColors = ["red", "green", "blue"];

new Chart("myChart2", {
    type: "pie",
    data: {
        labels: xValues,
        datasets: [{
            backgroundColor: barColors,
            data: yValues
        }]
    },
    options: {
        legend: {
            display: true
        },
        title: {
            display: true,
            text: "Debt servicing, Eu payments drill down "
        }
    }
});
```

Figure 4-16: Debt Servicing, EU Payment drilldown Pie Chart Code

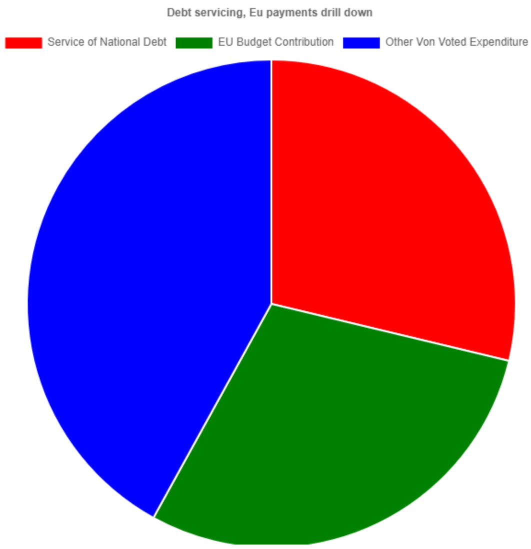

Figure 4-17: Pie chart of Debt servicing, EU payments drill down

4.7 The Challenge Complete Feedback

It was deemed beneficial to provide users feedback following the completion of the project, informing them if they had successfully met the 2030 Goal or not. This is in line with the functional requirements of the Microworld discussed earlier in the project. Key pieces of information such as Total Money Spent, Total Carbon Saved and Reduction Percentage are retrieved from local storage and presented to the user on the final page see Figure 4-18 and 4-19. This allows users the chance to reflect on the choices they made, making them more cognizant of their decision-making process.

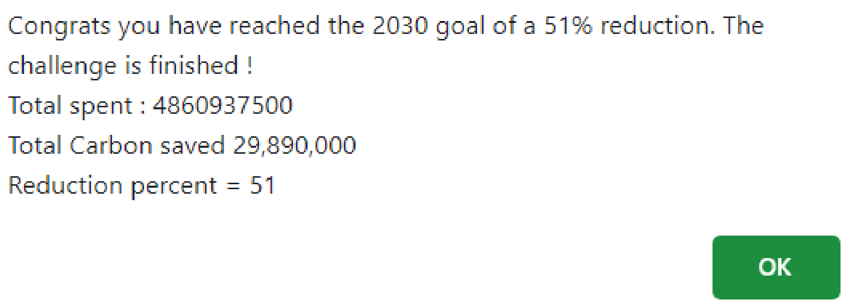

Figure 4-18: Challenge Complete

Figure 4-19: Challenge complete 2

4.8 User interface Flow and Enhancements

This subsection provides a summary of the user interfaces final flow as well as other enhancements in which enrich the Microworld, making it an overall more compelling experience for users. The final flow is heavily influenced by human-computer interaction theory. It is designed to provide the most relevant information when it is needed, enhancing the learners overall experience. This tool was designed with the user in mind, allowing it to be a part of the thinking process rather than hinder the learner. Easily recognisable features such as buttons, information buttons and navigation arrows, were tactfully chosen as it allows accessibility to both new and returning users. This tool was built based on scaffolding techniques, i.e. the next step is available following the completion of the previous step. This creates an intuitive learning experience for the users. Throughout the Microworld feedback is given to users, for instance when a user attempts an action that is not permitted by the tool. This can be seen in Figure 4-5 when the user inputs a value too high for the number of nuclear power stations they want to buy. These features were implemented to improve the flow of the tool and allow users to focus on exploring and learning.

4.9 Summary

This chapter centres on the implementation of the proposed Microworld, intended for the exploration of controlling the national carbon footprint. The chapter's aim was to provide a comprehensive understanding of the development process. As the simulator has met its functional and non-functional requirements, it was essential to commence testing and evaluation to determine the extent to which the project fulfilled its objectives. This evaluation would also help identify the strengths and weaknesses of the Microworld as an educational tool, and the feedback obtained could then be utilized to guide the future development and enhancement of the tool. The subsequent chapter will delve into the results and evaluations of the trends discovered.

5 Testing and Evaluation

To assess how effective this project was, a real-world evaluation of the tool with learners was imperative. The evaluation should encompass an appraisal of the project's accomplishment in leveraging contemporary and data visualisation technologies to build an interactive simulator that is supported by Human-Computer Interaction. Additionally, the evaluation should critique the educational value of the tool and its ability to successfully obtain its intended learning objectives.

Testing and evaluation were carried out in four stages as seen in Figure 5-1. These stages include Opportunistic Peer Evaluation part 1 & 2, B2C Workshop Facilitators and B2C students. Each stage of testing contributed to the success of the project.

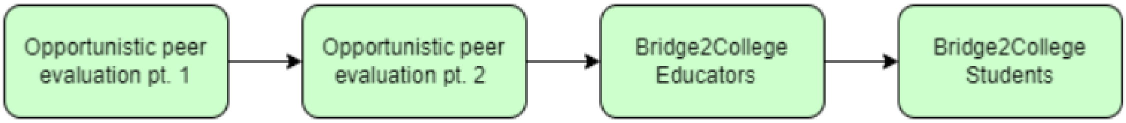

Figure 5-1: Testing and Evaluation (Made in Canva)

5.1 Opportunistic Peer Evaluation

Opportunistic Peer Evaluation took place in 2 forms: discussions, and evaluation with peers who were doing similar projects to this one and evaluation of peers that had not no prior knowledge.

<u>Opportunistic Peer Evaluation pt. 1:</u>

This evaluation method comprised of several feedback sessions and discussions with undergraduate students who had undertaken similar projects, during which Microworlds were presented and open discussions took place. These discussions were primarily centred around the construction and design of the Microworld. Discussion surrounded the design of the Microworld, the human-computer interaction elements and the learning outcomes. This led to pivotal design decisions, for example changing from the initial idea of using a weighing-scales metaphor for balancing the Carbon Footprint, see APPENDIX C, to the image of the footprint changing in size used in the final design (Figure 4-7). These feedback sessions allowed for a seamless design process, which helped to refine the design of the Microworld quickly and effectively. This opportunistic peer evaluations ultimately resulted in valuable insights that facilitated the creation of a more successful Microworld.

<u>Opportunistic Peer Evaluation pt. 2:</u>

The second form of opportunistic evaluation took place with peers who had not seen the Microworld before. N=5 classmates/friends used the tool for a brief period and gave feedback on the tool's usability and effectiveness. This exercise generated useful feedback from the perspective of a first-time user. This helped to identify usability issues and highlighted changes

that would improve the user experience. This process yielded valuable insights into the tool's functionality, the learners' interaction with it, and the adjustments that must be made before the B2C Transition Year student engaging with the tool. Feedback regarding the layout of the Microworld was given as well, for example, it was pointed out that not enough information was given when the learner completed the challenge. This was rectified by adding the amount of CO2EQ reduced and the total reduction percentage of carbon emissions when finishing the challenges (see Figure 4-18).
Some other key feedback was as follows.

"The layout made it intuitive to use and the facts about each method were very interesting. I did not realise how much certain mitigation techniques cost". - *Undergraduate Peer*

"Before using the carbon footprint simulator, I found the Irish Budget very confusing, and I found it confusing to know about how much the government should spend on Climate Change and sustainability. The Microworld made it much easier to understand, and now I feel like I've a much better understanding. It gave me an appreciation for how Ireland could potentially reduce its carbon footprint, whilst being budget cautious." - *Undergraduate Peer*

"As an educator, I believe that this tool holds tremendous potential for enhancing the learning experience. It has been thoughtfully designed and is easy to use, making it an asset in the classroom. I can envision this tool being integrated across various subjects, further enriching the educational journey for students." - *Secondary School Teacher with MSc in education*

Another change which was made to the Microworld based on feedback received, was to have "Click Here" buttons instead of information symbol ⓘ as this allowed for ease of flow aligning with the human computer interaction methods which refers to the ability of users to seamlessly navigate through digital interfaces with minimal cognitive or physical effort.

The feedback enabled the author to implement modifications that further enhanced the tool's effectiveness before proceeding with subsequent stages of deployment and testing. This approach allowed for the prioritization of critical issues and a structured process that leveraged feedback from a diverse range of peers. The continuous improvement and feedback prior to the leaners using the tool proved to be paramount. Implementing changes to ensures the tool remains pertinent and efficacious over time.

5.2 Bridge2College group-based learning task

For testing and evaluation, the tool was used by (N=23) TY students for a period of 2 hours as part of a two-day workshop, within the Bridge2College program, exploring different aspects of Climate Change. The schedule of the day can be found in APPENDIX B

B2C participants benefit from the guidance of undergraduate and postgraduate mentors who help facilitate a unique model of teamwork and promote the creative use of technology to deliver an innovative educational approach. This program provides an ideal framework within which to evaluate the efficacy of the program.

The workshop meticulously designed a series of activities anchored around the concept of the Microworld, where learners were provided with a unique opportunity to delve into the intricate dynamics of controlling the National Carbon Footprint.

The workshop was conducted by the B2C team of facilitators, in collaboration with the author. The B2C team established the optimal approach for conducting these classes, with the aim of maximizing the learning potential of the tool and providing every student with sufficient opportunities to experiment with the Microworld and offer their feedback afterwards.

The students were first given a brief presentation of the key information needed to complete these challenges. A fact sheet was provided to the students to further aid them whilst working with the Microworld, see Appendix D. The students were given a brief demonstration of the Microworld and then were broken up into teams in which they attempted the two challenges. After each challenge everyone reconvened into the class as a whole and presented their findings.

Figure 5-2: Learners interacting with the Microworld

Figure 5-3: Learners interacting with the Microworld

5.3 Bridge2College Group-Based Learning Task Discussion

After utilizing the Microworld, a discourse was conducted to deliberate on the findings of the learners. This segment provides a comprehensive account of the dialogue encompassing the Microworld.

The participants were divided into six teams consisting of four to five individuals and were tasked with presenting their climate action strategy to the remaining groups, including making a case for why they should be re-elected to office.

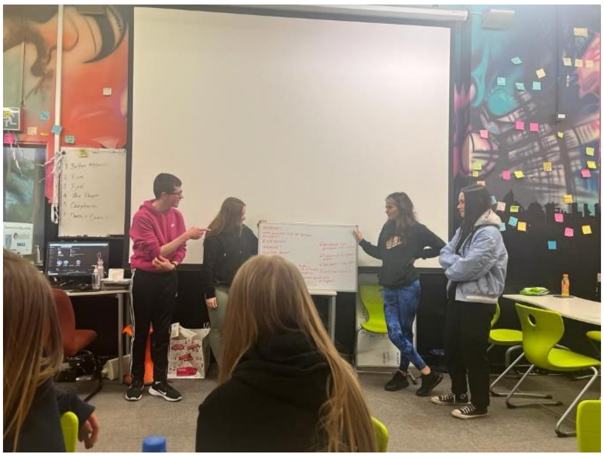

Figure 5-4: Presentation 1

Figure 5-5 Presentation 2

Key Points from the presentations by the teams included the following.

<u>Team 1 – Buffalo Mozzarella:</u>

- Tax the rich significantly more and increase tax in general.
- Invest in trees to lower the Carbon Footprint of Ireland.
- They believe that nuclear power was too expensive therefore decided not to invest.
- They also planned to invest in solar panels and wind turbines when they are waiting for the trees to grow.

<u>Team 2 – Rare:</u>

- Planned to invest in micro-hydropower.
- Will plant trees.
- They ranked the mitigation techniques and believed that planting trees was the most useful, followed by solar panels, then micro-hydropower.
- To fund their agenda, they reallocated the budget taking money from education, and social protection.
- They did not want to invest in nuclear power.

<u>Team 3 – Capybaras:</u>

- Their agenda focused solely on planting trees.
- They outlined the jobs they would create by implementing this plan.
- They decided to eradicate the current plan of only allowing 20,000 HA a year for tree planting.
- They aimed to mitigate 67.2 million tonnes of CO2EQ per year. Spending 1.2 Billion on Trees and using 12,000,000 out of the 17,000,000 free acres of land (they found this figure online)
- They would fund this using the surplus in the budget.
- The opted out of using other techniques. Nuclear was too expensive and dangerous. "*Wind turbine effects the birds*" and solar panels also "*effect the birds*".

<u>Team 4: Basl:</u>

- This team opted not to increase the taxes as they *"care for the people"* of Ireland.
- They opted to borrow money from the European union.
- They proposed building a nuclear power plant.
- They believed that this would generate jobs and effectively reach the 2030 goal.

Team 5: Double 'S' Double 'C':

- They choose to increase taxes by 15% and reallocate the budget taking from social protection and justice.
- They decided to give all the houses in Ireland solar panels.
- They also decided to plant the maximum number of trees each year.

Team 6: The People:

- They planned to build micro-hydropower.
- They were against nuclear power, outlining the devastating effects it has had in the past (Chernobyl)
- They planned to invest in solar panels, as they would help to reduce the national carbon footprint as well as reduce energy costs for the people of Ireland.

Following each team's pitch for re-election, the learners voted for which team they wanted to be elected. Team 2 – Rare – won the election, as seen in Figure 5-6.

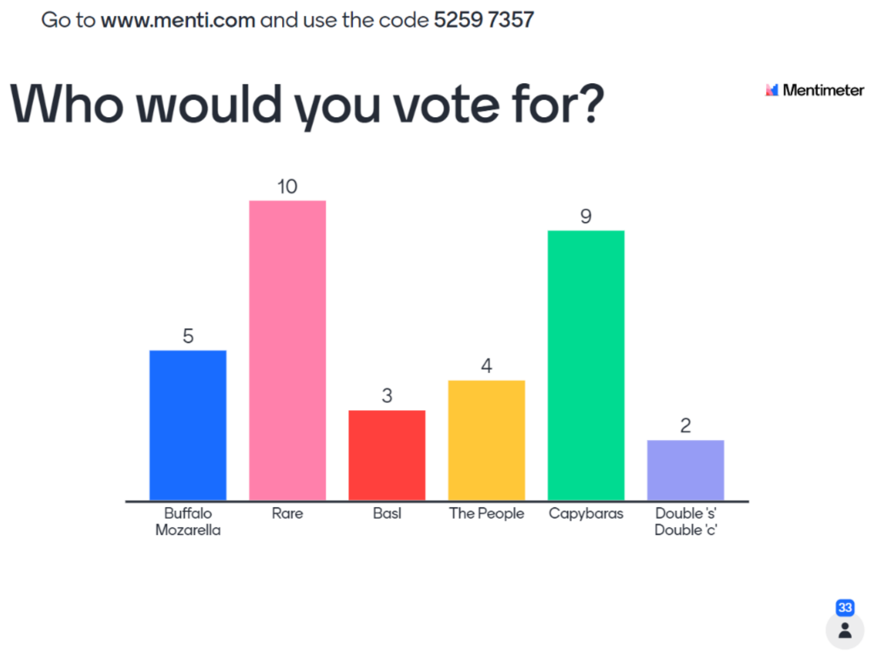

Figure 5-6: B2C Election Results

The presentations sparked debate about the 2030 goal, along with the different mitigation techniques used in the Microworld. Several noteworthy arguments raised during the debate include:

- **Wind Turbines:**
  - Where should we build the wind turbines? Some learners did not want to have them beside their house due to sound pollution and said they were "eye sores".

- Some learners believed that offshore wind farms such as "Arklow Bank" were more beneficial as the government doesn't have to deal with noise pollution and distance from popular areas.

- **<u>Nuclear Power:</u>**
    - A lot of debate surrounded nuclear power.
    - A walking debate was held with the statement *"I believe that nuclear power should be unbanned in Ireland."* The students separated themselves into three categories and outlined the reasons for their choices:
    - <u>Agree:</u>
      - Power Plants create a lot of jobs.
      - Nuclear power plants create more energy than waste.
      - To implement other mitigation techniques oils and fossil fuels are needed.
      - One student said, *"France has 58, and it has worked well for them."*
      - Another student noted that, *"People only remember nuclear power stations when they talk about disasters, but there are currently a lot of ones that did not end in disaster."*
      - *"Yes, nuclear power is risky, but so is everything else"* stated another student. *"A lot of deaths happen due to fossil fuels and oil, but they still get used."*
    - <u>Disagree:</u>
      - Disasters such as Hiroshima and Chernobyl were pointed out, showing the devastating effects when Nuclear Power Plants go wrong.
      -It is extremely not safe for pregnant women, if power stations are built near residential areas and the plant leaks into the water.
      - *"Other mitigation techniques can be just as good and less risky".*
    - <u>Undecided:</u>
      -Some students were undecided as they believed that they were uninformed and needed to research the subject further before stating their opinions.

Great discussion and debate were had surrounding the Microworld. It is important to note that the specifics of the re-election campaigns or the results of the debate are not statistically correct but that the learners got the opportunity to explore the decisions involved in controlling the National Carbon Footprint.

5.4 Usability Evaluation

The evaluation of a system's usability is a widely employed technique for determining the degree to which a system's user can accomplish their objectives, and as such, it was a fundamental principle in assessing this tool. In the expansive field of Human-Computer Interaction (HCI), there are numerous approaches for comparing and assessing the usability of interactive interfaces. One of the most used approaches is usability surveys. Several standardized surveys have been developed explicitly to determine a user's evaluation of a system's usability. The System Usability Scale (SUS) and the Post-Study System Usability Questionnaire (PSSUQ) are two of the most frequently used standardized surveys designed for this purpose.

5.5 System Usability Scale (SUS)

The system usability survey is a short 10-question survey, which is reliable for measuring usability. Five response options are available and range from Strongly agree to Strongly disagree. This questionnaire was originally created by John Brooke in 1986 to evaluate a range of products and services and has now become an industry standard. This can be attributed to its efficiency to differentiate between usable and non-usable systems and its reliability in small sample sizes (Brooke, 1995) .

	The System Usability Scale Standard Version		**Strongly disagree** 1	2	3	4	**Strongly agree** 5
1	I think that I would like to use this system.		○	○	○	○	○
2	I found the system unnecessarily complex.		○	○	○	○	○
3	I thought the system was easy to use.		○	○	○	○	○
4	I think that I would need the support of a technical person to be able to use this system.		○	○	○	○	○
5	I found the various functions in the system were well integrated.		○	○	○	○	○
6	I thought there was too much inconsistency in this system.		○	○	○	○	○
7	I would imagine that most people would learn to use this system very quickly.		○	○	○	○	○
8	I found the system very cumbersome to use.		○	○	○	○	○
9	I felt very confident using the system.		○	○	○	○	○
10	I needed to learn a lot of things before I could get going with this system.		○	○	○	○	○

Figure 5-7: System Usability Scale Questionnaire

5.6 Post study Usability Questionnaire (PSSQU)

The Post Study Usability Questionnaire (PSSQU) is a 16-question standardized questionnaire widely used to measure a user's satisfaction of a website or software system. Each question is evaluated using a 7-point Likert scale. The questionnaire provides sub-scores for each of the three domains as seen below. To calculate an overall score for the system, the average score of the 16 questions is taken, and this score ranges from 1 to 7. The PSSUQ is a reliable metric that can be used to compare a system's usability with industry standards (Lewis, 1995).

	The Computer System Usability Questionnaire Version 3	Strongly agree						Strongly disagree	
		1	2	3	4	5	6	7	NA
1	Overall, I am satisfied with how easy it is to use this system.	○	○	○	○	○	○	○	○
2	It is simple to use this system.	○	○	○	○	○	○	○	○
3	I am able to complete my work quickly using this system.	○	○	○	○	○	○	○	○
4	I feel comfortable using this system.	○	○	○	○	○	○	○	○
5	It was easy to learn to use this system.	○	○	○	○	○	○	○	○
6	I believe I became productive quickly using this system.	○	○	○	○	○	○	○	○
7	The system gives error messages that clearly tell me how to fix problems.	○	○	○	○	○	○	○	○
8	Whenever I make a mistake using the system, I recover easily and quickly.	○	○	○	○	○	○	○	○
9	The information (such as online help, on-screen messages, and other documentation) provided with this system is clear.	○	○	○	○	○	○	○	○
10	It is easy to find the information I needed.	○	○	○	○	○	○	○	○
11	The information provided with the system is effective in helping me complete my work.	○	○	○	○	○	○	○	○
12	The organization of information on the system screens is clear.	○	○	○	○	○	○	○	○
13	The interface* of this system is pleasant.	○	○	○	○	○	○	○	○
14	I like using the interface of this system.	○	○	○	○	○	○	○	○
15	This system has all the functions and capabilities I expect it to have.	○	○	○	○	○	○	○	○
16	Overall, I am satisfied with this system.	○	○	○	○	○	○	○	○

**The "interface" includes those items that you use to interact with the system. For example, some components of the interface are the keyboard, the mouse, the microphone, and the screens (including their graphics and language).*

Figure 5-8: Post-Study Usability Questionnaire

5.7 Questionnaire Choice

Based on an analysis of two questionnaires, it was decided to include a selection of questions from PSSUQ and SUS in this study. This makes the survey more effective, given that users are requested to complete a series of challenges. Moreover, since the application comprises interactive elements and background information on topics, the breakdown of scores for system usefulness, information quality, and interface quality is useful for comprehending the specific parts of the application that the user is referencing.

5.8 Usability Results

A total of 23 Transition Year Students filled out this questionnaire after the dedicated class. As this was the first time this system was evaluated using this metric there were no previous results to compare against.

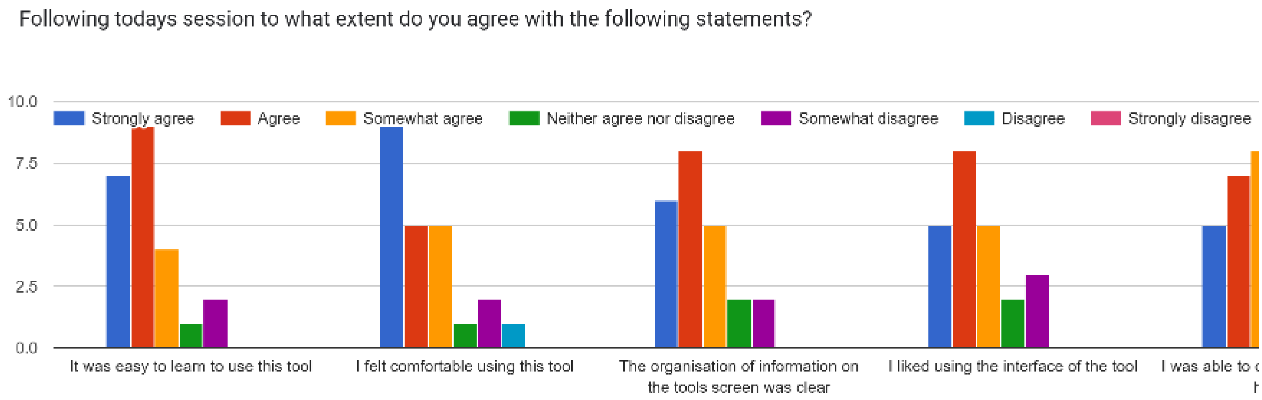

Figure 5-9: Results from the survey pt 1

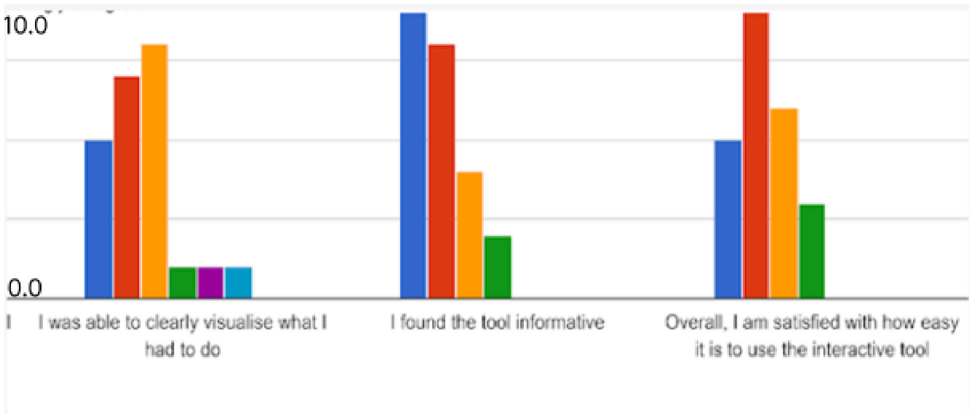

Figure 5-10: Results from the survey pt 2

Overall, the responses regarding the tool were positive. The tools greatest weakness seems to be it can be confusing at times to navigate and it was hard to reset. The tool proved to be highly informative, and overall, the learners were satisfied with how easy it was to use the interactive tool (See Figure 5-9 & 5-10). Most of the learners liked using the interface of the tool but it was noted in the survey that *"the design of it could be improved (e.g., colour scheme)"* so perhaps going forward a small focus group of participants could critique and improve this.

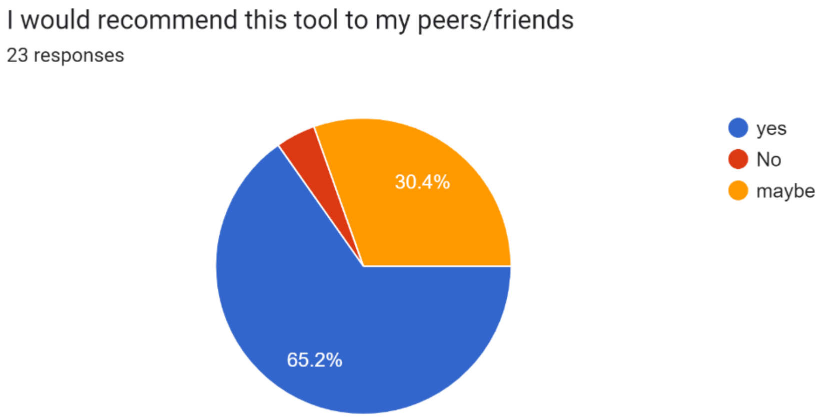

Figure 5-11: Results from Survey - I would recommend this tool to my peers.

When asked if the students would recommend this tool to their peers the majority (65.2%) said they would, and 30.4% said that they might as seen in Figure 5-11. When prompted for reasons for their answers, the learners said "It's easy to use and it is also informative" , "It is interesting and unique as a learning tool", "I would because it's an eye opener, it is really good and teaches things u or the government can do to decrease Ireland's carbon footprint", "it's very interesting and informative and puts bigger scale mitigation techniques into perspective", "It's easy to use, it brings awareness and it's fun". The one response that indicated that they would not recommend this to their peers said "I would not recommend it simply because I do not think that any of my friends would be interested in it. It was hard to restart."

In summary, the results imply that the application fulfils the objectives set forth at the beginning of this project, with the capacity for further enhancement in the future.

5.9 Education Benefit

The primary criterion for this tool is that it should be of educational benefit to the user, with the objective of helping them comprehend and explore how to regulate their country's Carbon Footprint. Based on the pedagogical theory discussed earlier, the tool demonstrates an ability to encourage critical thinking and constructivism. To assess the educational benefits of the tool, a survey was created that aimed to evaluate it in various ways. The survey's goal is to determine how much the user's understanding has improved on a range of subjects. Whilst the results would be more accurate with a larger sample size, this was not feasible at the time this survey was conducted.

According to the data collected from the survey, a preliminary examination indicates that an overwhelming majority of students (95.6%) believed that they had become more knowledgeable, or significantly more knowledgeable, regarding Carbon Footprint modelling at a national level as shown in Figure 5-12 below.

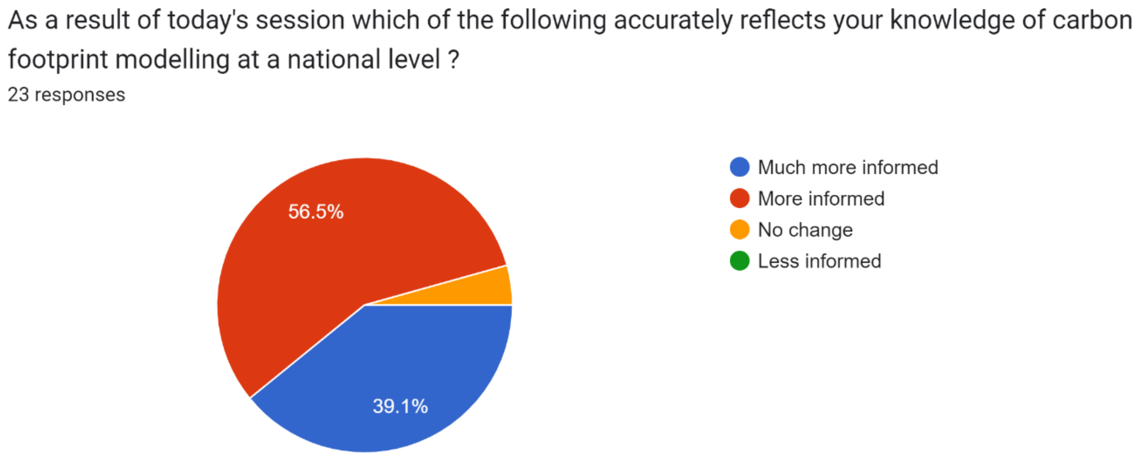

Figure 5-12: Survey Results – knowledgeability

To assess the educational effectiveness of the tool, an additional measure involved gathering user feedback on specific topics after using the Microworld, and examining how it impacted their opinions. Users were asked to rate their level of agreement with a series of statements following the use of the tool.

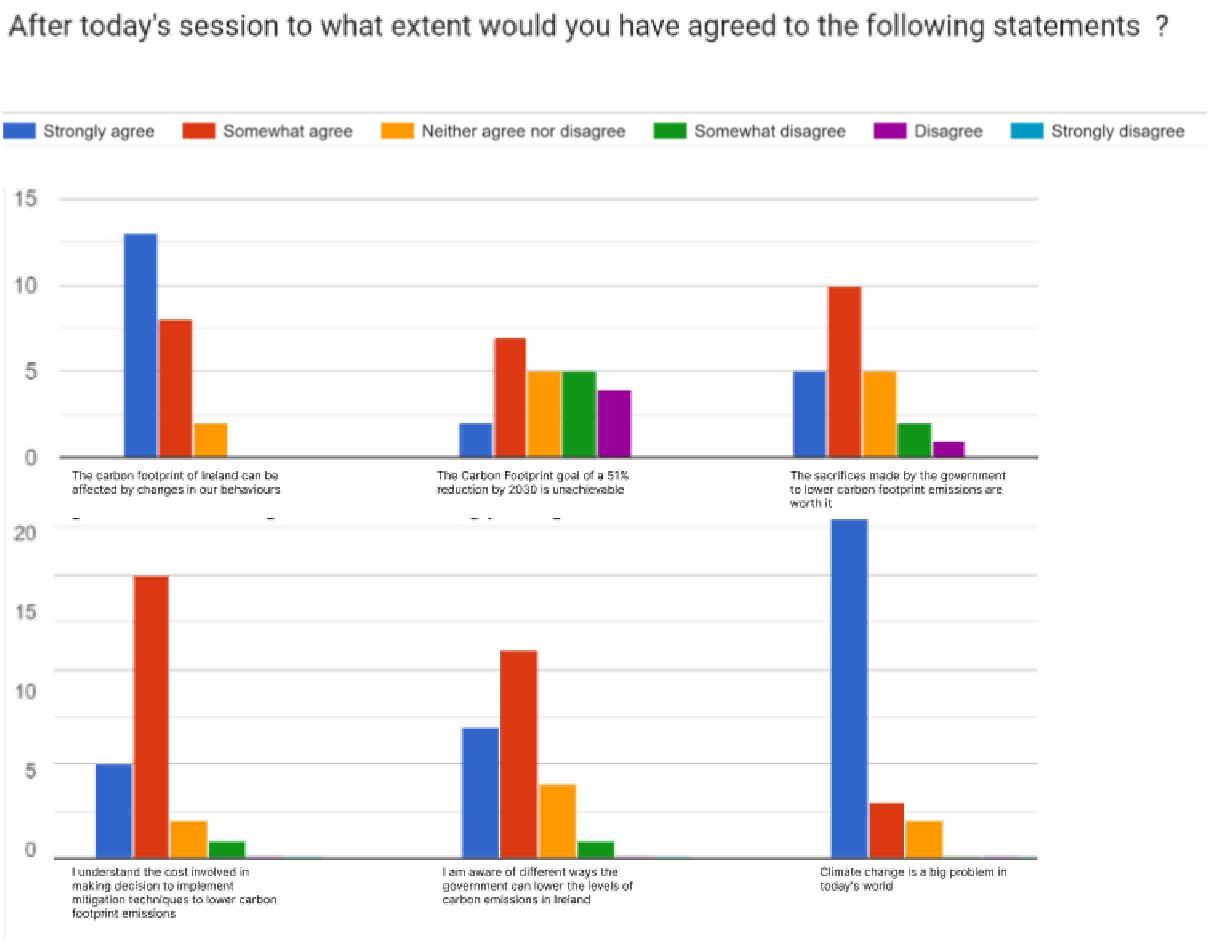

Figure 5-13: Education Benefit Survey Results

65% of learners said the sacrifices made by the government to lower carbon emissions are worth it and 86 % said they understand the cost involved in making decision to implement mitigation techniques to lower Carbon Footprint (Figure 5-13).

The evaluation techniques employed indicates that the tool is successful in achieving its objective of offering a simulation tool grounded in both pedagogical and Human-Computer Interaction principles, which can enhance students' comprehension of controlling the national carbon footprint. This assertion is supported by the qualitative feedback provided by the surveyed students. Below are a selection of quotes from the students talking of what they learned.

"The pros and cons of nuclear power, why budgeting in important, Learning to reduce our carbon footprint."

" Different mitigation techniques and their effectiveness. The pros and cons of mitigation techniques. I understood how much planning actually goes into making a country more sustainable e.g. be aware of money and budget and the time involved into seeing the result"

"Ways we can decrease carbon emissions."

5.10 Educator Feedback

Having carried out an initial testing with some age-relevant users, it was also deemed beneficial to capture the view of educators on the effectiveness of the tool from a pedagogical standpoint. Feedback from a number B2C educators, who helped to facilitate the workshops and witnesses the target demographic interact with the Microworld, was gathered. Some of the key feedback included:

- They "*would use the tool out in Citywise*." (Citywise is one of the programs run by the B2C educators.)
- *"It generally went really well*."
- *"There is a lot of milage using the tools."*
- *"The students didn't realize at first how much they were learning because it felt like a game."*
- *"They (the learners) were talking to each other quite a lot about the context and the tools among themselves."*
- The educators were *"impressed"* by how the learners *"unprompted, asked to take the tool back to their school and Identified that it was a good tool for themselves".*
- *"The Microworld has a good hook to get them engaged."*
- *"More impactful doing something with it", "more impactful than a book"*
- *"The debate and discussions afterward were quite good, we maybe underestimated the discussions, didn't quite know how it would go."*
- *"With Sarah's, the budget could be drawn out quite a lot more and connected it more to the business side of things. We could of had a follow up day or afternoon that expanded on that aspect of it because there was a lot of great learning opportunities there."*

5.11 Evaluation Summary

In summary, the testing and assessment carried out in this project have proven that the objective of creating a Microworld that facilitates learners in comprehending the management of the national Carbon Footprint has been achieved. The conducted evaluation has established a robust groundwork for refining future iterations of the tool, integrating the received feedback, and improving its potential as it evolves beyond the initial testing and assessment.

6 Conclusions

6.1 Summary

This paper was composed to highlight the benefit of contemporary data visualization methodologies and technologies, with the objective of conceptualizing a pedagogically informed simulator that is founded on principles of Human-Computer Interaction theory. This simulator was intended to facilitate the instruction and exploration of how to control the National Carbon Footprint.

Through both qualitative and quantitative analysis of the application, it can be posed that the application has been successful and has demonstrated an aptitude for enhancing learners' comprehension of how to manage the National Carbon Footprint. Perhaps, with a larger sample size, more accurate and reliable results would be seen in statistical analysis.

Through the completion of the project, it has been proven that the technological choices made in the design phase were good choices, which enhanced the user's experience. The use of Bootstrap and Chart.js allowed for the creation of intriguing and captivating visualisations in the Microworld. The design of the simulator incorporated numerous data visualization techniques aimed at improving the learning experience and didactic value of the tool. One of the primary objectives of the project was to develop a tool that integrated a dynamic and captivating visual element with the capability to interact and conduct experiments with the simulations in real-time, and this was achieved with the help of the use of the footprint decreasing when the user purchased a mitigation technique. Fleek enabled the easy and convenient deployment of the tool, and all users experienced seamless access without encountering any server or hosting errors.

According to the evaluation carried out, and the successful performance in the workshop scheduled for this purpose, the Microworld has effectively embodied the intended educational and constructionist characteristics intended for the project. The Microworld was said to be "*an eye-opening, informative tool, that brings awareness and makes learning fun.*"

On a concluding note, the simulator adequately fulfilled the specified requirements and objectives outlined during the planning and design phase, facilitated by the extensive literature review and background research, as well as meticulous planning and forethought. Having assessed the pro's and con's of the data visualisation techniques and technological options, this author is happy to commit to the decisions made. The Microworld exhibited its potential to assist in the exploration of the National Carbon Footprint, as made evident by the evaluation conducted on the tool. Nonetheless, it is recommended that additional evaluation and testing be conducted on a larger sample size to yield more informative feedback and inform future design and development efforts.

6.2 Future Work

This section posits several potential augmentations and extensions that may be applied to the work that has been presented in the future.

6.2.1 Further Evaluation

Based on the conclusions drawn, conducting further assessment and experimentation to obtain a larger set of quantitative and qualitative data would be beneficial in substantiating the positive outcomes observed during the initial testing phase. Moreover, facilitating workshop classes would allow the tool to be used by more students. Testing the tool in a typical classroom setting could prove beneficial. As the tool has been trialled on a group of Transition Year Students, exploring its feasibility across more diverse demographics could prove worthwhile to ascertain any modifications that may be necessary to tailor the tool to specific target populations.

6.2.2 More Complexity and Features

During the design and execution of the project, numerous features were evaluated but ultimately omitted due to time constraints. These additional functionalities could be incorporated into the simulator to heighten its complexity and permit the simulation of more intriguing scenarios. One example includes a "popularity meter," which would indicate the population's reaction to the reallocation of funds within the national budget. This would provide insight into the public's response if the user decided to reduce funding for education, for instance. Incorporating additional complexities into the tool would augment its intricacy and facilitate the creation of a more demanding and multifaceted simulator, thereby fostering heightened cognitive engagement among learners.

6.2.3 Alternative Mitigation Techniques

The Microworld predominantly focuses on mitigation techniques related to electricity, although the author contemplated other approaches during the design phase. The chosen techniques within the Microworld were a result of its initial evaluation. Future iterations of this project could consider examining additional ways to reduce the National Carbon Footprint that are not reliant on electricity. This exploration could encompass various options, such as sustainable farming practices, transport solutions, and general sustainability measures.

6.3 Authors piece

Reflecting on the project overall, I discovered it to be a highly demanding yet immensely gratifying experience. Prior to this project, my experience with planning, designing, building, and evaluating an application of this calibre was mostly limited to working on group projects and small internship projects. However, even in those instances, the scope and complexity of the work required were not as extensive as what was necessary for the successful completion of this project.

The most fulfilling aspect of the project was the creation of the tool. Witnessing the transformation of a system design into a functional tool during the development cycle and comprehending the limitations of the design while exploring its capabilities, was an incredibly satisfying experience.

To accomplish all components of the task, I had to integrate numerous skills acquired during my four-year college education. This project presented a rigorous challenge that pushed me to apply the diverse range of software skills I had cultivated throughout the years, from rudimentary programming basics learned in the first year to the creation of server architecture and intricate data manipulation. Furthermore, the project necessitated the acquisition of new skills. Prior to commencing the thesis, I possessed minimal experience in academic writing, and anything I had composed previously paled in comparison to the magnitude of this thesis.

Although it was challenging to balance the workload of this project amid an already hectic final year, I am grateful for the experience as it has made me a more versatile coder. By persevering through the project, I have gained a broader set of coding skills.

I am immensely grateful for the invaluable support I received from my project supervisors and the Bridge2College team, as I would not have been able to complete the project without their assistance and guidance.

I strongly hold the view that the core idea presented in this report holds great significance. Addressing the issue of Climate Change at any level requires collective efforts from people across the globe. Thus, it is imperative for everyone to take proactive measures in their daily lives to enhance our futures environmental condition. In my opinion, if this tool can alter even a single individual's perspective, it would be deemed successful.

In general, this was an immensely demanding yet exceedingly beneficial experience. One cannot ascertain their capacity to create a project of this magnitude until confronted with it for the first time. Thus, being able to successfully complete this project and be content with the outcome is a source of immense pride. It is a source of confidence for me as I transition from college education to the professional world.

7 Appendix A

A working version of the Microworld can be found at the following links:

Challenge 1 – https://challenge1.on.fleek.co/

Challenge 2 – https://challenge2.on.fleek.co/

The survey given to the students for evaluation can be found at:

https://docs.google.com/forms/d/e/1FAIpQLSfgU3i_loh6HhKK2LCsnXdD1SbgD9LxvZdELG69iovrFPgPVg/viewform?usp=sf_link

The source code of the application can be found at:

Challenge 1 – https://github.com/sarahdolan1/Challenge1-Carbonfootprint

Challenge 2 – https://github.com/sarahdolan1/challenge2-CarbonFootPrint

8 Appendix B

The workshop utilized a structured approach to flow and timings, with emphasis placed on the significance of the Icebreaker and warm-up activity as integral steps in promoting optimal student engagement and team collaboration.

	Tuesday 14th March	**Wednesday 15th March**
	Collective theme: Sustainable Development Goals and cutting Carbon Emissions in half	Collective theme: The importance of cooperation in overcoming common problems
09:00am	Meet in Oriel House for setup	Meet in Oriel House for setup
09:15am	Collect Students from Front Arch	Students begin to arrive in Oriel House
09:35am	Arrive in Oriel House 1. Intro to day 2. Icebreaker 3. Team Formation	Kick-off 1. Intro to day **Dom's Project** 1. Initial Learning Material & Demo 2. Simulation 3. Discussion 4. Survey
10:00am	**Michael's Project** 1. Initial Learning Material & Demo 2. Simulation	
11:00am	BREAK – DONUTS	BREAK
11:15am	**Michael's Project** 3. Discussion 4. Survey	**Yannick's Project** 1. Initial Learning Material & Demo 2. Simulation 3. Discussion
11:45am	**Sarah's Project** 1. Initial Learning Material & Demo 2. Simulation	
12:45pm	LUNCH	LUNCH - PIZZA
1:30pm	**Sarah's Project** 3. Discussion 4. Survey	**Yannick's Project** 4. Survey
2:30pm	Contingency time	Reflection 1. M&Ms Game 2. How have we cooperated in the past (CFCs/Ozone Layer)
3:00pm	Program ends	Program ends

Figure 8-1: Workshop Schedule

9 Appendix C – Mock Designs

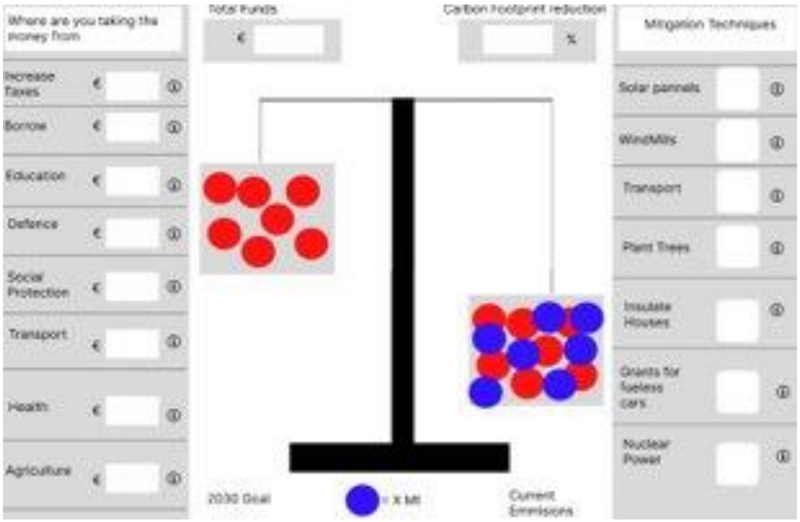

Figure 9-1: Mock Design 1

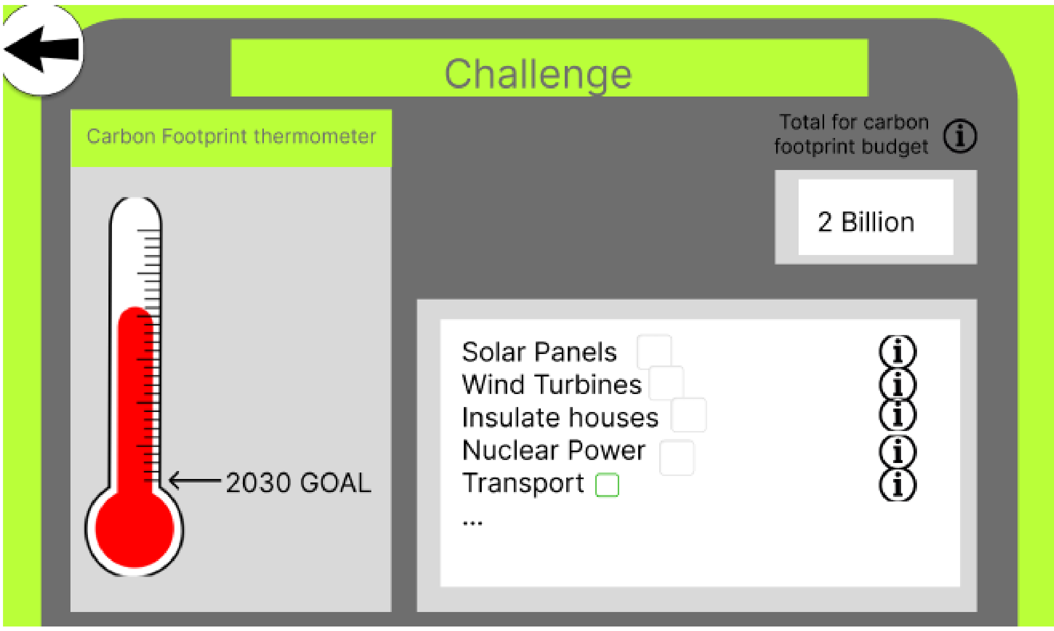

Figure 9-2: Mock Design 2

10 Appendix D – Fact Sheet

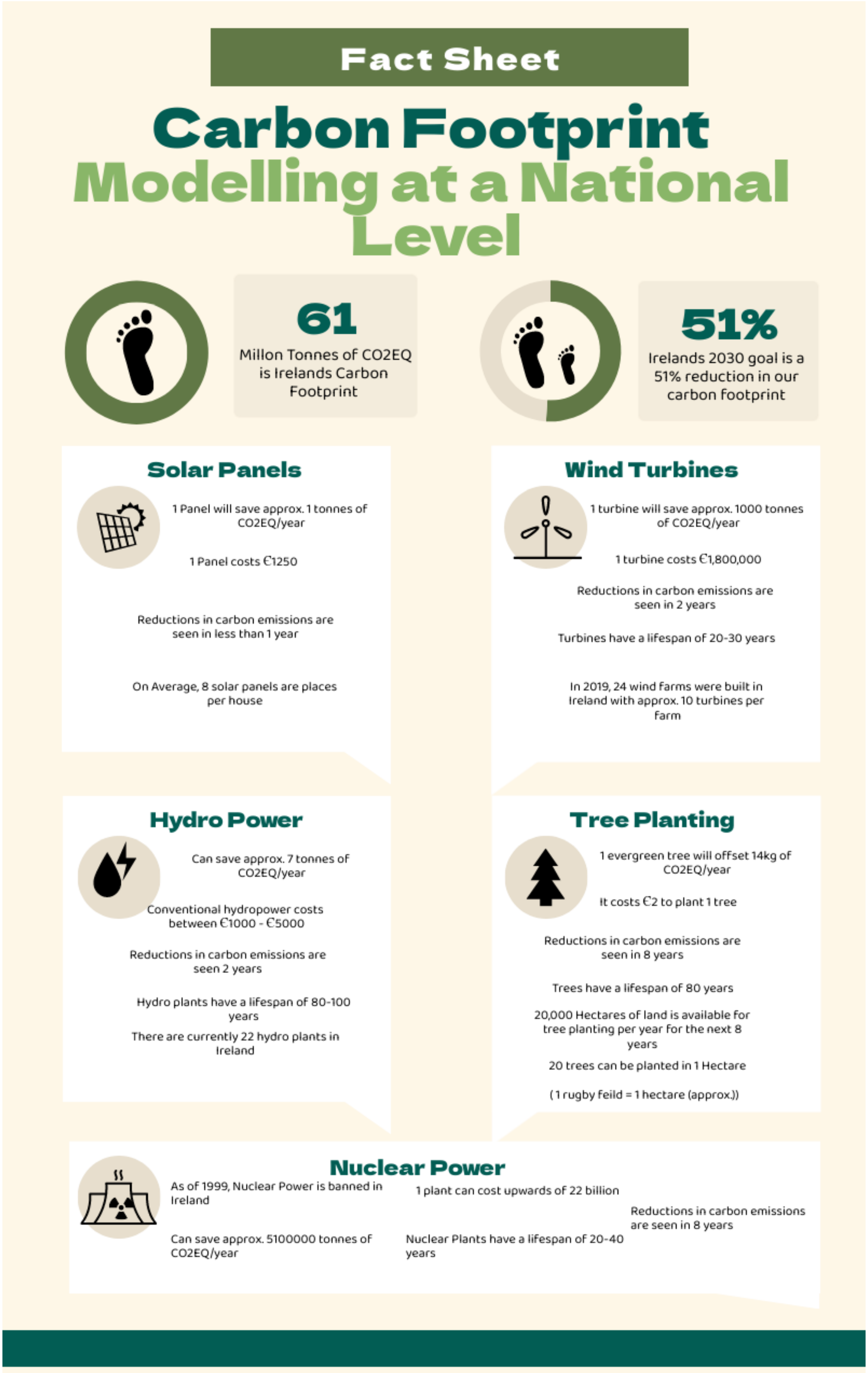

Figure 10-1: Fact Sheet

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