School of Computer Science and Statistics

A Microworld to Teach About Coastal Erosion

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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.

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Abstract

Coastal erosion is a serious environmental issue that poses risks to human populations, natural habitats, and the economy. Coastal erosion is caused by the combination of waves, tides, and winds, with the perfect storm capable of severely eroding the land along coastlines. The impact of climate change and the associated rise in sea level over the past few years, which shows no sign of slowing down, has only exacerbated the intensity of storms, which cause coastal erosion and threaten all aspects of coastal ecosystems and habitats.

In Ireland, sea level rise is occurring at around double the rate of the rest of the globe and storm severity and frequency has increased over the past decade. Focusing on Dublin Bay, which has the most significant coastal population in Ireland, has seen a yearly sea rise rate of 6-7mm over the past 20 years. The likely projections based on data from the IPCC say that by 2100 sea level rise in Dublin could increase by 1.1m, with a 1.98m sea rise in the worst case.

With most of the current population only likely to see the beginning of the worst effects of coastal erosion in Ireland, it is imperative that the younger populations are educated on coastal erosion. It is vital that they have the correct understanding and knowledge to allow them to make informed decisions as future leaders, not just to prevent coastal erosion but to live with it.

The number of technologies utilised to educate this demographic on the topic has been limited, focusing mainly on eye-catching videos and visualisations. With minimal technologies having been used to allow users to interact with simulations of coastal erosion, this study will consider all possible technologies available and discuss how learnings from these led to the creation of the tool described in this document. A number of pedagogical ideas, particularly constructivism and constructionism, have had an impact on the design of the microworld simulation. Principles from Human-Computer Interaction were incorporated to create a tool which would be usable and accessible for the target audience as well as to create visualisations which would encourage cognitive engagement.

The project involved the design, implementation, and evaluation of the efficacy of a Microworld to highlight key factors and choices involved in the mitigation of coastal erosion. The tool was created with the goal in mind of providing a learning experience for Transition Year students, with the coastal erosion modelling itself providing a low-fidelity simulation of coastal erosion on a fictional town based in the Dublin area. The Microworld allows learners to make decisions about prevention options and to view the impact of their choices each year up until 2100. The learner also has control over climate variables and an annual budget. This allows learners to challenge themselves with more complex scenarios and to visualise the outcomes of mitigation choices they make.

The main technical difficulties encountered during the tool development are explained, along with how they were resolved and how this influenced the microworld's design. The design was influenced by considering the complexity of modelling some of the coastal erosion factors and how these could be visualised simply and informally.

This tool was evaluated with a cohort of Transition Year students in the Bridge2College programme in a fluid classroom-based setting. Students worked in pairs to solve various challenges set. The students were provided with some brief introduction learning material and then interacted with the tool themselves before providing feedback. A post-activity survey assessed whether the Microworld succeeded in improving the users' understanding of coastal erosion and the tool's usability and suitability for teaching about coastal erosion.

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1. Introduction

Coastal areas are some of the most dynamic regions on Earth, as human and natural processes act in tight connection to each other. This dynamism poses one of the great societal challenges of the 21st Century as coastal populations are increasing at three times the global rate while at the same time there is an increasing threat of coastal erosion and flooding due to climate change (GSI, 2023).

The rapid worsening of climate change bringing with it increased storm severity and sea levels are beginning to show their impacts on coastal populations across the world with 34% of the world's coastline at high risk from erosion (UN, 2023).

The rate of coastal erosion for shorelines across the globe drastically depends on social and economic situations, global environmental impacts such as global sea level rise, and local environmental factors. Due to the nature of the process of coastal erosion, there is no one solution to prevent it which will work for all economies and coastlines, making the challenge of living with coastal erosion far more complex and costly. With the potential for severe damage to communities, ecosystems, and assets to only increase with the rise in coastal erosion, so too will the cost (Williams et al., 2018). Detailed planning and modelling of coastal erosion is needed as early as possible so that the cost of damage is minimised in the long run for coastal communities.

However, with the complexity of modelling future coastal erosion for coastlines, governments and leaders have been slow to act in certain regions, particularly among poorer populations. It is not only poorer regions at risk, however, with 86% of European coastal regions at risk (UN, 2023). While some nations, such as the Netherlands and cities, such as Venice have been already preparing for coastal erosion for many decades, many other economies do not have the resources available to them to implement their mitigations (Pranzini et al., 2015).

Coastal erosion is not as simple to solve as simply building barriers between land and sea. While coastal erosion is driven by sea level rise, it is the combination of this with a severe storm which can drastically change a coastline overnight. Factors such as the tide, wave height, wave period, and wind combine to create a storm capable of destroying many mitigations used to prevent coastal erosion. It is the unpredictable nature of how severe and frequently storms will occur that can make mitigating coastal erosion difficult, particularly when each kilometre of coastline is different in nature (Wang et al., 2008).

As of 2016, 40% of the population in Ireland live within 5km of the coast (CSO, 2016) which places a large proportion of the population in a particularly vulnerable position to the impacts of coastal erosion. Low-lying coastal areas are also particularly at risk of inundation, with sandy beach erosion two orders of magnitude greater than the rate of rise of sea level (Zhang et al., 2004). Portrane, Co. Dublin is a low-lying sandy beach in Dublin Bay which has already began to see the effects of coastal erosion over the past couple decades (Fingal County Council, 2021b), with fears that many of the homes there will be lost or at extreme risk of coastal erosion by the year 2050. The coastline modelled in this project is inspired by Portrane.

Despite the issues coastal erosion will cause, there is a lack of tools to aid in the teaching of coastal erosions. The reason being that coastal erosion is incredibly difficult to accurately model because of limited availability and accuracy of data, with all coastlines having their own unique features which need to be modelled (Vitousek et al., 2017). Additionally, the inherent uncertainty in future climate change scenarios, including sea level rise and extreme weather events, poses challenges for coastal erosion modelling. This is made even more complex when regional sea-level rise is influenced by local climate change (Hu & Deser, 2013), meaning any high-fidelity models created to simulate coastal erosion can only ever do so accurately for one particular region.

Because of this, most teaching tools are focused on teaching the theory of coastal erosion which can make it seem less of an issue as many visualisations aren't always based on real data. Thus, there is a need for a teaching tool which falls in between basic theory and high-fidelity simulations which allows its users to see long term effects of coastal erosion to better understand the long-term effects. This is particularly essential for young people to understand as they will be the ones suffering the worst effects of coastal erosion.

Microworlds are a specific type of simulator that allow users to explore, navigate, and test embedded ideas and concepts about real-world processes (Hoyles et al., 2002). Through the use of microworld simulators, students participate in cognitive exploration that would not be feasible without the aid of technology. This project will create a low-fidelity simulation of coastal erosion that leaners will be able to manipulate through a Microworld that should cognitively challenge them and result in them forming opinions about the long-term effects of coastal erosion that traditional teaching methods miss.

1.1 Goal

The goal of this project is to develop a Microworld tool which can simulate coastal erosion at a low fidelity and allow for users to interact with the simulation to better understand the choices available to them and their effects on coastal erosion between now and the year 2100. The design of the Microworld should:

1. Require the learner to be cognitively engaged.
2. Provide an interactive visualisation of coastal erosion that has learning as its main focus.
3. Provide a simulation based approximately on Portrane, Co. Dublin, which is a sandy beach already seeing extreme effects of coastal erosion.
4. Be designed with best Human-Computer Interaction (HCI) practices.

The resulting Microworld should allow the user to set climate variables for the run of the simulation and to put in place measures to prevent coastal erosion from occurring. The effects caused by the learners' choices should be clearly visualised and result in changes in the simulation that allow for comparison between different choices available to the learner.

The tool should be suitable and accessible for use by Transition Year students (15-16 years of age) and should provide an informative and engaging visualisation of coastal erosion. The tool will be of low fidelity in relation to coastal erosion modelling due to the complexity in accurately modelling coastal erosion on a region and should focus on providing a better understanding of the short and long term effects of preventions available.

The last goal of the project is to test the usability and accessibility of the resulting Microworld as well as its effectiveness in teaching and raising awareness to the learners about the realistic choices councils and governments have in relation to preventing coastal erosion.

1.2 Ethics

The tool was used by (N=25) TY students for a period of 1.5 hours as part of a two-day workshop, within the Bridge2College programme, exploring different aspects of climate change. Ethical approval for researching different aspects of the Bridge2College programme had been granted by the School of Computer Science & Statistics.

1.3 Roadmap

The project will begin with the exploration of relevant background material and research that provides the fundamentals for the project. Considerations will be given for similar applications and discuss their functionalities and limitations that will aid with certain features of this project. Investigation into key design choices made for the development of the microworld will be discussed with user interface mock-ups forming the basis for development. The challenges faced during the technical development will be discussed and overview of the implementation. Finally, the project will conclude with analysis on the testing and evaluation carried out on the Microworld.

2. Background

This chapter describes the review of research and literature that the author conducted. The findings from an analysis of the body of information pertinent to this study are presented in this section. The background section is divided into four subsections: coastal erosion modelling, pedagogical and microworld theories, human-computer interaction, and similar applications.

2.1 Coastal Erosion Modelling

There are many factors which play a role in coastal erosion modelling. Climate factors, coastal mitigations, and coastline geomorphology all have large roles in the effect of coast erosion across all coastlines across the world. This section will review in detail the affects these have in coastal erosion and they are influenced by each other.

2.1.1 Climate Factors

Sea-level Rise

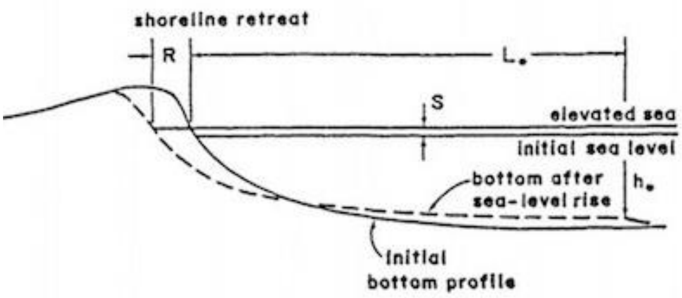
Sea-level rise is one of the main driving forces of coastal erosion and it impacts all shorelines across the world. Sea-level rise increases the inundation of coastal areas and increases the erosion effect of storms when they occur. Sea-level rise is primarily caused by global warming. The Earth's temperature increase causes the melting of glaciers and ice sheets which add to the volume of water in seas and also increases the temperature of seawater causing thermal expansion (IPCC, 2014). There are also localized natural climate variables caused by events such as El Nino and geological activity which can produce temporary local changes in sea-level.

Sea-level rise is not the same for all points in the world, with particular areas seeing faster rates of increase in comparison to others due local exacerbating factors such as glacial isostatic adjustment (McCarthy et al., 2022). Glacial Isostatic Adjustment is the ongoing movement of land once burdened by ice-age glaciers (NOAA, 2023b). Dublin Bay has seen a rise of sea-level double that of the rate of global sea-level rise in recent years (O'Sullivan, 2022).

Sea-level rise exacerbates coastal erosion in several ways due to the sea level bringing the water line closer to shore. An increase in sea-level also means waves carry more energy and reach further inland. Low-lying coastal areas are particularly at risk of inundation, with sandy beach erosion two orders of magnitude greater than the rate of rise of sea level (Zhang et al., 2004). This makes sandy beaches particularly vulnerable to an increase in sea-level rise and its retreat can be estimated using the Bruun Rule (Bruun, 1962). The Bruun Rule established a linear relationship between sea-level rise and shoreline retreat based on equilibrium profile theory (Aagaard & Sørensen, 2012). See figure on top of next page for calculation and visualisation.

Note the Bruun Rule is limited as it can only be applied to soft-sediment coasts, sandy beaches, and that the upper beach is eroded as the shore profile moves landward with the material eroded deposited offshore resulting in a rise of the nearshore bottom.

However, it does provide a very simple method to calculate dune erosion and profiling of the seabed near shore.



$$R = \frac{SL}{h + B} = \frac{S}{\tan \beta}$$

B = dune height above sea-level
β = average slope of the active profile

Figure 2.1: Illustration and calculation of the Bruun Rule
https://en.wikipedia.org/wiki/Bruun_Rule

Sea-level rise in Dublin Bay between the years of 1953 and 2016 has been 1.1mm per year. However, this does not tell the entire story as the rate of sea-level rise has fluctuated during this period. During the period of 1997 to 2016, the rate of sea-level rise in Dublin Bay has been 7mm per year, approximately double the rate of global sea level rise (Shoari Nejad et al., 2022). Experts have struggled to come to agreement with what yearly sea-level rise could be in the years leading up to 2100 (Reuters, 2016), particularly for certain areas of the world. Currently the IPCC projects 0.6m to 1.1m of global sea level rise by 2100 if greenhouse gases remain high (Volland, 2021), and assuming that Dublin seeing a rate of sea-level rise double that of the global average remains the same then it can be assumed that 2m sea-level rise by 2100 isn't beyond the realms of possibility for Dublin Bay.

Storms and Waves

Waves are a constant feature of seas and will continually erode (destructive waves) and deposit sediment (constructive waves) on coastlines. Waves carry energy which cause several types of erosion; hydraulic action, abrasion, attrition, solution, and scour, several of which are amplified when wave energy increases. Hydraulic action occurs when waves crash against a coastline causing air and water to be pushed into the coastline resulting in exerted pressure causing the coastline to break apart over time (Keaton, 2017). During periods of storm surges, wave energy increases due to higher wind speed, increased wavelength, and decreased wave period.

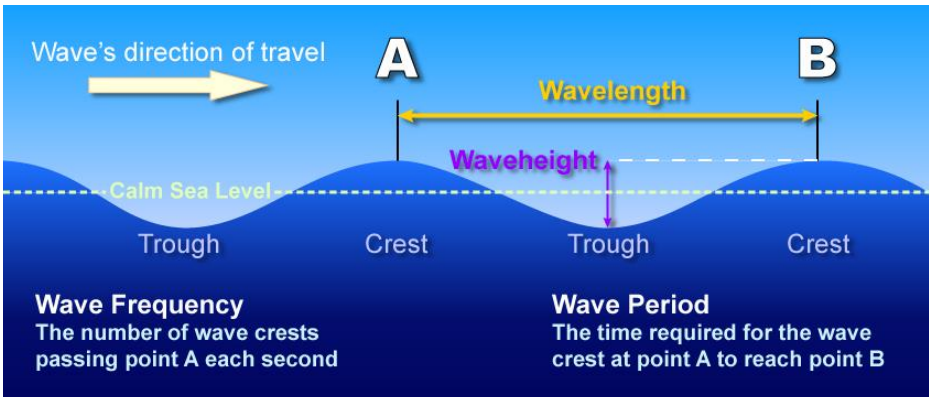


Figure 2.2: Anatomy of a wave
https://www.weather.gov/jetstream/wave_max

Waves have always been a factor in coastal erosion, but this alone doesn't account for the increased rate of coastal erosion. The worst effects of wave energy come from times during stormy weather when wave energy increases. Due to global warming, storm frequency and severity has increased in Ireland over the past few decades with this trend to continue for the foreseeable future (GSI, 2023). With increased storm frequency and severity, coastal erosion will become ever more severe for Dublin Bay with many areas already at extreme risk of coastal inundation (Hutton, 2019).

The M2 buoy is the closest weather buoy to Dublin Bay, which lies 32km east of Howth Head, and it recorded a record wave height of 9.84m in March 2018 (Met Eireann, 2018). This record is likely to be broken again in the coming years but it is extremely difficult to accurately predict when it will be and how much it will be broken by (Wang et al., 2008). This makes predicting coastal erosion extremely unpredictable under storm circumstances, particularly as wind direction can change the usually wave path (Mortlock et al., 2017), and that worst case storm scenarios should be considered when modelling coastal erosion.

Tide

Tides are very long waves that move across oceans which are caused by the gravitational pull on the Earth by the moon, called the tidal force (NOAA, 2023a). The tidal force causes the Earth and water to bulge out on the sides closest and farthest to the moon, and these bulges are what cause high tide. This leads to two cycles of both high and low tide each day on coastlines across the world.

Tidal range is the difference between high and low tide, and the tidal range also changes throughout each lunar month. When the gravitational forces of the Moon and Sun are aligned, then the tidal range is at its largest, called spring tide (a historical term which doesn't imply occurrence in only Spring). This occurs when there is a new or full moon. Tidal range is the vertical difference between high and low tide and not the horizontal distance between the two.

Tides also play a role in coastal erosion themselves, regardless of sea-level rise and waves. However, their effect on coastal erosion is often minimal due to daily high and lows, they often erode and deposit sediment back and help with the natural eco-system of coasts. Like sea-level rise, they help to determine where the waterline is in relation to land. However at high tide, the effects of a storm surge are far greater than at low tide as the sea level may be 2m higher than at low tide (Kim et al., 2008). Thus, at high tide, waves will be able to reach further inland and cause higher a degree of coastal erosion compared to when low tide occurs (Talke & Jay, 2020).

Each shoreline will have a different tidal range depending on coastal configuration and sea-floor topography. Tides in Dublin Bay have a tidal range of approximately 2m to 3m, depending on the specific position.

2.1.2 Prevention Methods

There are many coastal erosion prevention methods and options for governments to choose from, each with their own set of advantages and disadvantages. Human placed coastal erosion prevention methods often provide temporary short-term relief from coastal erosion, but throughout time are damaged themselves and coastal ecosystems as well as worsening coastal erosion (Browne & Chapman, 2011). Below I will talk through some prevention methods that were made available to Portrane.

Seawalls

Seawalls are artificial barriers built parallel to the coastline often made of concrete, steel, or other materials and are meant to withstand the effects of waves, tides, and storms. Seawalls protect coastlines by providing a physical barrier between land and sea, absorbing the energy of waves that crash against it (Kraus, 1988).

Seawalls do have their disadvantages such as increasing the rate of coastal erosion in front of the seawall causing the beach to become very narrow or disappear completely. They also provide visual impacts and accessibility to beaches which cause many coastal communities to side against the implementation of seawalls on their coastline.

Figure 2.3: Example of Seawall on beach
https://commons.wikimedia.org/wiki/File:Seawall.jpg

Seabees

Seabees, or honeycomb seawalls, are a series of interconnected hexagonal cells made of concrete which resemble the structure of a honeycomb. The cells are hollow with material such as sand or rocks placed within them to provide additional stability. They help break up the force of incoming waves. During periods of high wave energy, the waves lose energy as they travel down the holes (Wikipedia, 2023). They allow water to return to the sea by the upward flow from the holes which then disturb the oncoming waves creating more loss of wave energy. This allows Seabees to still allow for the natural coastal erosion processes to occur but help to reduce the amplified effect of coastal erosion during times of high energy waves, by as much as 50% (RPS). They also provide a quicker and cheaper implementation compared to traditional seawalls which can be suitable for coastlines needing emergency measures (Fingal County Council, 2020c).

Figure 2.4: Seabees placed on Portrane beach
https://www.thejournal.ie/seabees-moved-portrane-5223946-Oct2020/

Beach Nourishment

Beach nourishment is the process of adding sand or other sediment to a beach to enhance or restore a beach's height, width, or both. It involves using dredging of sediment from another source which is then deposited by dumping it onto the beach and then shaped to resemble the natural beach profile (Climate ADAPT, 2023). Unlike the previous prevention methods described, it allows for the beach to retain its profile without a hard defence impeding the beach. Beach nourishment helps to protect beaches from natural coastal erosion but is limited in its effectiveness in storm conditions.

Figure 2.5: Example implementation of beach nourishment
https://www.dredgingtoday.com/2019/10/21/beach-nourishment-begins-at-hayling-island/

Beach nourishment disrupts the natural coastal processes along the beach and requires continuous maintenance so that the additional sediment added does not itself wash away (Peterson & Bishop, 2005). Beach nourishment was found to have lifespan of 2 to10 years depending on local conditions and management (Climate ADAPT, 2023). It also is of large concern that the sediment source may also then be negatively impacted due to its loss of sediment.

“Do Nothing”

The “Do Nothing” option is less of a prevention but acceptance of the coastal erosion process. Rather than spending substantial amounts of money on coastal defences which may only provide temporary relief from coastal erosion, it is often the case that doing nothing to stop it is the best choice in the long term. The reason being that by doing nothing, it allows for time to move residents and communities away from the shoreline (Adriadapt, 2022), often being compensated to do so, and the most cost-effective option due to no new building and maintenance of defence options.

Figure 2.6: House on Portrane beach, collapsed due to coastal erosion damage
https://www.irishtimes.com/news/science/sea-level-rise-and-storminess-threaten-ireland-s-sandy-beaches-1.4877496

2.1.3 Prevention Costs

The following table shows the cost of the prevention methods listed above for a 1km stretch of beach. These values were taken from the Coastal Defence Proposals for Portrane & Rush (Fingal County Council, 2020a). Note that in the reports, "The Burrow" refers to Portrane beach.

Prevention	Unit Type	Cost per Unit (€)	No. Units	Total Cost (€)
Seawall – 1m high	m	5,200	1000	5,200,000
Seawall – 2m high	m	10,400	1000	10,400,000
Seabees	m	1,500	1000	1,500,000 (Fingal County Council, 2020b)
Beach Nourishment - 1m elevation added (incl. mobilisation and placement)	m^3	20	75,000	2,320,000

Figure 2.7: Table of costs of prevention methods listed

2.1.4 Geology of Location

The geology of a coastline is a critical factor in determining its vulnerability to coastal erosion. Factors such as sediment type, soil composition, seabed slope, and other natural features, all impact the rate of erosion for a particular location (Bird, 2011).

Beaches in particular are at risk of coastal erosion due to the presence of soft sediments such as sand and silt (Climate Ireland, 2023), Portrane's coastline consists of soft sediment material. As sand has large particles which water can easily flow through, it allows for it to be carried away from the beach more easily than harder sediments which need to be eroded down further before being lost (Vousdoukas et al., 2020). This makes sand particularly vulnerable in times of high energy waves compared to harder sediments which can absorb energy more easily. These factors also apply to soil composition.

The shape and structure of a coastline also determines the severity of coastal erosion, particularly in times of a storm surge. In coastlines where the seabed has a steep slope up to land, wave energy is concentrated in a smaller area as waves grow in height approaching land causing them to break closer to land causing more erosion than a gentle slope. If the seabed slope is gentle approaching land, wave energy can be dissipated over a longer distance causing less erosion (Weitzner, 2016).

The below figure shows the slope of the beach for Portrane, Co. Dublin, which was manually retrieved using Google Earth Pro. The average slope of the range shown is approximately 1:12, which can be considered steep (Global Security, 2023). However, from the above we can see that the beach range is roughly 60ft to 151ft with a rise of 6ft, which gives us a slope of 1:15 which is considered steep.

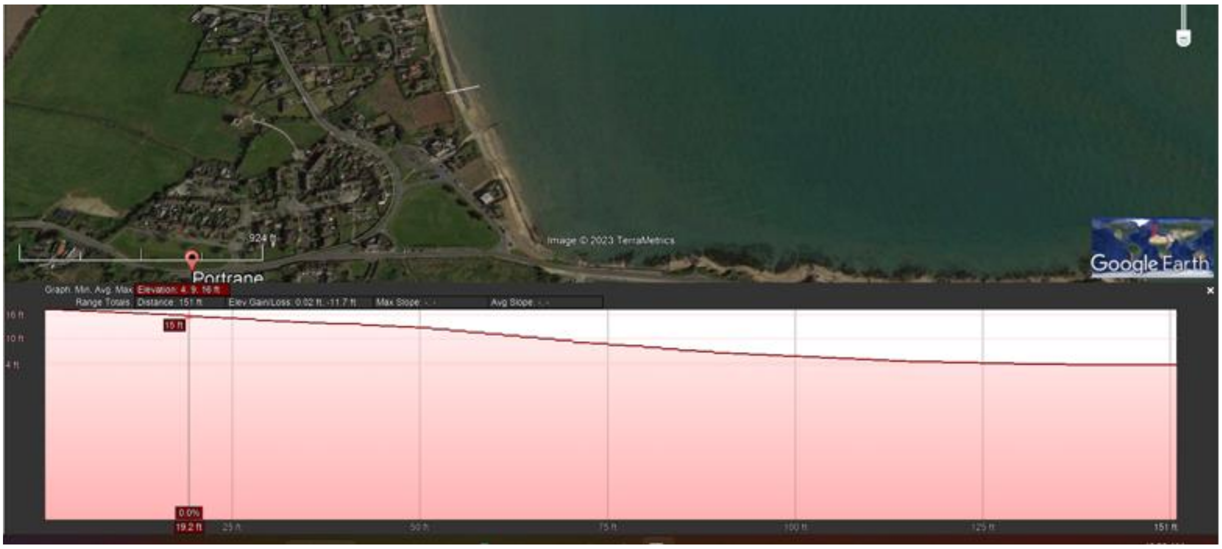


Figure 2.8: Portrane beach slope
https://www.google.com/earth/versions/

In conclusion, Portrane's geomorphology makes it particularly vulnerable to coastal erosion due to its beach being composed of sand and other soft sediments, while having a steep seabed leading up to land.

2.1.5 Budget Limitations

While many preventions are available to mitigate against coastal erosion, these can incur large costs for councils and governments that limit the availability of suitable preventions. This is a factor that often is not realised until it is too late due to the scale of preventions required to mitigate against coastal erosion.

Fingal county council, the constituency which Portrane falls into, provisioned approximately €1.2 million for climate change and flooding costs (Fingal County Council, 2021a). Considering that the Fingal consistency has a coastline of 88km (Fingal County Council, 2023) and Portrane's is approximately 2km, this is quite a low budget considering the coastal erosion risk in the short-term at Portrane.

From these budget figures, Fingal county council will have to pay higher fees for emergency preventions (Fingal County Council, 2020c) given the costs associated with purchasing preventions listed in the section 2.1.3. In the long run these will cost more than proper planning and evaluation of coastal erosion risk and demonstrates that careful long-term planning is required to mitigate against coastal erosion.

2.2 Pedagogy and Microworld Theories

Microworlds allow for simulations that provide users with the ability to manipulate objects and understand the effects of their manipulations within the simulation, and with the use of modern pedagogy theory can be used to create alternative solutions to teaching outside of traditional methods (Costa et al., 2020). Microworlds can provide an immersive and interactive environment which can facilitate active learning and critical thinking skills that traditional education methods often fail to provide (Papert, 1980).

Microworlds and pedagogy theories aim to create teaching tools that provide the following characteristics:

- Active Learning: Pedagogical theories such as constructivism and experiential learning emphasise the importance of active learning. Microworlds provide the platform for learners to actively explore and manipulate virtual environments, experiment with different scenarios, and observe the outcomes of their actions. This facilitates active learning by allowing for learners to build their own understanding and knowledge through hands-on experiences (Prince, 2004).

- Problem-based Learning: Microworlds can present learners with realistic and complex problems that require critical thinking, decision-making, and problem-solving skills to solve (Rieber, 1996). This promotes deeper learning and higher-order thinking skills by encouraging learners to actively participate in problem-solving techniques.

- Contextualised Learning: Microworlds can be created to simulate real-world situations, enabling learners to put their knowledge and abilities to use in useful and meaningful ways (Márta, 1997). Microworlds assist learners to connect abstract ideas to real-world circumstances by offering a contextualized learning environment, which improves their comprehension and memory of the subject matter.

- Motivation and Engagement: Microworlds are designed to be interactive, immersive, and challenging, which can enhance learners' motivation and engagement in the subject area (Wang et al., 2018). Learning outcomes are improved when learners are motivated and engaged as they are more likely to place more effort and time necessary than traditional teaching methods.

- Feedback: Microworlds can provide immediate feedback to learners based on their actions and decisions in a simulation. This feedback fosters a deeper comprehension of the subject matter by encouraging learners to consider their decisions and learn from their errors (Hoyles, 1995).

In conclusion, pedagogy and microworld theories aim to provide alternative teaching tools that differ from traditional methods, particularly for topics which require a problem-solving based approach. Along with visualisations, they can create powerful tools that allow learners to interact with their topic and see the impact of their actions within the microworld.

The ability for learners to review and revise actions taken in the use of microworlds allows for comparisons to be drawn is vital for learners to acquire further understanding and knowledge in the topic area. This project will aim to show how a microworld provides a unique learning experience that challenges and cognitively engages learners to enhance their understanding of coastal erosion.

2.3 Human-Computer Interaction

Human-Computer Interaction (HCI) is a multidisciplinary field concerned with computer science, human factors, and cognitive science, which studies the interaction between humans and technology. The main goal of HCI is to develop or enhance computer-based systems and technologies, particularly user interfaces, so that the system is user-friendly, efficient, and effective to create a pleasurable experience for the user. While the exact meaning varies, in order for a computer based interaction to be successful with a human both functionality and usability should be of most priority (Sinha et al., 2010).

Functionality of a system in terms of HCI is defined as the set of actions which a user has available to them to them to interact with the system in order to accomplish their task. Usability of the system relates to the efficiency and efficacy to which the user can perform the functionality. Both functionality and usability are dependant of each other, thus the effectiveness a computer system is achieved when there is balance between the two of these.

In order to achieve optimal HCI for a system design, HCI studies both a human and a computers interaction and responses with another and considers both when drawing conclusion. In relation to the human interaction, social sciences, communication theory, linguistics, cognitive psychology and human performance are all relevant to optimising HCI (Hewett et al., 1992). On the computer side, computer graphics, operating systems, programming, and development environments are relevant. The point between the human user and the computers, human-computer interface, which must have a defined set of interactions to create a flow in communication between them. A successful user interface design should consider and manage the following principles (Constantine & Lockwood, 1999):

- Tolerance
- Simplicity
- Visibility
- Affordance
- Consistency
- Structure
- Feedback

All mentioned above are essential in implementing best HCI practises but determining what makes a certain HCI design good is extremely subjective and context dependant (Karray et al., 2008). While careful consideration to HCI will be needed for the design of the microworld, receiving feedback in terms of usability and functionality will be vital to understand if optimal HCI has been achieved.

In relation to microworlds, they have large amounts of user interactivity and visualisations that need to be clear and understandable yet efficient to the user. Thus, the user interface will have a large part in determining the successfulness of the project.

2.4 Similar Applications

There are a limited number of similar applications available for teaching about coastal erosion, but none that this author has identified that combined both an engaging simulation and interactivity for the user. There are however applications and other material that provided useful inspiration and ideas that would form features in the author's system.

2.4.1 Non-interactive Tools

These tools provided no interactivity to the user but provided very engaging and educational visualisations of some of the defence mitigations of coastal erosion.

Wave Tank Demonstration Showing the Impact of Coastal Defences on Flood Risk

Figure 2.9: Wave tank demonstration of a vertical sea wall

URL: https://youtu.be/3yNoy4H2Z-o

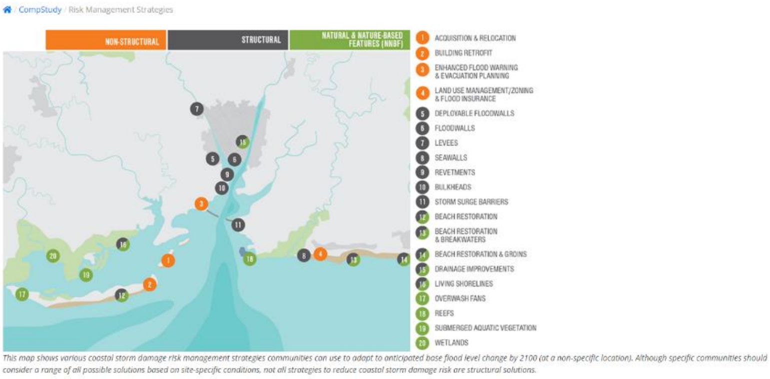
Platform: YouTube Video

Overview: This is an informative YouTube video by JBA Trust in which various coastal defences are demonstrated in a wave tank under the same wave conditions to show how they differ in preventing coastal flooding.

Description: In the video, the presenter first demonstrates how waves from a storm surge floods the end of the tank without any coastal defence. There is also a measuring glass at the end of the tank which collects the flood water, so that comparisons can be quantified between the different defences. The video then goes on to explain and demonstrate several coastal defences under the same conditions which are compared by the excess flood water from each. Interesting comparisons between the defences are shown, particularly with very minuet design differences in some of the defences resulting in much different levels of flood water.

Evaluation: This is a really educational and interesting video that demonstrates several coastal defences in action. It visualises the defences effects against flood risk very well and also allows the learner to compare the defences easily. The explanations from the presenter are very clear and concise too. While the visualisation using the wave tank in this YouTube video is very helpful in understanding the concepts of some coastal defences, it doesn't allow for interactivity with the user or to visual the impacts of sea rise over many years.

Coastal Risk Management Strategies – US Army Corps of Engineering



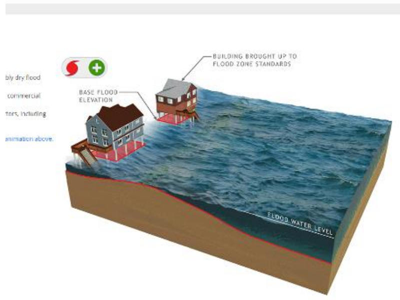


Figure 2.10: USACE coastal storm damage risk strategies

URL: https://www.nad.usace.army.mil/CompStudy/Risk-Management-Strategies/

Platform: Online Article

Overview: This page by the US Army Corps of Engineering was designed to give readers an overview of some of the mitigations that can be used in coastal management. It provides a basic textual description with a short animation for each of the mitigations.

Description: This page provides a list of potential coastal storm risk management strategies for coastal communities to use to adapt to coastal flood levels. The page breaks down the mitigations into categories of non-structural, structural, and natural & nature-based features, with some mitigations incorporating elements of two categories. The map on the left image provides the list of mitigations the user can click on to view more specific details on the mitigation. Each mitigation has a short description and animation to demonstrate how the mitigation is effective against coastal flooding. There is no modelling of coastal erosion on this page.

Evaluation: This page provides educational animations of many mitigations for coastal flooding but does not provide any simulation of coastal erosion. The visualisations used however in the animations are extremely appealing to the user, with them being extremely clear and simple to understand without much prior knowledge. This page is best suited to learn about the fundamentals of different mitigations available and doesn't provide any simulation of them.

2.4.2 Interactive Tools

These tools provided interactivity to the user, but often lacked a simulation of coastal erosion.

The Ocean Game

Figure 2.11: The Ocean Game gameplay

URL: https://www.latimes.com/projects/la-me-climate-change-ocean-game/

Platform: Online Game

Overview: The game was designed by the LA Times, with the goal of allowing users to understand the difficulty in defending against coastal erosion and some of the ethical issues around managed retreats.

Description: The game runs for 8 turns and at each turn allows the user to select one of three options; add sand, add a rock wall, perform a managed retreat. Each of these comes with their own cost, with a budget set for the duration of the game. With the managed retreat, there are four categories of homeowners which offers are made to that can then be accepted or declined. Their willingness to accept a lower offer increases the closer the sea gets to their homes. There are storms that occur through the turns which can remove the sand or rock wall bought.

Evaluation: While the game provides some basic functionality, the user doesn't have any ability to set climate factors and much control over preventions. The only way to win the game is through a managed retreat. There is also no concept of real-world time or coastal factors.

My Coastal Futures

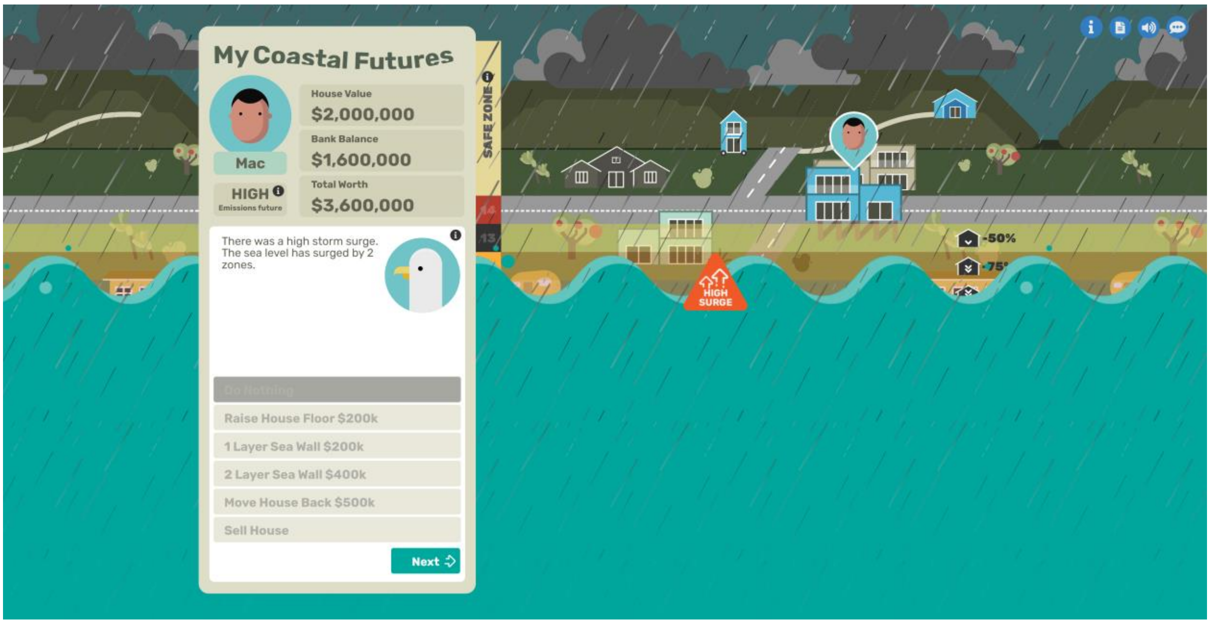


Figure 2.12: My Coastal Futures gameplay after numerous turns

URL: https://mycoastalfutures.niwa.co.nz/

Platform: Online Game

Overview: My Coastal Futures was developed to help New Zealanders begin to form views and opinions on how they might have to adapt to rising sea-levels.

Description: Before beginning the game, users select a character and flip a coin to determine the level of emissions for the run which determine the rate of rise in sea-level. The game shows the levels which are currently safe from the rising sea-level, with the user's initial house placement being placed close to the sea. The closer the user's house is to the sea, the lower the value of their house. The game itself runs for a duration of 100 years at intervals of 10 years and at each turn requires the user to make a decision to what they will do next to protect their home from the rising sea-level. Options such as do nothing, raise house floor, build sea walls, move house back, and sell house are all options available to the user at each turn. After making a decision about what choice to make, the user rolls a "Storm Surge Dice" which randomises how many zones the sea will surge into. The user's current house value is shown and they also have a bank balance which is supplemented at each turn. The game ends when the user's house has either been submerged, the 100 years is complete, or they have moved away far enough inland.

Evaluation: The game provides a simple and easy to use user interface which makes it usable for children of a young age. It focuses more on an individual protecting their own home, rather than an entire area but provides many options in this respect. The user doesn't have the ability to set climate factors themselves, or have the ability to view the metrics of the sea-level rise other than what zone the sea-level is now in. It also doesn't show the coastal erosion process occurring, with only the sea-level being shown. The simulation itself is of very low fidelity and is more concerned with showing how rising sea-level impacts the user's house value.

RiverCraft – Minecraft

Figure 2.13: RiverCraft gameplay showing flooding

URL: https://education.minecraft.net/en-us/lessons/rivercraft

Platform: Downloadable Game Extension

Overview: RiverCraft is an extension for Minecraft which allows users to learn about key areas related to flood mitigation, climate change, and the local environment.

Description: RiverCraft contains three games; managing flood risk, climate change and flooding, and environment and wellbeing, which take around 45 minutes to complete. It provides a fun and interactive learning tool focused on teaching children the concepts of flood prevention and the impact of climate change. While focused more on rivers, it conveys strong concepts which relate to coastal erosion and provides a unique learning experience in one of the most popular games for children and adults. The climate change and flooding game teaches users about the impacts of climate change on flooding and the pros and cons of mitigations available to them. It also facilitates multiplayer so that users can collaborate in the gameplay.

Evaluation: RiverCraft provides an extremely unique and interactive gameplay within a familiar game to help learners understand about flood mitigation and climate change. The visualisations are in keeping with Minecraft blocks which allows the user to be familiar with the game itself but don't provide a true-world geology of the location, Preston, England, which it is based within. However, it does not provide an accurate simulation of flooding or coastal erosion and is geared towards teaching concepts. It also does not translate exactly to coastal erosion but still conveys ideas around communities at risk from flooding, but it does provide a unique pedagogical approach to teach key concepts of flooding and mitigations.

2.4.3 Comparison of Similar Applications

	Interactivity	Sea-level rise	Simulation of Coastal Erosion & Mitigations	Realistic Climate Variables	Engaging Visualisation	Challenged Based Learning
Wave Tank Demo	⊗	⊗	☑	⊗	☑	⊗
Coastal Risk Management - USACE	⊗	☑	☑	⊗	☑	⊗
The Ocean Game	☑	☑	⊗	⊗	☑	☑
My Coastal Future	☑	☑	⊗	⊗	☑	☑
RiverCraft	☑	☑	⊗	⊗	☑	☑

Figure 2.14: Table comparing similar applications

The above table compares the previously analysed applications under a few key areas which have been identified as imperative to the system required for this project. While all the applications show some degree of mitigations or coastal erosion, they don't convey the process involved with them and how they interact with one another. For instance, none of the applications allow the user to place mitigations where they would like and consider the effect of their purchase in the longer term.

There is functionality identified by the author which are useful and should be considered for the development of the author's project. There are also some limitations identified in the above applications which will be solved and implemented in the developed system. The design of the microworld will incorporate aspects from the applications above such as multiple views of the coastline, visualise sea-level rise, interactivity of mitigations and climate variables. The microworld must all be able to provide challenges for the users, which vary and increase in difficulty so that users will have to be cognitively engaged to plan mitigation purchases.

2.5 Summary

Considering the background research conducted, it is clear that modelling coastal erosion can be complex and difficult to accurately do so but there is still a lack of tools available to teach about the long-term potential effects of coastal erosion. While not all coastal mitigations have been reviewed due to there being many, the ones listed provide the most suitable possibility to be accurately simulated while still being very commonly used mitigations across the world. Utilising pedagogical and human-computer interaction theories have great potential to create a unique learning tool, with Microworlds providing the ideal intermediary blend of realism with user interactivity.

While the tool will not be of high-fidelity simulation, to convey the importance of coastal mitigation planning it requires to be visually impactful to keep the user interested and cognitively engaged. This project attempts to integrate all these components to expand upon similar applications and develop a tool which will enable learners to form their own knowledge and opinions about coastal erosion without being overwhelmed with the complexity of modelling coastal erosion.

3. Design

This chapter describes the analysis of design choices available to the author to implement a microworld that incorporates findings researched in the previous chapter to create a visually appealing and educational interactive simulation of coastal erosion. This section is divided into several subsections: considerations, scope, functional and non-functional requirements, simulation design, user interface design, technology choices, and system design.

3.1 Considerations

The Microworld should be designed and usable for use by Transition Year (15-16 years of age) students in Ireland. However, it should be suitable for the general population as well who are of fundamental or basic understanding of coastal erosion. In that respect, there are several considerations which have been taken into account in the design process.

- Prior Knowledge: Transition year students' will have approximately received 200 hours of engagement of Geography during the three year period of the Junior Cycle curriculum (NCAA, 2023). As part of this curriculum, students will have received teaching in coastal erosion and will have a satisfactory level of knowledge in relation to coastal erosion processes and preventions.

- Learning Environment: The microworld will be used within a classroom environment with computers for the evaluation workshop where the students will be placed into pairs to collaborate with the tool together. The tool should still be usable for individual use. However, the tool will still be accessible to students outside of this context and thus should be self-explanatory to use.

- Accessibility: The tool must be usable, accessible, and intuitive for all students regardless of ability and technological literacy. Learners should be able to participate easily and be guided on the tool by best practises from Human Computer Interaction to easily understand and control the tool.

- Ethics: The tool should avoid directly and indirectly identifying Portrane, Co. Dublin as the basis for the simulation of coastal erosion due to students, students' families, potentially being from the area. In this regard, the tool must clarify that simplifications and assumptions were made in the simulation of coastal erosion, and that it does not perform scientific modelling of coastal erosion.

3.2 Scope

Considering the complexity and vast nature of coastal erosion modelling outlined in the previous chapter, it was necessary to place certain constraints on the scope of this project with the context of the project's aims and the background research conducted previously.

- To develop an engaging and usable microworld suitable for the target learners, assumptions and simplifications will be made when modelling coastal erosion in the microworld. This will result in a microworld that contains a low fidelity simulation which focuses more on visualising the impact of the learners' choices in the microworld rather than precisely modelling coastal erosion. This will result in a tool which minimises the complexity and variability of coastal erosion which otherwise could potentially lower the educational benefit of the microworld.

- To avoid overloading the learner, rather than running the simulation day by day until the year 2100 the simulation is incremented one year at a time. Each year will visualise the parameters set for the weather variables, which fluctuate largely in the real world throughout a given year. This is to avoid complexity that climate plays in coastal erosion and for the learner to be able to continually visualise the worst possible case storm for the year they are on. This will also increase engagement with the learner as the simulation will be quicker to run and increase the likelihood of them running the simulation multiple times with different microworld parameters.

- To further reduce complexity with climate variables, the climate variables will be set before the simulation begins by the learner and will not be able to be changed unless the learner restarts the simulation. This is to avoid the learner changing climate variables such as wave height and tide throughout the simulation, which intends to depict the worst-possible case storm for a year.

- It was also decided that to visualise coastal erosion that the screen size would have to be large and thus development would be focused on improving the Human-Computer Interaction on laptops and PCs. The microworld would not be suitable for use on smaller screens such as mobile phones as the visualisation would not be large enough to interact with.

3.3 Functional Requirements

Coastal Erosion Simulation and System Configuration:

- The user must be able to view the topology of the area.
- The user must be able to view the true world dimensions of the topology.
- The user must be able to switch between a side-view and aerial-view.
- The user must be able to run, pause, and stop the simulation at their choice.
- The user must be able to set their climate variables and annual budget prior to the running of the simulation.
- The user must be able to view the sea rising for each year the simulation runs.
- The user should be able to purchase preventions, and select their height when appropriate, when within their budget and be able to place these on the simulation where they desire.

- The user must be able to witness the effects of their preventions on the simulation.
- The user must be able to witness coastal erosion of the sand dune and houses collapsing when applicable.

Simulation Results:

- When the simulation has ended, either by all houses being collapsed or the year 2100 is reached, the results of the simulation should be automatically displayed.
- The user should be able to still view the end state of the coastal erosion simulation.
- The user must be able to see the amount of dune, in meters, lost to coastal erosion.
- The user must be able to view the amount of budget spent over the entirety of the simulation.
- The user must be able to view the end year of the simulation if the simulation ended prior to the year 2100.

3.4 Non-functional Requirements

Accessibility:

- The user must be able to access the tool from a standard PC or laptop.
- The tool should be supported on at least the 4 of the most common web browsers (Chrome, Safari, Firefox, Edge).
- The tool should be able to handle multiple users on the sit at once and scalable if necessary.

Documentation:

- The tool should provide learners with a PowerPoint covering the fundamentals of coastal erosion to help them understand the concepts covered within the simulation.
- The tool should provide enough information to allow learners to begin manipulating the simulation and improve their understanding of coastal erosion.

Usability:

- The tool must be suitably usable for Transition Year students.
- The simulation must be able to clearly and quickly visualise changes made by the user.
- The tool should incorporate key principles of HCI so that it is visually appealing and keeps the user cognitively engaged.
- The tool should be effective for a collaborative learning environment and individual use.
- The tool should enable users to develop opinions and create conversations about different preventions available to mitigate coastal erosion.

- The tool should be intuitive and easy to use for all users, regardless of their technical ability.

3.5 Simulation Design

This section discusses some of the design choices made by the author in coordination with the co-supervisor and PhD candidate in geography upon completion of the background research taken.

3.5.1 Climate Variables

While there are numerous climate variables that impact the rate of coastal erosion, they had to be simplified for suitability within the simulation of coastal erosion. Firstly, sea-level rise was found to be detrimental to the effects of coastal erosion.

Sea-level rise impacts all coastlines across the world, and in particular to beaches. The Bruun Rule discussed in the background chapter provided the most simplistic calculation that could be used to estimate dune retreat of a sandy sediment coastline.

Tides also have a large impact on the on coastal erosion during times of a storm surge. It was imperative to include this as a variable in the modelling of coastal erosion as when a storm occurs at high tide, the rate of coastal erosion is much greater than when that of a storm at low tide. The option to include the average tide, or the median tide, was also to be included to allow for tidal effects to be modelled in the most likely tidal value.

On completion of the research conducted in relation to storms, they are by far the most complex climate variable to model. This is due to many factors determining the severity of a storm. It was proposed that rather than modelling storms themselves, modelling the most significant wave height would be less complex for the learner to understand than including all the variables factored in a storm while still visualising the impact of them. No variables such as wavelength, wind direction, or wave period were decided to be modelled due to complexity which would have resulted in overwhelming the learner, taking away from the main goal of educating the learner about coastal erosion.

3.5.2 Mitigations

While there are an abundance of coastal erosion mitigations available, it was decided it wouldn't be possible to model these all in the simulation because of the time constraints of the project. It was decided that following mitigations would be implemented:

Seabees were chosen due to being implemented in Portrane already and data being available for their effectiveness in wave energy reduction in Portrane.

Sea walls were also selected as they are one of the most commonly used mitigations across the world. While there are many variations of sea walls that could be simulated, a simple vertical sea wall was decided upon as this would be less complex to model in terms of their ability to prevent the effects of sea-level rise and waves.

Beach nourishment is another commonly used mitigation specifically for beaches due to them being able to retain the appearance and temporally retaining the original profile of the beach. Adding additional sand to the beach would also be visually impactful for learners and simple to model within the simulation. It was also decided to set the lifespan of the beach nourishment purchase to 10 years, which is within lifespan range mentioned in the background research. This was decided due to any other value being too short for the purpose of visualisation but still educated users that beach nourishment is not a permanent solution.

Do nothing is a mitigation that could be implemented without the need for complex modelling. While managed retreats would perhaps have been beneficial to add, the difficulty in accurately calculating house cost in relation to sea-level rise and modelling population willingness to do so meant that it was decided not to implement. The "do nothing" option also meant that visually for leaners, they would be able to see the severity of coastal erosion with animations of houses collapsing.

3.5.3 Geology of Coast

The geology of the coastline was decided to be based on factors contained in Portrane's geomorphology. The slope of the beach was to be based on the average of that discussed in the background chapter. It was also decided that the dune's slope in the simulation would be slightly increased, to increase the visual impact. This was so that it would be visually distinct from that of the beach's slope and allow learners to distinguish between them easily.

While sediment transport is also involved in the geomorphology of the coastal erosion process, modelling this would be quite difficult because of complexities in the modelling storms. Without creating a high-fidelity simulation of storms, it was decided to omit the aspect of sediment transport as it wouldn't be possible to accurately model this.

3.6 User Interface Design

Upon considering the similar applications analysed in Chapter 2 and to satisfy the requirements of creating a highly interactive low-fidelity simulation, the following mock-up were created.

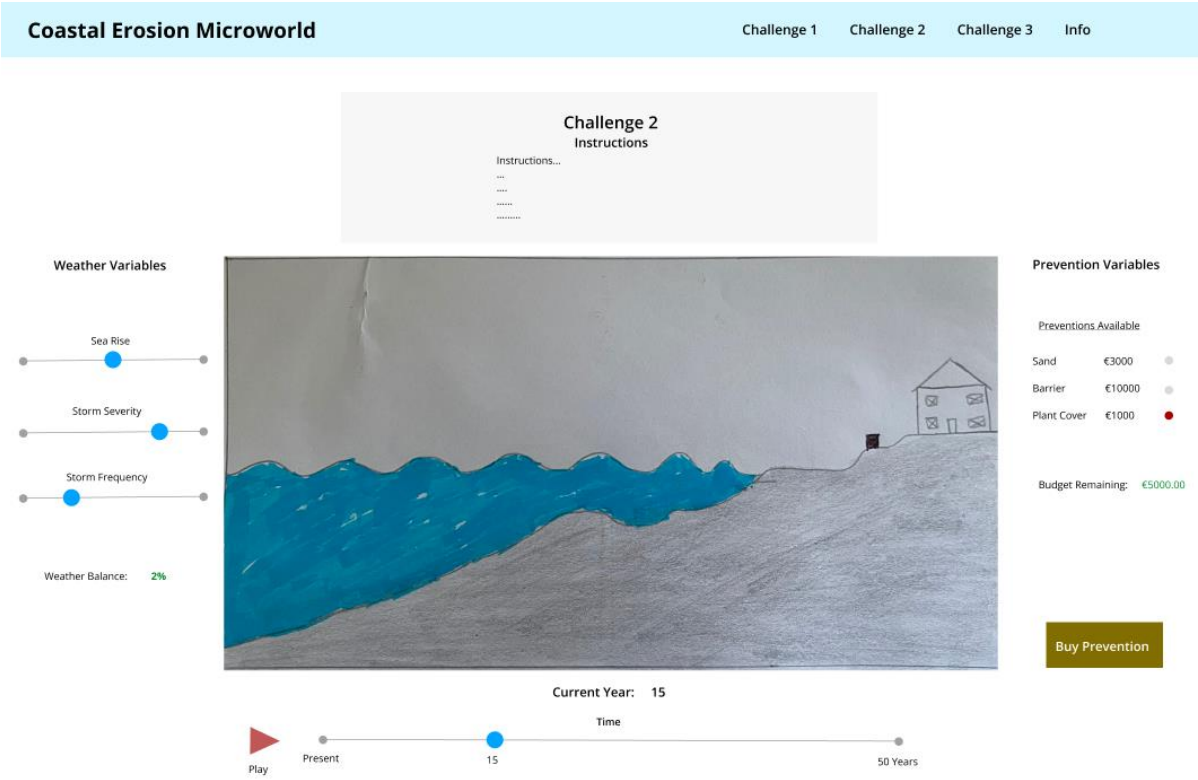


Figure 3.1: UI mock-up side view

The mock-up above details the basic layout of the microworld simulation where the user has control of the climate variables on the left-hand side. By using the sliders, the user would have to set their climate variables prior to beginning the simulation which would then feed into the simulation. On the right-hand side, preventions become available to purchase once the simulation begins and they have enough money within their budget to purchase a prevention. The running of the simulation can be controlled by the user below the visualisation, where they can increment the slider year by year, or decide to click the "Play" button whereby the simulation would run for 5 years before then pausing and letting the user decide their next move.

The mock-up shows the coastal erosion process from the side view. This shows the rise in sea-level, and the user can also see the height of the waves in relation to the dune and house. From this view, the user can also best determine where to place purchased preventions if applicable.

To give the user further context of the coastline, a second visualisation will be able to be switched to and from, showing the coastline from an aerial view; shown below. From this view, they will also be able to run and interact with the simulation in the same manner as the first mock-up.

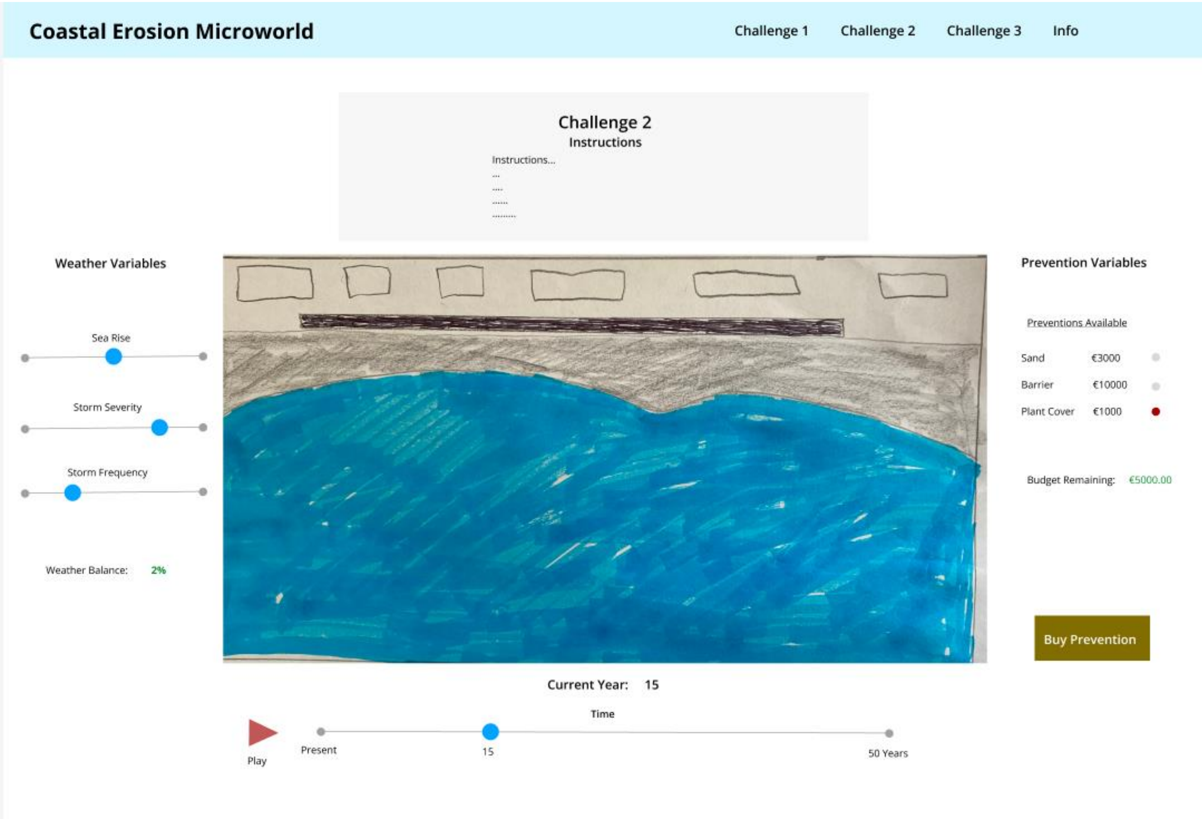


Figure 3.2: UI mock-up aerial view

While both mock-ups are not the final versions of the user interface, they do provide the inspiration and foundations for the final implemented user interface.

3.7 Initial Technology Choices

Considering both the functional and non-functional requirements of the tool, development of a web application was deemed to be the most suitable form for the tool. A web application is one of the most accessible and familiar forms of technology for the majority of users which makes it the ideal form of system to go with. It can be accessed by multiple users in any location, with the only requirement to access them being a strong internet connection. However, in today's world the internet is prominent in all aspects of daily life so this shouldn't be in an issue for the tool. As the tool is a web-based application, it won't require the users to install or setup any of the application which a desktop application would. Unlike desktop apps, web apps are compatible across different platforms (Windows, iOS, etc.) which makes it the ideal candidate for the tool. The majority, if not all, of the target learners will be familiar with using the internet so access to the tool should be seamless.

In order to develop a successful web application, there are several technologies which will be utilised.

HTML, CSS & Bootstrap

HTML (Hypertext Markup Language) and CSS (Cascading Style Sheets) are two of the most used technologies in web development. HTML is the markup language used to structure and create the content of webpages, with CSS used for describing the design and visual appearance of HTML pages. Together, they provide the fundamental building blocks for the visual appearance for a webpage.

Bootstrap is one of the most popular open-source front-end frameworks that offers pre-made CSS and JavaScript components for creating responsive web applications. It provides a collection of UI components that can be quickly altered and incorporated in a webpage such as forms, buttons, and more that simplify the development of online applications. It also has a responsive grid system that makes it easier to design layouts that adjust to different screen sizes and devices. This made Bootstrap ideal for the design of the Microworld to help with interactivity with the user and to also create a clean and responsive design which would be visually appealing to the user.

JavaScript

JavaScript works together with HTML & CSS to provide functionality and interactivity to create dynamic and versatile a web pages. There are a few reasons why JavaScript was chosen:

- JavaScript has a wide array of libraries and frameworks that can be used to create visualisations and interactivity.
- It allows for webpages to react to user actions in real-time without the need to reload the webpage and works across all platforms and browsers.
- It supports DOM (Document Object Model) manipulation which provides a means to dynamically modify the HTML & CSS of a web page.
- It supports both client-side and server-side capabilities, allowing for flexibility in the design of a web application.

GitHub

GitHub is an online platform that provides version control, code management, and hosting. GitHub's main feature is its robust version control system which facilitates developers to track their changes, create separate branches and merge seamlessly when no conflicts arise. Although mostly used for collaboration, the author's familiarity with it meant it was vital to use from the beginning of the project to create multiple branches and versions so that new features wouldn't be deployed until it was tested and satisfied the requirements fully.

GitHub also provides hosting services for web applications, allowing for the deployment of web applications directly from repositories using GitHub Pages. This simplifies the process of hosting and deploying new versions of a web application with it being accessible on the web within minutes of a new deployment. Alternatives such as Google Firebase and AWS provided suitable alternatives although GitHub provided a familiar platform for the author to manage the codebase with seamless deployment of the web application to the web.

3.8 Visualisation Technology Choices

This section leads on from the created use interface mock-ups and chosen technology choices made in the previous section and explores potential visualisation libraries to model coastal erosion. As coastal erosion has many unique factors, there are no pre-built visualisations to simulate it. Objects will have to be defined and rules created, so that they can be drawn and manipulated within the microworld. Before conducting the analysis, selection criteria are set to detail what is required to be visualised. The selection criteria are as follows:

- Visualise unique and abstract objects which can be altered through the simulation.
- Interactivity of objects between each other.
- Interactivity of objects with the user.
- Responsive generation of object drawings.
- Flexibility of the visualisation to fit various screen sizes.

As the selection criteria has been set, there are two potential frameworks which the author could implement based upon their research.

D3.js

D3.js is a JavaScript framework for data visualization that allows developers to create dynamic and interactive visualizations on the web. With a rich set of features and a flexible API, D3.js enables the creation of a wide variety of charts, graphs, maps, and other visualizations using HTML, SVG, and CSS. It provides data binding, data manipulation, and data-driven rendering capabilities, making it ideal for creating data-driven visualisations that respond to changes in data or user interactions. D3.js is highly customisable and supports complex data visualization scenarios, making it a popular choice for creating interactive data visualizations in web applications and websites.

P5.js

P5.js is a JavaScript library that makes it easy for artists, designers, and developers to create interactive graphics and animations on the web. It provides an accessible and intuitive API for drawing graphics, animations, and interactive elements using HTML5 canvas and WebGL. With p5.js, users can create a wide range of visual effects, animations, games, and interactive art projects by simply writing JavaScript code. P5.js includes a rich set of built-in functions for drawing shapes, colours, images, and text, as well as support for user input, physics simulations, and interactivity. It is widely used in the creative coding community for creating expressive and interactive web-based experiences that blend art and technology.

Comparison

Library	Bespoke Visualisation from Objects	Compatibility	Extensibility	Rendering	Learning Curve
D3.js	Yes – can be built from scratch - lots of community examples	Yes – all modern browsers	High	SVG elements – high flexibility in manipulating elements	Steep initially but plenty of community aid.
P5.js	Yes – can be built from scratch - some community examples	Yes – all modern browsers	High	HTML5 canvas elements – less flexible than SVG but faster	Easy initially, gets more complex when more objects added.

Figure 3.3: Visualisation libraries comparison table

Based on the analysis of the visualisation libraries presented above, D3.js was chosen for the development of this web application for several reasons:

- D3 uses SVG elements which have high flexibility and potential to manipulate.
- In P5 the canvas element is used which draws images by pixel, rather than a vector like SVG. This would make visualising on some screens an issue.
- D3 offers endless possibilities with interactivity with many pre-built listeners and functions.
- There is a large community, with a large array of examples covering many aspects of the library. Despite the steep learning curve, there is an array of material and documentation online to refer to.

3.9 System Design

This section covers the potential system architectures that could be selected to render the web application. The key criteria for the tool include interactivity, load-times, responsive and compatibility with D3. Data and security are not of most concern as the coastal erosion model will be calculated based on information provided by the user, and not need to rely on information from a database.

Client-Side

In a client-side application, a HTML is provided by the server to the client's browser. All the linked scripts and styles are then executed in the client's browser, with no information being fed between the client and server after the initial loading.

- Allows for responsive applications.
- Fast responses and interactions between user and application.

- Initial load time can be slow.

Server-Side

In a server-side application, requests from the client browser are sent to the server which then generates a response to be sent back to the client browser.

- Allows for greater control over data and security.
- Slower response time due to latency, a new page is sent back for each client request.
- High load on the server.

Client-Server

Client-server is a combination of both approaches mentioned above and allows for division of tasks between the client and server.

- Complex design and management to ensure proper communication, security, and performance.
- Moderate load on the server.
- Facilitates scalable, flexible, and efficient resource utilisation.

Choice of Design

On conclusion of the above analysis of the different possible approaches, a client-side approach was chosen for the following reasons:

- Interactivity and responsiveness are vital to the success of this application.
- There is no database which needs to be communicated with.
- With D3 all the data manipulation and visualisations are carried out on the client side.
- A static web application can be hosted directly from GitHub Pages.
- Static web applications are highly scalable as there is very minimal server load, allowing for many users using the application at the same time with no issues.

3.10 Summary

The design of the microworld aimed to encompass as many of the coastal factors possible without creating a simulation that would be overwhelming and complex for the target audience. Its design was inspired by some of the similar applications taking into consideration both their advantages and disadvantages, with the aim of creating an engaging and educational tool that was unique. The analysis of the different technologies was performed to find those most suitable for this application and initial mock-ups were created to facilitate the beginning of the implementation of the microworld.

4. Implementation

This chapter describes the implementation of the microworld based upon the background research and design process conducted. This section will highlight the key challenges in implementing the proposed microworld and discuss how the challenges faced were resolved.

4.1 Simulation Architecture

To form the basis of the implementation, the system architecture was divided into three key areas; user input/output, draw functions, and object manipulation. These three categories would form the basis to create the Microworld using D3 to draw the objects, which would be instantiated and manipulated in a separate JavaScript to the drawing file. There was only the need for one HTML page to facilitate the control and present the visualisation of coastal erosion.

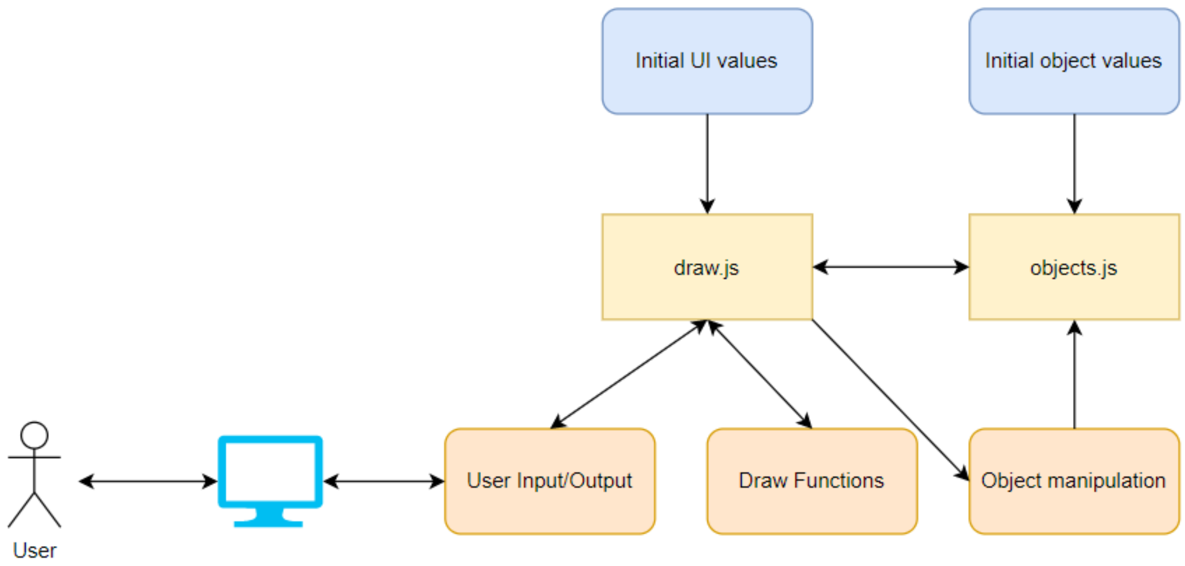


Figure 4.1: Simulation architecture diagram

4.2 Visualisation and UI Approach

To form the foundations for the visualisation of coastal erosion, it was necessary to be able to translate the visualisation screen dimensions to real-world dimensions. Once the initial HTML page had been loaded by the client, a flexible div element using Bootstrap was created call ‘canvas’ where the SVG from D3.js would be placed within. The following code snippet retrieved the height and width of this element on the client’s browser.

```
// Gets the client's (user) canvas dimensions to set within our canvasProp
canvasProp.setCanvasHeight = document.getElementById('canvas').getBoundingClientRect().height;
canvasProp.setCanvasWidth = document.getElementById('canvas').getBoundingClientRect().width;
```
Figure 4.2: Client SVG placeholder dimensions retrieval

With the dimensions of the SVG placeholder on the client's browser retrieved, these values set the height and width for the created SVG visualisation, as well as then being set in the 'canvasProp' object. This formed the basis for calculations of object dimensions between true-world values and the microworld. Within the canvasProp, other settings relating to simulation control and gameplay are set along with relevant getters and setters.

```
export const canvasProp = {
    height: 0, // div element height
    width: 0,   // div element width
    realHeight: 15,
    realWidth: 1000,
    realLength: 100,
    state: 0,   // 0 = side view, 1 = aerial view
    year: 0,    // year of sim
    dimensions: 0,  // 0 = dimensions not shown
    wavesState: 1,  // 1 = waves shown
    weatherStatus: false, // true once weather is set by user
    budgetStatus: false, // true once weather is set by user
    simStatus: false,
    housesDestroyed: false,
    ..
};
```
Figure 4.3: CanvasProp object initial values

4.3 Drawing Functionality & Visualisation

To facilitate the visualisation of objects to the user that can be flexible and allow for interactivity, using D3 to create an SVG was the most appropriate approach. With D3, there is the ability to draw objects within an SVG by either using a predefined object such as a circle or rectangle, or creating a line function which takes an array of points to create unique and irregular objects.

```
var lineFunction = d3.line()
        .x(function(d) { return d.x; })
        .y(function(d) { return d.y; });

canvas.append("path")
        .attr("d", lineFunction(line))
        .attr("fill", "#87CEFA")
```
Figure 4.4: Commonly used line function to draw object from an array

The above line function creates the x and y coordinates from an array to draw straight lines which can then be used to draw the path of the object. The objects created have their values as a percentage of the canvas, which need to then be translated to a pixel value of the SVG. The canvasProp object retains the values of the height and width of the SVG placeholder on the client's browser which allows for pixel values to be calculated from the object's attributes. Regardless of the screen size of the client user, the proportions of the visualisation would remain consistent. The below code defines the shape for the beach object. Note that the coordinates (0,0) denote the top-left corner of the SVG and (cW, cH) denote the bottom-right corner of the SVG.

```
const cH = canvasProp.getCanvasHeight
const cW = canvasProp.getCanvasWidth
var line = [
        {"x": cW * beach.getBeachWidth, "y": cH},
        {"x": cW * beach.getBeachWidth, "y": cH * beach.getBeachMaxHeight},
        {"x": cW * beach.getSlopeWidth, "y": cH * beach.getBeachMaxHeight},
        {"x": 0, "y": cH * beach.getBeachMinHeight},
        {"x": 0, "y": cH},
        {"x": cW * beach.getSlopeWidth, "y": cH}
];
```

Figure 4.5: Beach object line array for drawing

By using this method to implement the visualisation of an object in the SVG, the various objects required to model coastal erosion could be drawn distinctly in this manner and appended onto the SVG. Each object required careful detailing of their own line array in order to successful represent the object within the visualisation. As there are two possible views the user can select from, both side and aerial draw functions would be required for each object.

To support the drawing of the entire SVG, a function was required where the objects could be redrawn if the simulation incremented a year, or the user interacted with the visualisation. This would be needed for both the side and aerial views.

```
function drawSideCanvas(canvas) {
    canvas.selectAll("*").remove();
    console.log("Drawing the Side")
    var tideOption = setSelectedTide();
    setSelectWaveHeight()
    canvas = drawBackground(canvas)
    canvas = drawSideSea(canvas)
    if (canvasProp.getStateWaves == 1) {canvas = drawSideMaxWave(canvas)}
    canvas = drawSideTide(canvas);
    canvas = drawSidePreventions(canvas)
    canvas = drawSideBeach(canvas)
    canvas = drawSideDune(canvas)
    canvas = drawSideHouse(canvas)
    canvas = drawBorder(canvas)
```

```
    if (canvasProp.getStateDim == 1) {canvas = drawRealDimLabels(canvas,
canvasProp.getRealLength, canvasProp.getRealHeight)}
    return canvas
}
```
Figure 4.6: Function to visualise objects in the side view

4.4 User Interaction

User interaction with the simulation was imperative to the success in this project's main goal of implementing an educational microworld. All of the user interactivity was implemented through the use of event listeners.

In JavaScript, an event listener is a function that watches for and reacts to a certain event that takes place on a web page, such as a click or form submission. It serves as a callback function that is activated when the browser recognizes the event. Event listeners are used to handle user interactions and make web pages dynamic and interactive. They can be used to perform various actions, such as updating content, manipulating styles, or triggering other functions. They allow for buttons created in HTML to be interactive by creating a gateway between the user and JavaScript functions.

```
const preventionPurchase = document.getElementById('confirmedPurchase');
preventionPurchase.addEventListener('click', purchasePrevention);
```
Figure 4.7: Example event listener

Many of the event listeners in this project were implemented to call functions that performed actions that resulted in a visual change in the microworld. These ranged from performing tasks such as changing the simulation view, showing and hiding objects in the simulation, setting climate and budget variables, and running the simulation over years.

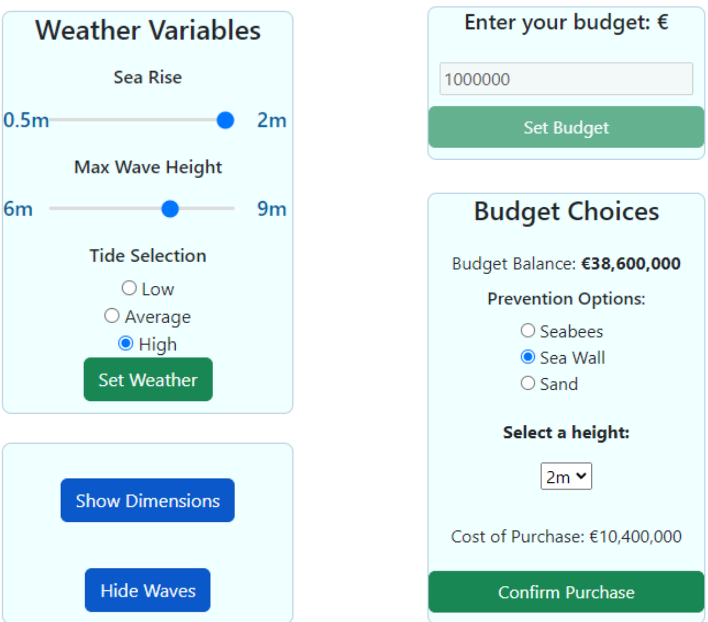


Figure 4.8: Climate and budget control panels implemented for user interactivity

4.5 Simulating Climate Factors

As part of the key functionality, allowing the user to have some control over climate variables was essential in allowing for a challenge-based tool. There are three climate factors that the user must set before the beginning of the simulation: sea rise, max wave height, and tide. Each of these objects are visualised and simulated in different ways.

Sea Rise

The user selects the sea rise for the duration of the simulation, and it assumed that this value is divided evenly between all years of the simulation to avoid complexity. On the incrementation of each year, the sea-level is increased and the length of the sea is then then re-calculated to draw where along the beach or dune it intercepts.

```
// this function takes in a value as meters, and calculates the result as % of canvas
increaseSeaRise: function(val) {
        var tempSeaRise = (1 / canvasProp.getRealHeight) * val;
        this.totalSeaRise = this.totalSeaRise + tempSeaRise;
        this.height = this.height + tempSeaRise;
        this.calcSeaLength();
}
calcSeaLength: function() {
        if ((beach.getAbsMinHeight - this.height) >= beach.getBeachMinHeight) {
            this.length = 0;
        } else if ((beach.getAbsMinHeight - this.height) >= beach.getBeachMaxHeight) {
            this.length = (this.height - (beach.getAbsMinHeight - beach.getBeachMinHeight)) / beach.getBeachSlope;
        } else if ((beach.getAbsMinHeight - this.height) >= (beach.getBeachMaxHeight - dune.getDuneHeight)) {
            var duneWaterLine = beach.getBeachMaxHeight - (beach.getAbsMinHeight - this.height);
            this.length = beach.getBeachWidth + (duneWaterLine/ dune.getSlope);
        } else {
            this.length = 1
        }
}
```
Figure 4.9: Sea rise object manipulation

Tide

The user selects one of three options for the tide for duration of the simulation. These are low, average, and high. The tide selection adds additional water level to the sea, and they are drawn separately but visualised as one, despite being separate objects. While low tide in the real-world still tends to add additional height to mean sea-level, in this simulation low tide has been accounted for in the sea-level already. Thus, high tide's value is the difference between low and high tide based on the discussion in the background chapter. In the case of the user selecting low tide, this will add no additional height and not be drawn in the visualisation. Similar to the calculation of the sea length above, the length the tide reaches up the beach is calculated at each turn to visualise where it intercepts the coastline.

```
setTidalHeight: function(tideOption) {
        if (tideOption == 1) {this.currHeight = this.getLow}
        else if (tideOption == 2) {this.currHeight = this.getAverage()}
        else {this.currHeight = this.getHigh}
        this.calculateTideLength()
},
```

Figure 4.10: Tide selection

Max Wave Height

The max wave height is simple to model in comparison to the two previous climate factors. The user selects the max weight for the duration of the simulation which is then visualised on top of the sea and tide objects. The user can also toggle the show option for the waves, so that they can view the visualisation in times of low energy waves. However, if the waves are toggled to be hidden, they are still factored in when simulating the coastal erosion. The help distinguish the sea and tide in the aerial view, the wave object has a lighter blue colour.

4.6 Simulating Mitigations

Simulating some of the coastal mitigations available was one of the next key pieces of functionality required for the simulation. Based on the research and design conducted, it was decided that seabees, sea walls, beach nourishment and "do nothing" would be implemented in the simulation.

Seabees

Seabees regardless would always allow for the sea and tide to pass through them as they prevented the worst effects of wave energy on the dune. When the sea-level and tide heights were below the prevention height, based upon the background research conducted, it was found to reduce wave energy by 50% when implemented in Portrane. However, there was no data available to calculate seabees effectiveness in reducing wave energy when the sea and tide level were above it. It was discussed with the subject matter experts that rather than not implementing any change, that it would be best to say that their effectiveness was only half as good. Thus, it was implemented that when water level was above the seabees height, wave energy was reduced by 25%.

Seawall

Seawalls were simple to implement in their effectiveness against sea-level and tides. If they were below the height of the sea wall, then they would simply not be able to pass through the sea wall and if they were greater than the height of the seawall, then the effectiveness of the sea wall was nullified. In the case of where sea-level and tide were below the sea wall height but with the waves the waves could crash over the sea wall it was decided that the difference in sea wall height and wave would result in that height of water level after the prevention. Thus,

- If sea wall height 2m
- And beach height at the location of the sea wall was 2m

- Water-level and tide combined was 1m
- Max wave height of 4.5m
- Then the result would be that sea-level and tide would not pass through the sea wall but there would be 1.5m in height of excess wave height after the seawall for the remaining portion of the beach.

In the below figure, seabees and sea walls were purchased and visualised. While it was easy to implement their effectiveness in relation to sea-level and tide, it was soon realised that there would have to be additional conditions added in relation to wave energy.

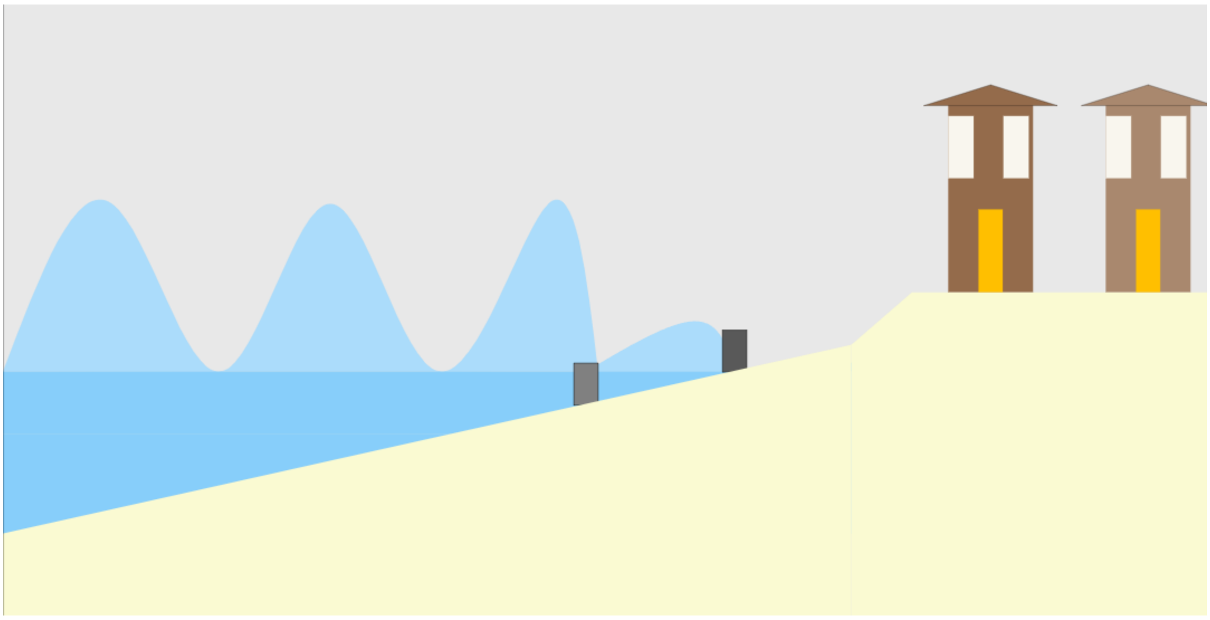


Figure 4.11: Simulator showing seabees and sea wall in action

Beach Nourishment

Beach nourishment was a lot simpler to implement compared to the previously implemented mitigations. The height of sand the user selected, would result in the beach object being raised by that height. Based upon the research conducted, it was decided that the life span of the beach nourishment would be 10 years. This was implemented linearly within the simulation, thus if 2m of sand was added, for each year of its life span the beach would reduce in height by 0.2m until no sand remained from the beach nourishment.

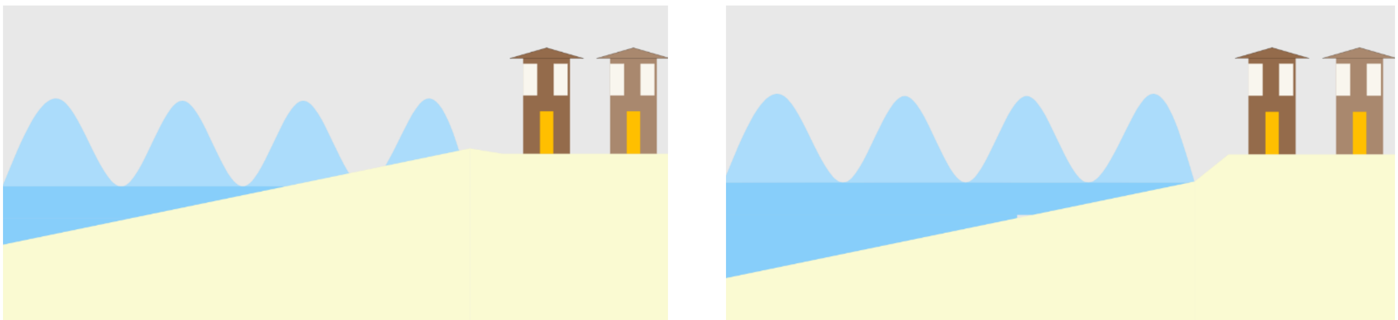


Figure 4.12: Simulator showing 3m of sand purchased initially and 10 years later

To facilitate further user interaction, the ability to place both seabees and sea walls where the user desired was an additional feature that was implemented once the initial planned implementation of the mitigations was completed. Once the user confirmed their purchase of one of these mitigations, they had to select where the prevention by moving their curser over the visualisation. When the curser was hovered over the visualisation, a semi-transparent image of the prevention was shown on the visualisation to aid the user in assessing where the prevention was best placed. This was done through the use of implementing conditional event listeners in the function purchasePrevention(). User selection of the height for the sea wall and beach nourishment was also implemented to allow for further interactivity with users.

4.7 Simulating Coastal Erosion

Originally it was planned that the Bruun Rule would be implemented to model the erosion of the dune in relation to sea-level rise however because sediment transport was not being modelled, the rule did not accurately reflect the erosion of the dune. After discussion with the subject matter experts, it was devised to implement a simple erosion method for the dune that visually encapsulated erosion but was not precise in doing so.

It was agreed that the erosion rate would equal the height of the water level at the dune. The erosion rate was then used to retreat the dune length fully if the sea level and tide reached the dune. As the max wave height was to demonstrate the worst possible case storm surge for a given year, if the water level reaches the dune but the sea-level and tide did not, the erosion rate would be reduced by 80% before retreating the dune.

```
// this function erodes the dune by the given erosionRate
    // two erosion types occur,
    erode: function(erosionRate) {
        if(this.slope <= -1) {
            this.setDuneBankLength = 0;
        } else if (tide.getLength > beach.getSlopeWidth) {                //
Normal Erosion
            this.setDuneBankLength = this.getDuneBankLength - erosionRate;
            beach.setBeachWidth = beach.getBeachWidth + erosionRate;
            this.increaseLengthLost(erosionRate)
        } else if (beach.getBeachWidth + maxWave.getWashLength >
beach.getSlopeWidth) {     // Wave Erosion
            var erosionRate = erosionRate / 5;          // 80% erosion reduction
due to being storm erosion
            this.setDuneBankLength = this.getDuneBankLength - erosionRate;
            beach.setBeachWidth = beach.getBeachWidth + erosionRate;
            this.increaseLengthLost(erosionRate)
        }
    }
```

Figure 4.13: Dune erosion function

To visualise the erosion of the dune, the sand on the dune would have an undercut effect whereby there would be an overhang of sand. This would allow for water to pass under the undercut which and erode the dune at a faster rate which is representative of real-world dune erosion. Once the overhang slope reached a threshold, -1, then the overhang would "fall" (visualised as disappearing) before potentially developing a new overhang.

To visualise houses falling, the author assumed that the house would remain intact if a minimum of half of the dune below the house remained. Once half of the dune below the houses had eroded, the house would fall and show the remains of the house on the dune.

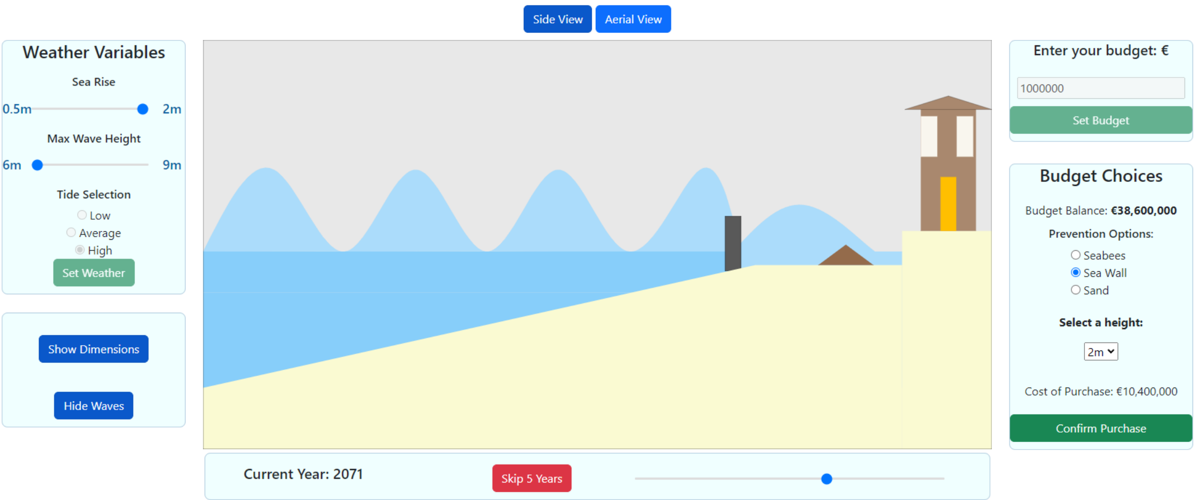


Figure 4.14: Visualisation of dune erosion causing a house to fall

In summary, many changes had to be made to the implementation of dune erosion due to the complexity of accurately modelling. While compromises had to be made in the precision, the subject matter experts were content that the simulation visualised the dune erosion accurately enough for the purposes of creating an educational tool for the target audience.

4.8 Simulation Result

The simulation finishes when either 100% of the houses have been destroyed or when the simulation reaches the year 2100. Once either condition is met, the controls available to the user are disabled and the result of the simulation is presented to the user above the visualisation, replacing the challenge instructions. The user is presented with some metrics on the result of their run through of the simulation and is able to restart the simulation again, allowing the user to try new climate variables or try purchase alternative preventions to further understand coastal erosion.

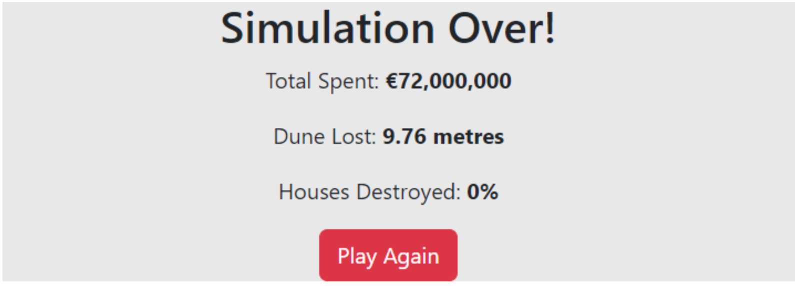


Figure 4.15: Simulation complete resulting metrics

4.9 Final User Interface

The final user interface followed the initial design mock-ups quite similarly initially, however through the implementation of the project there were minor design changes made. The key concepts of the user interface remained the same, with control panels left and right of the simulation visualisation for climate variable control and prevention purchases. The key changes made to the user interface after the initial design phase were:

- The option to allow the user to enter their own value for the budget was added.
- 'Control panels' were added around the control options for better visual aesthetics.
- Buttons above the screen were added to allow for the user to switch between side and aerial views.
- There were also buttons added to the left of the simulation visualisation to show the real-world dimensions of the simulation, and another to also show or hide the waves.
- Minuet visual appearances to buttons were utilised, to show when buttons were active or disabled.

Apart from these changes, the visual layout of the user interface remained largely the same as that planned in the design phase. As there was only one HTML page created, that rendered either the side or aerial view depending on user selection, user interface flow never had to be considered.

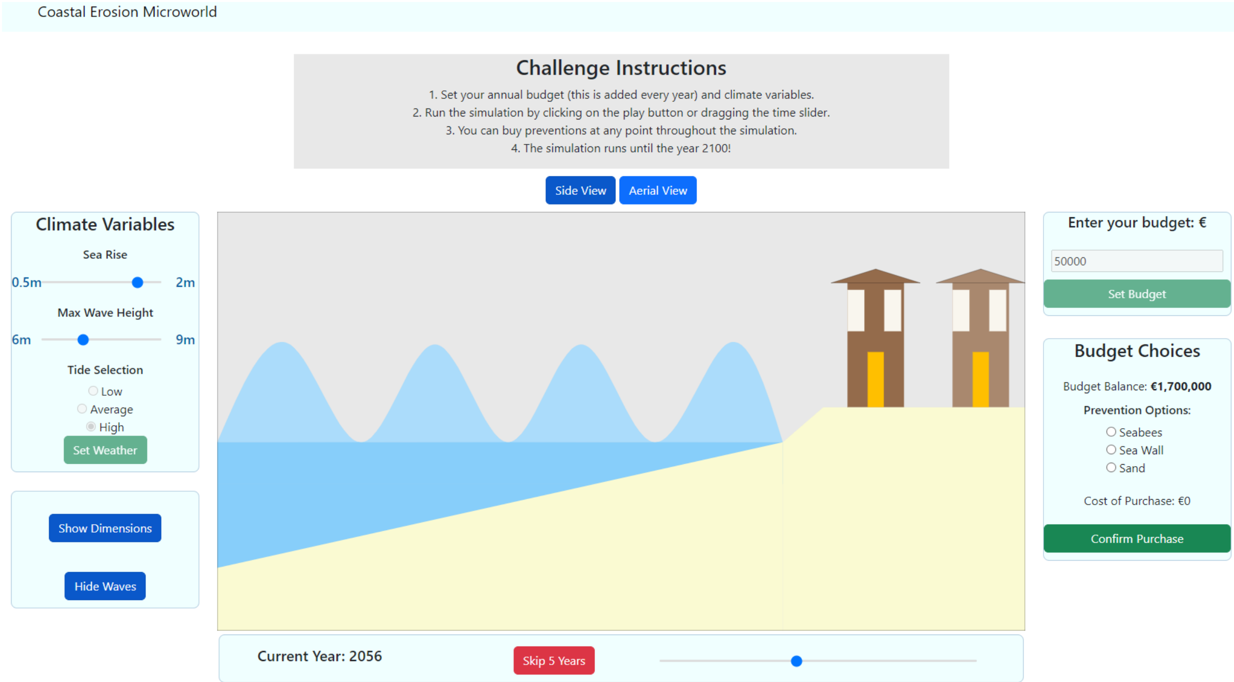


Figure 4.16: Final side view of user interface

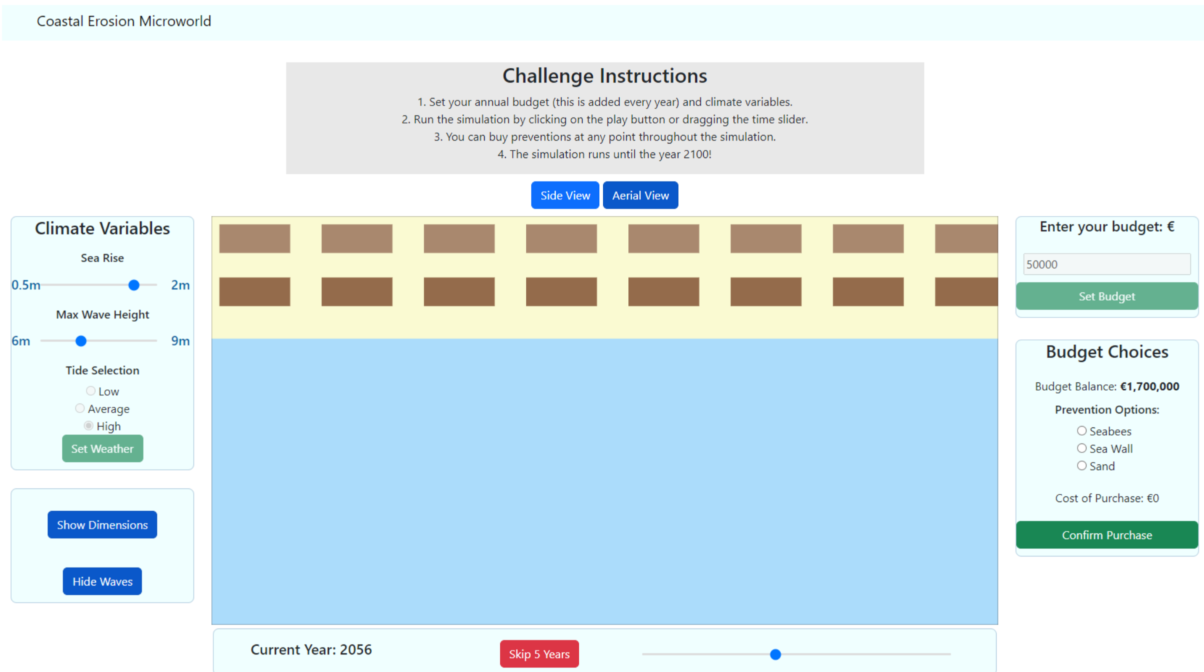


Figure 4.17: Final aerial view of user interface

4.10 Summary

After conducting the background research and design for this project, an educational simulation of coastal erosion was created through a microworld. While assumptions and simplifications had to be made due to the complexity of modelling coastal erosion, the microworld was able to encapsulate the main concepts of coastal erosion and mitigations available. The result was a highly interactive and user-friendly implementation that should provide an educational tool that facilitated a unique and engaging alternative to traditional teaching methods.

5. Testing and Evaluation

This chapter discusses the testing and evaluation carried out to determine the success of the project's in meeting its goals. Initial pilot testing was conducted with the educators who would be facilitating the evaluation workshop with Transition Year students. The usability evaluation with Transition Year students, the target audience of this application, will determine the project's success in creating a microworld that provided a unique and cognitively engaging platform to teach about coastal erosion.

5.1 Pilot Testing

This tool was initially tested with the facilitators (N=6) who would be running the workshop in the later evaluation. The initial evaluation was conducted to test if the application would be suitable for an educational workshop, as well as to identify any potential issues or enhancements with the application. The initial feedback from the testing was positive in relation to the suitability of the application for an educational and interactivity workshop. The visualisations of coastal erosion were found to be clear and impactful and the high degree of user interactivity meant the workshop facilitators were happy with the microworld's functionality.

There were some discussions around the format of how challenges would be presented within the workshop. At this point, the climate variables were able to be changed during the run of the simulation. It was decided that it was best to allow the learner to set these at the beginning, before running the simulation and not allowing these to be altered until the simulation was complete. To also enhance the challenge-based approach of the application, the way in which the budget worked was also altered. Originally, the learner would set their budget for the entire simulation and would receive no additional budget throughout the simulation. It was decided that the budget should be changed to an annual budget, so that at each year of the simulation the learner would receive an additional amount to the remains of their budget.

Both changes were implemented before the workshop and facilitated the opportunity to create numerous unique challenges for the learners.

5.2 Workshop and Evaluation

The workshop and evaluation were carried out as part of the Bridge2College programme run by the Trinity Access Programme. The programme's overall aim is to provide a learning experience for Transition Year students to become confident in the use of technology and teamwork to develop skills and experience needed to help fulfil ambitions to attend third level education (Sullivan et al., 2021).

A two-day session on climate change and sustainability was conducted with the aid of the facilitators mentioned in the above section. Four tools created, by the author and three other final year project students, to teach about different aspects of climate change were presented to the students over the course of the two-day session. The author's workshop was conducted on the morning of the second day. The format for the workshop was as follows:

- The author initially presented a short presentation about the fundamentals of coastal erosion so that all learners had a minimum understand of the subject matter.
- A short demonstration of the application was performed by the author.
- Learners, paired up, then faced their first challenge to become familiar with the application.
- Learners were then presented with the second challenge, which sought to challenge them and facilitate teamwork.
- Some learners then presented their solutions to the second challenge to the class.
- Discussion was then conducted to discuss the issues raised and to generate conversation around possible solutions and concerns about coastal erosion.

5.2.1 Workshop Challenges

Challenge 1:

The first challenge the learners were given was to simply interact with the microworld as they liked. They were allowed to set any desired values for the climate variables and annual budget. The motivation to do this was for learners to become familiar with using the microworld and for them to learn how the climate factors and mitigations impacted coastal erosion.

Challenge 2:

The second challenge provided to learners gave them predefined climate variables and annual budget. The reasoning for this was to set limitations their budget to constrain the mitigations they could purchase to prevent coastal erosion for the given climate variables they were given.

Each pair of learners were given two predefined challenges. These ranged from climate variables that were extremely safe, to absolute worst-case. The annual budgets also varied from a realistic budget for an area of the size of Portrane, to extreme high and lows.

5.2.2 Usability Evaluation

Usability evaluation is a crucial method in the development of any application to understand the extent of which the application is efficient and effective in meeting its intended goals. Usability evaluation involves assessing the application's success of incorporating the best practices of HCI with the end-users. Usability questionnaires are one of the most popular methods to carry out such evaluation. The System Usability Scale (SUS) and the Post-Study System Usability Questionnaire (PSSUQ) are two of the most popular and standardised methods of assessment that can be used across various applications.

5.2.3 System Usability Scale (SUS)

The System Usability Scale is a widely used tool to measure the usability and learnability of a system. It is a 10-item questionnaire that evaluates a system's learnability, effectiveness, and satisfaction. Participants score statements on a 5-point Likert scale from "Strongly Agree" to "Strongly Disagree" and generates scores from 0 to 100 (Brooke, 1996). SUS is renowned for being straightforward, adaptable, and reliable, which has meant that it is one of the most popular tools to evaluate a system. Thus, making it a useful tool for assessing and comparing the user experience of a variety of systems.

	The System Usability Scale Standard Version		Strongly disagree				Strongly agree
			1	2	3	4	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 5.1: System Usability Scale (SUS)
https://www.researchgate.net/figure/System-Usability-Scale-Questionnaire_fig1_306893875

5.2.4 Post-Study System Usability Questionnaire (PSSUQ)

The Post-Study System Usability Questionnaire is a questionnaire which consists of 16 items that measure three critical dimensions of usability: system usefulness, information quality, and interface quality. Participants rate their agreement with statements on a 7-point Likert scale, ranging from "Strongly Agree" to "Strongly Disagree." PSSUQ scores are calculated by averaging the ratings, with higher scores indicating better usability. Similarly to SUS, PSSUQ is renowned for its comprehensive coverage of various usability elements (Sauro & Lewis, 2012), making it an invaluable instrument for gathering indepth user feedback on system usability that can guide design advancements and improve the user experience as a whole.

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

Figure 5.2: Post-Study System Usability Questionnaire (PSSUQ)
https://uxpsychology.substack.com/p/standardized-usability-questionnaires

5.2.5 Chosen Questionnaire

Despite both SUS and PSSUQ being suitable evaluation methods for the microworld, neither were selected as the chosen questionnaire. This was due to the Bridge2College facilitators concerned that due to the number of questions, learners would be uninclined to properly engage with the questionnaire, particularly with the number of applications they would review across the two-day session. This meant that the author modified the PSSUQ questionnaire to ask more specific effects of the microworld and reduce the number of overall questions within the questionnaire.

5.2.6 Usability Results

Upon completion of session, the Transition Year students were then asked to fill out the usability questionnaire. 21 students filled out the questionnaire which was the first time the application had been evaluated. As this was first evaluation of the microworld using the usability questionnaire, and that the questionnaire itself did not exactly match the PSSUQ standard, there was no way to compare it to any previous usability evaluation.

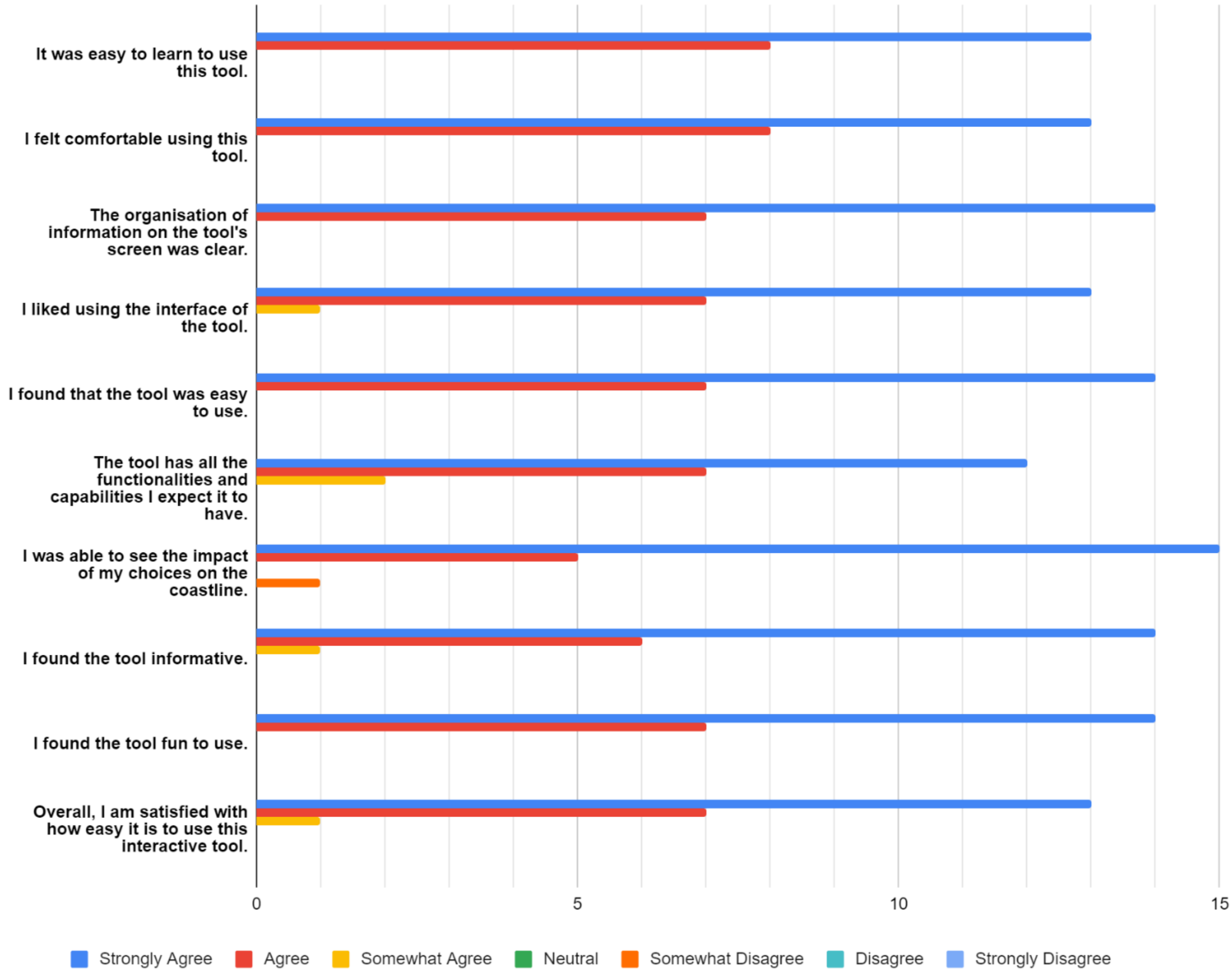


Figure 5.3: Usability questionnaire responses

Overall, the feedback received from the usability questionnaire was extremely positive. One response for the “I was able to see the impact of my choices on the coastline” disagreed, but apart from this all-other feedback was positive. The students particularly found that the tool was easy to use, clear and had an appealing user interface. There was an additional option for leaners to make specific feedback regarding the usability of the tool.

One area which the tool could improve on is some of the visualisations of certain objects within the simulation. The visualisation of houses was identified as an area that could do with some additional design updates, as well adding wave animations to the waves themselves. Apart from these comments, the responses were positive and highlighted how smooth and clear the simulation ran.

5.2.7 Educational Evaluation

The fundamental requirement of the project was to create a tool that educated users about coastal erosion and the importance of awareness and planning of preventions that can be utilised to mitigate the effects of coastal erosion. After completion of the usability questionnaire, the learners were asked to give their feedback in relation to their understanding of coastal erosion after using the microworld. There were 20 students who participated in this questionnaire, one less than the usability questionnaire, the results of which are discussed below.

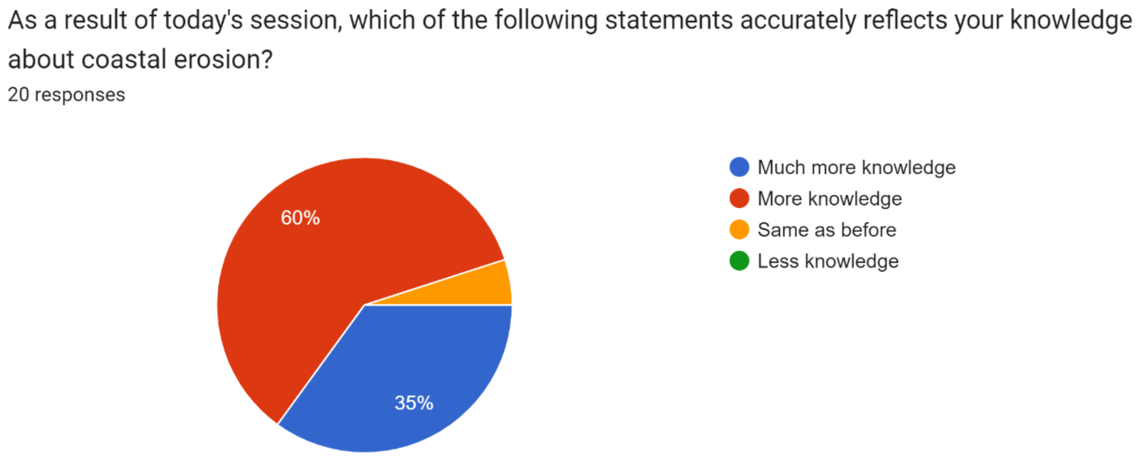


Figure 5.4: Pie chart comparing change in knowledge

The author wanted to identify if the microworld was suitable to enhance learners' knowledge of coastal erosion. An overwhelming 95% of learners stated that they improved their knowledge about coastal erosion.

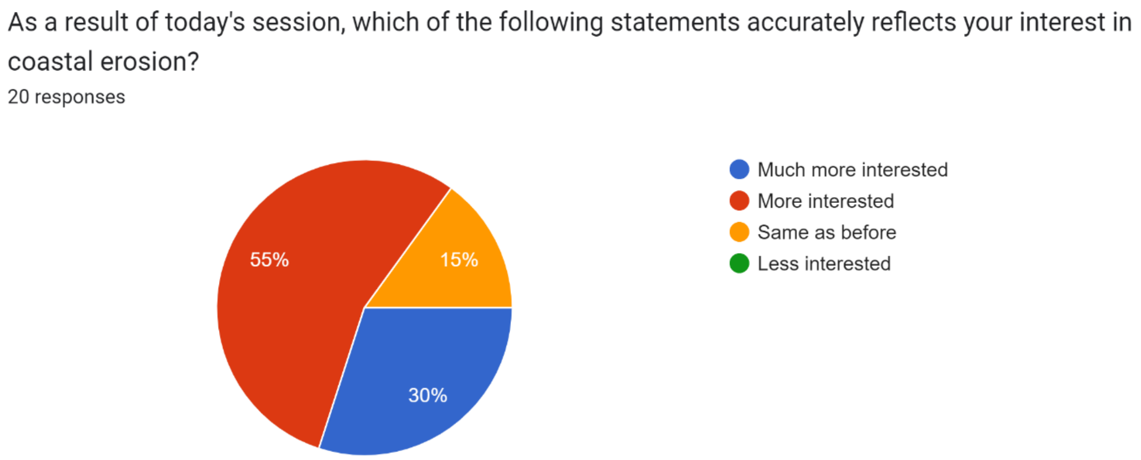


Figure 5.5: Pie chart comparing change in interest

Not only was it key for the microworld to enhance the learners' knowledge of coastal erosion, but to also create interest and discussion in relation to it. 85% of learners felt they had a greater interest in coastal erosion after using the microworld.

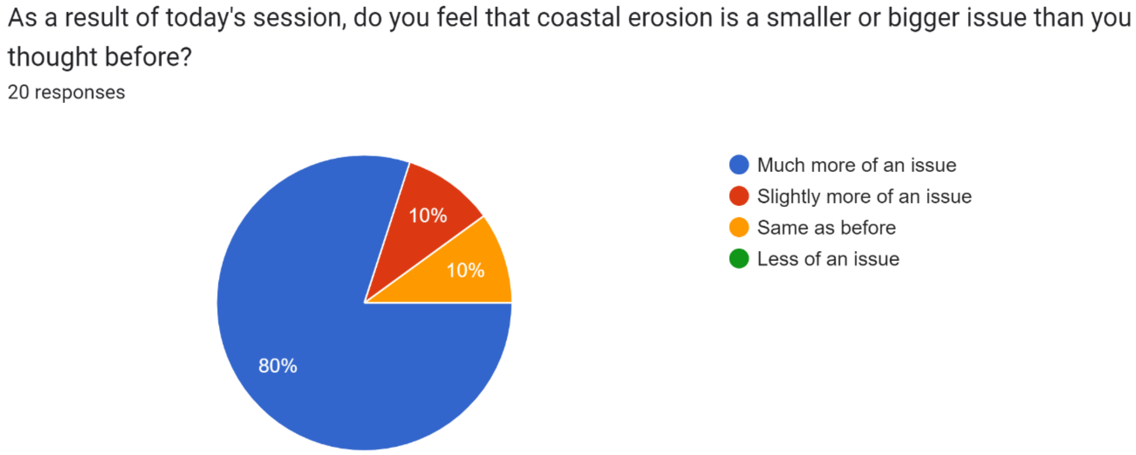


Figure 5.6: Pie chart comparing change in issue

Another key aspect of the project was to highlight and raise the issue of coastal erosion, particularly as the worst effects of coastal erosion will not be seen for many more decades. 90% of learners stated that it was a bigger issue than thought, 80% saying much more, after using the microworld.

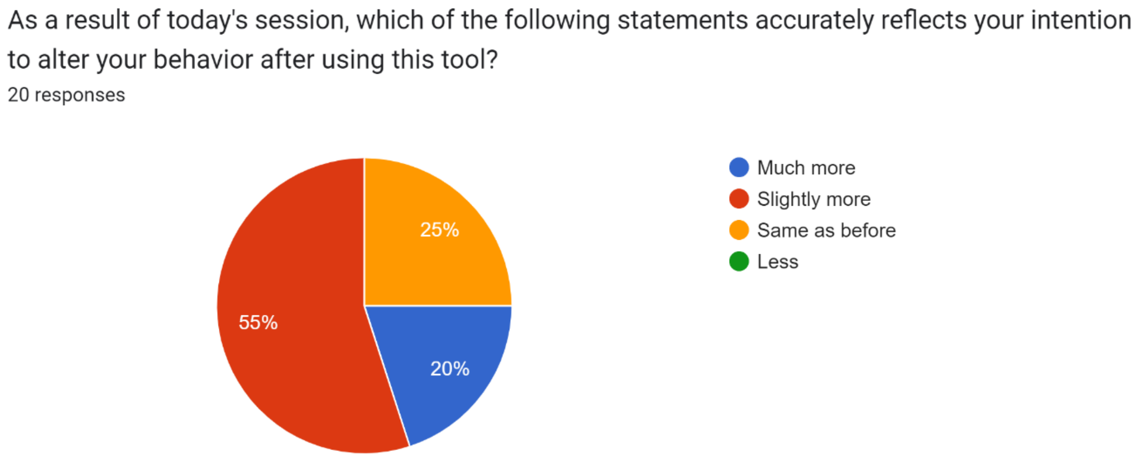


Figure 5.7:Pie chart comparing behaviour alteration

While it is not up to an individual to change the effects of coastal erosion, the author wanted to understand if the leaners would change their behaviour in relation to coastal erosion. While not as high of a proportion of learners supported this statement as the previous, 75% stated that they would although only 20% said they would be much more.

Overall, the feedback on the educational questionnaire provides a positive look for the microworlds suitability to enhance and challenge learners' knowledge about coastal erosion. The microworld was effective in engaging the users in the area of coastal erosion, particularly with a large majority stating they had a larger interest in coastal erosion after using the tool. While there was no previous metrics collected on the learners' knowledge and intertest in coastal erosion prior to using the microworld, the feedback provides a positive outlook that the microworld did so.

There was a general discussion conducted post using the microworld and the questionnaire allowed learners to record their views of what they learnt after using the microworld. Here are some of the remarks which were made in relation to this:

- *"I think the tool was brilliant in terms of how easy it was to use it. It is a clever way to raise awareness about the topic while showing the impact the solutions have. The cost was also important as an aspect of real-life problem solving!"*
- *"Stop building houses at the edge of cliffs."*
- *"I knew almost nothing about it before so everything there was new to me. It made me think more about that issue and I hadn't done that before."*
- *"Making preventions are very expensive."*
- *"The budget for protecting the coast and how little budget there is."*
- *"I learned how useless it is to put extra sand on beaches as it only seems to increase problems. Finally I learned how dire coastal erosion can be, especially for those that live on the coast."*

5.3 Educator and Subject-matter Expert Feedback

5.3.1 Educator Feedback

After completion of the workshop, the views of the educators who facilitated the Bridge2College programme were also gathered to understand the effectiveness of the microworld as an option for educators to use as an alternative learning tool. The educators were present for the duration of the workshop, and some of their key feedback was:

- *"The students didn't realise at first how much they were learning because it felt like a game."*
- *"Seem to understand the concepts really well in a visual way compared to textbooks."*
- *"The microworld has a good hook to get them engaged."*
- *"The debate and discussions afterward were quite good, we maybe underestimated the discussions, didn't know how it would go."*
- *"Impressed how they unprompted asked to take tool back to their schools."*

5.3.2 Subject Matter Expert Feedback

The author had support from the co-supervisor of this project, Dr. Iris Moeller, who provided information pertaining to the modelling of coastal erosion and the mitigations available. Upon completion of the final implementation of the microworld, the author also received the views of their opinion of the tool from both a coastal erosion modelling and educational aspect. Their views of the microworld were as follows.

- The simulation of coastal erosion provided an abstract level of coastal erosion that was suitable for educational purposes with the target audience.
- The interactivity of the simulation was well implemented.
- There is potential for future work on enhancing the microworld, particularly with changing climate variable predictions and adding further mitigations.
- The user interface is simple and intuitive.
- Explanations of the prevention methods could be explained within the application.

Throughout the duration of the project, the author was also in contact with a PhD candidate studying coastal erosion at Trinity College Dublin who helped with providing details for the research and review of the tool throughout the design and implementation phases. Their final view of the tool was also captured and some of their key feedback was as follows.

- Climate variables are accurate in relation to respective data projections.
- The simulation is adaptable to encompass new projections which is valuable considering the dynamism of coastal erosion modelling.
- Effective in accurately modelling coastal erosion but not precise, but for suitability with the target audience and educational aspect this is not required.
- Sediment processes aren't captured but overall do not impact the teaching aspect of the mitigations for coastal erosion.
- Storm variability could potentially be reviewed rather than modelling the worst-case storm each year.

5.4 Summary

The testing and evaluation carried out on this project has confirmed that the main aim of creating a microworld to teach learners about coastal erosion has been achieved. While large studies would need to be conducted and on potentially different target demographics to reaffirm this, the initial evaluation performed has affirmed that the microworld provides a unique tool to teach and engage learners with the potential to further improve the application based upon the feedback received.

6. Conclusions

This project aimed to use modern technology, with key concepts of pedagogical theory and Human-Computer Interaction, to create an interactive tool that would aid in teaching learners about coastal erosion. The primary goal was to create an interactive model of coastal erosion that would be suitable for use with Transition Year students that cognitively engaged and challenged them compared to traditional teaching methods. Based upon the quantitative and qualitative analysis, the microworld was successful in these aspects and showed to enhance learners' knowledge and interest in coastal erosion.

The background research conducted highlighted the complexity and difficulty in accurately modelling coastal erosion which thus led the project to take the direction of creating a low-fidelity coastal erosion model. Whilst there are a range of climate variables, particularly in relation to wave generation, that could have been modelled, the complexity of such meant that it would have been difficult to visualise all aspects and for learners to understand the relationships between them. Upon completion of the background research, it was decided that it was best to create a flexible and visually appealing microworld that would allow for high amounts of learner interactivity which incorporated the best practises of HCI. The implementation highlighted some of the key difficulties and challenges in creating the tool to satisfy these conditions.

Whilst the initial evaluation conducted in this project was deemed successful in satisfying its main aims, there are some limitations of the study that should be considered. There was a small sample size (N=21) of Transition Year students, which provides limited feedback. Such a small sample size may not accurately reflect the entire target demographic. With access to a larger number of students, a standardised analysis could have been performed to allow for better comparison to other tools available to learners. However, the feedback received from educators and the subject matter expert were positive, highlighting the tool's successful ability to provide a cognitively engaging and challenging learning platform.

In conclusion, the microworld successfully incorporated a coastal erosion simulation that met the goals and requirements set out for the project during the design phase. Upon completion of the limited evaluation, the microworld was able to aid learners build their knowledge and interest in coastal erosion which was imperative to the success of this project. Whilst this project satisfied the goals it set out, there is still room for improvement in the application and some of the areas in which it could be are discussed below.

6.1 Future Work

This section discusses enhancements and extensions that could made be to the work that has been presented.

6.1.1 Improved Visualisation of Modelling Coastal Erosion

The complexity of modelling coastal erosion has been discussed in the research of this paper but despite this, potential future work could involve a improving some of the visualisations of the simulation. Certain aspects of the simulation could be enhanced visually, particularly the dune erosion, occurrence of storms, and waves. From the initial evaluation, the visual appeal of some of the model's objects were highlighted as lacking and could be further improved. This should be one of the key goals for future work on future iterations of this project.

6.1.2 Further Evaluation

Continuing from the evaluation conducted already in this paper, by performing further evaluation a larger amount of qualitative and quantitative data would be effective in determining to verify if the initial evaluation carried was successful. Conducting further research on different demographics of learners would be interesting to see if the usability and educational benefits of the microworld satisfy a broader spectrum. Performing a more standardised evaluation method for usability would be beneficial to compare against alternative applications, hopefully reaffirming the tool's ability to be a unique and educational tool for coastal erosion.

6.1.3 Additional Mitigation Techniques

The microworld developed in this project has a limited set of mitigations methods available to the learner to defend against coastal erosion. While the chosen mitigations were chosen based upon findings conducted in the research, there are still numerous others which would provide some benefit to fully understand all available mitigations. The mitigation of managed retreat would be extremely beneficial for learners to interact with, particularly if concepts such as house value in relation to sea-level and population willingness could be accurately captured and modelled.

Appendix

Live version of the microworld can be found at:

https://dme789.github.io/

The source code of the microworld can be found at:

https://github.com/dme789/coastal-erosion-microworld

The UI mock-ups are available at:

https://www.figma.com/file/bhXlU16yPDcfPQVQpQOVuR/Coastal-Erosion-UI?node-id=0%3A1&t=ypbivPhfRYM5jCqm-1

The survey given to the students for the evaluation is available at:

https://forms.gle/FS9t4vLLrT3UR3uT7

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