Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

School of Computer Science and Statistics

A Microworld to teach the impact of transport on Ireland’s carbon emissions

Michael Sweeney

April 2023

A Report submitted in partial fulfilment

of the requirements for the degree of

BA(Mod) in Science in Computer Science

Acknowledgments

First and foremost, I want to extend my appreciation to Professor Brendan Tangney, my project supervisor, for his support and invaluable feedback throughout the year. His guidance has been crucial in enabling me to produce a high-quality piece of work, and I have gained immense knowledge from his feedback. I am grateful for his valuable meetings and constructive criticism, which has challenged me to think beyond the conventional and develop a more comprehensive understanding of the subject.

I am immensely thankful to the Bridge2College team for their support, without which this paper would have been arduous. The participation of the students and the resources provided by the team have been instrumental in the successful completion of this project.

I would like to express my gratitude to my parents for affording me this incredible opportunity and for their unwavering support throughout the last 23 years. Their encouragement has been a constant source of motivation for me. I would also like to thank my brother Brendan for his constant support throughout my academic journey.

Lastly, I extend my appreciation to all my friends for the wonderful experiences we shared during the past four years of college. The memories we made will remain etched in my mind forever, and I will cherish them for a lifetime.

M

Abstract

Climate change is one of the most prominent challenges facing humanity today, with potentially devastating consequences for human societies and natural ecosystems. The primary cause of climate change is the release of greenhouse gases (GHGs) such as carbon dioxide (CO_2) and methane into the atmosphere. To mitigate the impacts of climate change, it is crucial to address the factors contributing to GHG emissions, one of which is transport. Addressing this challenge requires educating future leaders and decision-makers on the impacts of their choices. This report details the design, implementation, and evaluation of a microworld tool aimed at teaching the impact of transport on Ireland's carbon emissions and is targeted at Transition Year students as it fits best with the student curriculum at that level.

Ireland is a country that has experienced rapid economic growth over the past few decades, leading to a substantial increase in transport demand resulting in the sector becoming a significant contributor to the country's carbon emissions. This report aims to provide an in-depth understanding of factors that drive Ireland's carbon emissions, focusing primarily on the transport sector, and explore the potential of a microworld tool to educate young people on their contribution to those emissions.

Limited technology has been utilized to educate students on issues related to sustainability and climate change, particularly in relation to transport. Therefore, we will explore various available technologies and analyse their potential impact on the development of a Microworld that educates users on sustainable transportation choices and greenhouse gas emissions. The microworld tool is consistent with constructivist and constructionist educational philosophies, functioning as a simplified simulation that illustrates the complexities and compromises associated with addressing transportation's impact on Ireland's carbon emissions. The tool presents two key challenges to engage learners and illustrate the essential dynamics at play.

The design of the microworld includes multiple components that aim to engage students in understanding the relationship between transportation choices and GHG emissions. These components consist of an interactive data presentation, a calendar-based challenge to estimate individual carbon emissions and a final challenge for the individual student to meet the 2030/2050 emission reduction goals. The implementation process involves the selection of appropriate technologies, such as web-based programming languages and data visualization libraries, to create an engaging and user-friendly microworld with real impact.

The development process encountered several technical challenges, which are discussed alongside the solutions implemented and their influence on the microworld design. The tool was evaluated and tested in a workshop setting by a cohort of 26 students participating in the Bridge2College program, a university outreach activity.

Students interacted with the tool and provided feedback, while a survey assessed its usability and pedagogical effectiveness. Both quantitative and qualitative feedback indicated the success of the microworld in achieving its main aim: to develop a tool with pedagogical and constructionist characteristics that improve learners' understanding of how to control transport's impact on Ireland's carbon emissions. The microworld's effectiveness is assessed through improving students' understanding and knowledge of these issues. The insights and experiences gained from the development and evaluation of this microworld contribute to the potential of educational microworlds to address complex environmental and societal issues as well as the need for greater integration of such educational approaches into mainstream education to address the pressing challenges of climate change and sustainability.

Contents

1 Introduction

Climate change is an urgent global issue with far-reaching consequences that demand immediate action. The growing levels of greenhouse gas (GHG) emissions, particularly carbon dioxide (CO_2), are a primary driver of climate change, resulting in rising temperatures, sea-level rise, and extreme weather events (IPCC, 2021). Various human activities including burning fossil fuels, deforestation and farming contribute significantly to the increase in GHG emissions. Among these, the transportation sector plays a pivotal role, accounting for approximately 23% of global energy-related CO_2 emissions in 2019 (International Energy Agency [IEA], 2019).

The transportation sector's reliance on fossil fuels has made it one of the most challenging areas to decarbonize. Road transportation is the largest contributor to transportation-related emissions, responsible for around 70% of transport-related CO_2 emissions (IEA, 2019). Light-duty vehicles such as cars and SUVs are the leading sources of these emissions, accounting for approximately 40% of transport-related CO_2 emissions (IEA, 2019).

To address the pressing issue of climate change, international agreements such as the Paris Agreement have been established, targeting significant reductions in GHG emissions and limiting global warming to well below 2°C above pre-industrial levels. Achieving these targets necessitates a comprehensive understanding of the factors contributing to GHG emissions and the implementation of effective mitigation strategies across various sectors, including transportation.

Education plays a crucial role in raising awareness about climate change and fostering understanding of the necessary measures to mitigate its impacts. The lack of understanding and awareness of these issues, particularly among students, has been identified as a significant barrier to achieving sustainable transportation and reducing GHG emissions. Research has shown that educational interventions can influence students' knowledge, attitudes, and behaviours relating to environmental issues, including climate change. However, traditional educational methods may not be sufficient to engage learners and facilitate deep understanding of the complex issues related to climate change and sustainable transportation.

In recent years, educational microworlds have emerged as a promising approach to engaging students in learning about complex environmental and societal issues (Gomes et al., 2018). Educational microworlds are computer-based simulations or virtual environments designed to support learning and instruction by providing learners with an interactive and immersive experience, allowing them to explore, experiment, and discover new concepts, skills, and knowledge. Microworlds align well with constructivist and constructionist pedagogical approaches, which emphasize active learning, knowledge construction, and learner-centeredness (Gomes et al., 2018).

In the context of sustainable transportation, educational microworlds offer a unique opportunity to engage students in exploring the relationship between transportation choices and GHG emissions while promoting sustainable behaviours (Gomes et al., 2018). By simulating real-life scenarios and allowing students to experiment with different transportation modes and situations, microworlds can foster a deeper understanding of the impact of transportation choices on the environment and encourage students to make more sustainable decisions.

The development and evaluation of an interactive microworld for sustainable transportation education is the primary focus of this report. The microworld aims to provide students with a multi-step, engaging learning experience, which begins with presenting statistics and diagrams about transportation emissions and the impact of various transportation modes. Following this, students are guided through a calendar-based challenge to estimate their yearly transport-based carbon emissions using different transportation modes and situations, the students then are challenged with reducing their emissions to reach 2030 and 2050 emission reduction goals. By incorporating game-like elements such as challenges and rewards, the microworld aims to motivate students to continue making fulfilling life choices while reducing their transportation-related emissions.

The report is structured as follows: Chapter 1 explains the goals of the project and an overview, Chapter 2 provides a background on transportation and GHG emissions, as well as the role of education in promoting sustainable transportation. Chapter 3 offers an overview of the project, including the design and components of the microworld. Chapter 4 presents the implementation of the microworld and a detailed account of the building process. Chapter 5 outlines the evaluation methodology and assessment of the microworld's effectiveness in improving students' understanding and knowledge of sustainable transportation issues. Finally, Chapter 6 presents the conclusion and discusses future work and potential extensions of the project.

1.1 Project Goal

The primary goal of this project is to meticulously design, implement, and evaluate an interactive, and engaging educational microworld tool that helps Transition Year students learn about the impact of transportation choices on the country's carbon emissions, contributing to a broader understanding of climate change and sustainable development. This project aims to address the challenge of fostering a deep understanding of the relationship between sustainable transportation and greenhouse gas emissions, as well as promoting the adoption of more sustainable behaviours among students, ultimately shaping future leaders and decision-makers who are knowledgeable and committed to combating climate change.

To achieve this goal, the project will encompass several key objectives and steps to ensure the successful development and implementation of the educational microworld tool. Beginning with research on climate change, sustainable transportation, and greenhouse gas emissions. This background research will provide the necessary foundation for understanding the critical issues and factors contributing to transportation-related emissions and will be used in the design of the microworld.

Secondly, the project will explore the potential of various technologies and educational approaches for teaching students about complex environmental issues. The project will investigate the use of computer-based simulations and virtual environments to create an engaging and learner centred educational experience. By leveraging these innovative educational approaches, the microworld tool will aim to overcome the limitations of traditional teaching methods and give a deeper understanding of the impact of transportation choices on greenhouse gas emissions.

The next objective is the design and development of the microworld tool itself. The tool will be designed to include multiple interactive components and two challenges that engage students in understanding the relationship between transportation choices and their greenhouse gas emissions. The microworld will consist of an interactive data presentation, a personalised calendar-based challenge to estimate individual carbon emissions, and a final challenge to meet the 2030/2050 emission reduction goals. The design process will detail the selection of appropriate technologies, such as web-based programming languages and data visualization libraries, to create an engaging and user-friendly microworld that caters to learners.

Following the design and development of the microworld tool, the project will focus on its implementation in educational settings. The microworld’s effectiveness will be evaluated through a workshop in the Bridge2College program. Bridge2College is an extracurricular educational program, tailored for students in their Transition Year. It employs an innovative, team-centric learning methodology that highlights the application of technology and project-oriented learning to teach students in authentic, real-life situations.

The evaluation process will utilize a combination of quantitative and qualitative research methods, such as surveys and feedback to assess the usability, effectiveness, and overall impact of the microworld tool on students' understanding of sustainable transportation and greenhouse gas emissions.

Finally, the project will assess the findings from the evaluation process and draw conclusions about the success of the microworld tool in achieving its primary goal by assessing feedback from the students. The project will also identify potential areas for improvement, future research, and the scaling-up of the microworld tool to reach a broader audience of students and educators. By sharing the insights and experiences gained from this project, I hope to contribute to the growing body of knowledge on the potential of educational microworlds for addressing complex environmental and societal issues and the need for greater integration of such educational approaches into mainstream education.

1.2 Ethics

The tool was used by 26 TY students for a period of 1.5 hours as part of a two-day workshop within the Bridge2College program, exploring different aspects of climate change. Ethical approval was sought and received from The School of Computer Science & Statistics for the collection of all information relevant to the project in relation to the Bridge2College program. The project was carried out with respect to the ethical principles of research, including respect for individuals and subject matter. Care was taken to ensure that all participants' data was handled appropriately, and strict confidentiality was maintained throughout.
Any potential consequences of the study, both positive and negative, were considered, and steps were taken to minimize any negative impacts and maximize any positive impacts. Overall, the project was carried out with the utmost care and attention to ethical principles and guidelines.

1.3 Bridge2College

Bridge2College, based at Trinity College Dublin, is an innovative, extracurricular educational program designed for students during their Transition Year. It adopts a unique, team-based learning approach that emphasizes the use of technology and project-based learning to engage students in real-world scenarios. The program provides students with the opportunity to immerse themselves in a wide array of projects, including those focused on science, technology, engineering, and mathematics (STEM). By leveraging a flexible and creative learning environment, Bridge2College aims to cultivate the skills necessary for students to thrive in a rapidly evolving, technology-driven world.

In a recent study it was found that students who participated in the Bridge2College program exhibited significant increased self-reported levels of confidence in their abilities to collaborate, communicate, think critically, and solve problems. Furthermore, the program appeared to have a positive effect on students' motivation and engagement in learning, which are essential factors in promoting skill development (Kevin Sullivan, Aibhín Bray & Brendan Tangney, 2021).

Through its unique, technology-driven, and project-based approach to learning, the program enables participants with the collaboration, communication, critical thinking, and problem-solving abilities necessary to succeed and learn in an increasingly complex, globalized world. As such, the

Bridge2College program serves as a powerful place to test and gain feedback on how impactful an interactive microworld can be.

2 Background

This chapter describes the review of literature that the author conducted. The findings from an analysis of the body of information pertinent to this study are presented in this section.

2.1 Climate Change and Transportation: A Global Change

Climate change is one of the most pressing challenges faced by humanity today. The transportation sector, which is responsible for a quarter of global greenhouse gas (GHG) emissions, has been identified as a key area in the global effort to mitigate the effects of climate change. Below we delve into the body of research on the relationship between climate change and transportation, as well as highlight the key strategies and technologies that can contribute to a more sustainable transportation system.

- **Transportation and its contribution to climate change:** According to the UN Environment Programme, the transport sector contributes approximately one quarter of all energy related GHG emissions The combustion of fossil fuels in various modes of transport, such as road, rail, aviation, and shipping, releases a range of GHGs, including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Global emissions from transportation are projected to increase in the coming decades due to population growth, urbanization, and economic development, particularly in growing economies. (UN Environment Programme)

- **Technologies and strategies for reducing transportation emissions:** There is a growing need to implement effective strategies to reduce the carbon footprint of the transport sector. Researchers have explored a range of approaches to achieve this goal, including the electrification of transport and improved public transportation and active travel.

  - **Electrification of transport:** The transition from fossil-fuel-based vehicles to electric vehicles (EVs) is considered a crucial step towards reducing transportation emissions. Research indicates that widespread adoption of EVs could significantly reduce CO_2 emissions and improve air quality in urban areas (Buehler et al., 2017).
  - **Improved public transportation and active travel:** Promoting public transportation and active travel modes, such as walking and cycling, can help reduce GHG emissions by reducing reliance on private vehicles. Investments in public transport infrastructure and policies that support this kind of transportation can encourage more sustainable travel behaviour (Buehler et al., 2017).

To have real societal impact, the information gathered from the review has been taken forward in the development of the microworld. By focusing on the identified areas, students will learn about the barriers to the adoption of low-carbon transportation technologies and strategies. Additionally, the project will highlight the most effective policy interventions that can be tailored to suit different needs. By exploring the potential benefits of sustainable transportation, the project aims to strengthen the case for investment in low-carbon transportation systems and garner greater support from policymakers and the public.

2.2 The Environmental Impact of Different Modes of Transportation

The transportation sector plays a vital role in modern society, as it facilitates the movement of people and goods, driving economic growth and development. However, the sector's environmental impact warrants thorough examination to devise strategies that ensure reductions in its carbon footprint. Below we delve into the environmental repercussions of various transportation modes, such as road, rail, aviation, and maritime transport.

2.2.1 Road Transport

Figure 1: Road Transport

Road transport is the most prevalent mode of transportation globally and is responsible for a large share of transportation related GHG emissions and air pollution. Private vehicles are significant contributors to these environmental impacts due to their widespread use and reliance on fossil fuels. Emissions from road transport include carbon dioxide (CO_2), nitrogen oxides (NOX), particulate matter (PM), and volatile organic compounds (VOCs), which accounts for three-quarters of transport emissions globally (Environmental Protection Agency, 2022). Strategies to reduce the environmental impact of road transport include promoting electric vehicles (EVs), improving fuel efficiency, and encouraging the use of public transport.

2.2.2 Rail Transport

Figure 2: Rail Transport

Rail transport is generally considered a more environmentally friendly mode of transportation compared to road transport, particularly for freight transport and long-distance passenger travel.

Electric trains, which account for a significant proportion of rail transport, produce lower GHG emissions and air pollutants than their diesel counterparts. However, rail transport still has environmental impacts, such as noise pollution and land use changes associated with infrastructure development. Increasing the share of rail transport in the overall transportation system could help reduce the sector's environmental footprint (DfT, 2021).

2.2.3 Aviation

Figure 3: Aviation

The aviation industry is a major contributor to global GHG emissions, accounting for around 2.5% of total CO_2 emissions worldwide (International Energy Agency [IEA], 2019). The environmental impacts of aviation are not limited to CO_2 emissions; other emissions, such as NOx and water vapor, can also contribute to climate change. Furthermore, aviation is associated with noise pollution and local air quality degradation near airports. Strategies to reduce the environmental impact of aviation include improving aircraft fuel efficiency, implementing market-based mechanisms such as carbon pricing, and exploring alternative fuels, such as biofuels (Lee et al, 2021).

2.2.4 Maritime Transport

Figure 4: Solar panel

Maritime transport is responsible for a significant portion of global CO_2 emissions, contributing approximately 2.5% of total emissions (International Energy Agency [IEA], 2019). In addition to CO_2, ships emit other pollutants, such as NOx, sulfur oxides (SOx), and PM, which can have adverse effects on air quality and human health. The environmental impact of maritime transport can be mitigated through various strategies, including the implementation of more stringent emissions standards, the adoption of energy-efficient technologies, and the use of cleaner fuels, such as liquefied natural gas (LNG) or biofuels (Psaraftis & Kontovas, 2016).

2.2.5 Comparison of the transport emissions for each mode of transport

Mode of Transportation	Percentage of Worldwide Transport Emissions	CO_2 Emissions per km per Person	Environmental Impact	Possible Improvements	How to Improve that Transportation
Car (Gasoline)	40%	150-250 g CO_2/km	High CO_2 emissions, air pollution, noise pollution, habitat destruction, resource consumption	Increase fuel efficiency, transition to hybrid or electric vehicles, carpooling, use public transportation	Implement policies and incentives for sustainable vehicle choices, improve public transportation, encourage carpooling
Car (Electric)	1% (growing)	0-100 g CO_2/km	Lower CO_2 emissions, air pollution, noise pollution, habitat destruction, resource consumption (battery	Use renewable energy for charging, improve battery technology, carpooling, use	Implement policies and incentives for sustainable vehicle choices, improve charging infrastructure,

Mode of Transportation	Percentage of Worldwide Transport Emissions	CO_2 Emissions per km per Person	Environmental Impact	Possible Improvements	How to Improve that Transportation
			production)	public transportation	promote renewable energy
Bicycle	<1%	0 g CO_2/km	Minimal CO_2 emissions, minimal noise pollution, minimal habitat destruction	Encourage bike-sharing programs, improve cycling infrastructure, promote e-bikes for longer distances	Create bicycle-friendly cities, promote bike-sharing programs, educate the public about the benefits of cycling
Walking	<1%	0 g CO_2/km	No CO_2 emissions, no noise pollution, minimal habitat destruction	Improve pedestrian infrastructure, promote walkable communities, encourage active transportation	Create pedestrian-friendly cities, promote walkable communities, educate the public about the benefits of walking
Bus (Diesel)	6%	40-100 g CO_2/km	Moderate CO_2 emissions, air pollution, noise pollution, resource consumption	Transition to hybrid or electric buses, improve route efficiency, encourage ridership	Implement policies and incentives for cleaner buses, improve public transportation infrastructure, promote ridership
Bus (Electric)	<1% (growing)	0-20 g CO_2/km	Lower CO_2 emissions, air pollution, noise pollution, resource consumption (battery production)	Use renewable energy for charging, improve route efficiency, encourage ridership	Implement policies and incentives for cleaner buses, improve public transportation infrastructure, promote renewable energy
Train (Diesel)	4%	40-90 g CO_2/km	Moderate CO_2 emissions, air pollution, noise pollution, habitat destruction, resource consumption	Transition to electric trains, improve route efficiency, encourage ridership	Implement policies and incentives for cleaner trains, improve railway infrastructure, promote ridership

Mode of Transportation	Percentage of Worldwide Transport Emissions	CO_2 Emissions per km per Person	Environmental Impact	Possible Improvements	How to Improve that Transportation
Train (Electric)	2%	15-50 g CO_2/km	Lower CO_2 emissions, air pollution, noise pollution, habitat destruction, resource consumption (energy production)	Use renewable energy for operations, improve route efficiency, encourage ridership	Implement policies and incentives for cleaner trains, improve railway infrastructure, promote renewable energy
Aviation	2%	150-285 g CO_2/km	High CO_2 emissions, air pollution, noise pollution, habitat destruction, resource consumption	Increase aircraft fuel efficiency, transition to sustainable aviation fuels, reduce air traffic	Implement policies and incentives for sustainable aviation, invest in fuel-efficient aircraft, support sustainable fuels
Maritime Transport	2.5%	15-70 g CO_2/km	Moderate CO_2 emissions, air pollution, noise pollution, habitat destruction, resource consumption, water pollution	Increase fuel efficiency, transition to alternative fuels, optimize shipping routes	Implement policies and incentives for sustainable maritime transport, invest in alternative fuels and efficient ships

Figure 5: Table of emissions from different modes of transportation (Our World in Data, 2019: multiple sources)

2.2.6 Summary

Different modes of transportation have varying environmental impacts, with road and aviation transport typically causing the most significant emissions and air pollution. However, all modes of transportation contribute to environmental degradation in some form.

In the microworld, the environmental impacts of different modes of transportation will be incorporated to help students understand and compare the consequences of their choices. By integrating the varying emissions and pollution levels associated with each transport mode, the microworld will provide a comprehensive and realistic representation of the transportation landscape.

Students will have the opportunity to explore the impact of various transportation options on the environment, including road and aviation transport, which typically generate the highest emissions, as well as cleaner alternatives such as rail and electric vehicles. They will also learn about strategies to mitigate these environmental impacts, such as improving fuel efficiency and implementing policy interventions to incentivize the adoption of sustainable transportation options.

2.3 Sustainable Transportation: Strategies and Best Practices

Sustainable transportation seeks to minimize the negative environmental impacts of transportation while maintaining its essential function of moving people and goods. As the transportation sector is a major contributor to greenhouse gas (GHG) emissions and air pollution, adopting sustainable transportation practices is crucial for mitigating climate change and improving air quality. Below we explore the key strategies and best practices that have been identified to promote sustainable transportation, including improvements in vehicle technology, infrastructure development, and policy interventions.

2.3.1 Vehicle Technology Improvements

Improving the energy efficiency and environmental performance of vehicles is essential for advancing sustainable transportation. Some key areas of focus include:

- Electrification: The transition from fossil-fuel-based vehicles to electric vehicles (EVs) can significantly reduce GHG emissions and improve air quality. Research suggests that widespread adoption of EVs, particularly in urban areas, can lead to substantial reductions in transportation-related emissions (Nykvist & Nilsson, 2015).
- Fuel efficiency: Improving the fuel efficiency of conventional vehicles can also contribute to lower emissions. Advanced engine technologies, lightweight materials, and aerodynamic design improvements have been shown to effectively reduce fuel consumption and CO_2 emissions (Nykvist & Nilsson, 2015).
- Alternative fuels: The use of alternative fuels, such as biofuels, natural gas, and hydrogen, can help reduce the environmental impact of transportation by decreasing reliance on fossil fuels (Nykvist & Nilsson, 2015).

2.3.2 Infrastructure development

The development of sustainable transportation infrastructure can facilitate the adoption of cleaner modes of transport and promote more environmentally friendly travel behaviours. Key areas of focus include:

- Public transportation: Investing in public transportation infrastructure, such as bus rapid transit (BRT), light rail, and commuter rail, can encourage a shift away from private vehicles, thereby reducing GHG emissions and congestion. Enhancing the accessibility, reliability, and affordability of public transportation can further promote its use (Litman, 2014).
- Active transportation: Developing infrastructure for active transportation modes, such as walking and cycling, can encourage more sustainable travel behaviours and contribute to reduced emissions and improved public health (Litman, 2014). Implementing safe and well-connected pedestrian and cycling networks can help promote active transportation.
- Multimodal transportation: Supporting multimodal transportation through the integration of different transport modes, such as public transit, car-sharing, bike-sharing, and EV charging infrastructure, can improve the efficiency of the transportation system and promote more sustainable travel options (Litman, 2014).

2.3.3 Policy Interventions

Policy interventions play a crucial role in driving the transition to sustainable transportation. Effective policies can create incentives for the adoption of cleaner transportation options and shape travel behaviours. Some key policy interventions include:

a) Carbon pricing: Implementing carbon pricing mechanisms, such as carbon taxes or cap-and-trade systems, can internalize the environmental costs of transportation and incentivize the adoption of low-emission vehicles and alternative fuels (Metcalf, 2009).

b) Vehicle standards: Establishing stringent vehicle efficiency standards and emissions regulations can drive improvements in vehicle technology and reduce emissions from the transportation sector (Metcalf, 2009).

c) Land use planning: Integrating transportation and land use planning can promote compact urban development, reduce the need for private vehicle use, and encourage more sustainable transportation modes, such as public transit, walking, and cycling (Metcalf, 2009).

2.3.4 Summary

Promoting sustainable transportation requires a combination of vehicle technology improvements, infrastructure development, and policy interventions. Implementing these strategies and best practices can help reduce the environmental impact of transportation, improve air quality, and mitigate climate change.

2.4 Future Transport Emission Goals

The 2030 transport goals in Ireland and across the world are primarily aimed at significantly reducing greenhouse gas (GHG) emissions from the transport sector to combat climate change and promote sustainable development. Achieving these goals is critical for meeting the commitments outlined in the Paris Agreement (United Nations Framework Convention on Climate Change, 2015).

In Ireland, the government has set ambitious targets for reducing GHG emissions from the transport sector as part of its broader national climate action plan. The Climate Action Plan 2019 establishes a roadmap to achieve a 51% reduction in national GHG emissions by 2030, with a specific focus on the transport sector (Department of Communications, Climate Action & Environment, 2019). Key strategies outlined in the plan include the decarbonization of the transport sector through the accelerated deployment of electric vehicles (EVs), improvements in public transportation, and the promotion of sustainable mobility solutions such as walking, cycling, and car-sharing.

One of the main targets of the Irish government is to have 936,000 EVs on the road by 2030, accounting for approximately 50% of the total passenger vehicle fleet (Department of Communications, Climate Action & Environment, 2019). This will be supported by a range of incentives, including grants for EV purchases, reduced toll fees, and investments in charging infrastructure. Additionally, the government aims to phase out the sale of new internal combustion engine (ICE) vehicles by 2030 and promote the use of biofuels and renewable energy in the transport sector.

The Climate Action Plan also emphasizes the importance of enhancing public transportation and investing in sustainable mobility solutions. The government plans to increase the share of public transport, walking, and cycling in urban areas, with a target of 45% of all trips to be made by these modes by 2030 (Department of Transport, Tourism and Sport, 2019). This will be achieved through investments in public transport infrastructure, such as the expansion of light rail and bus networks, as well as the development of safe and accessible cycling and walking routes.

At the global level, the International Transport Forum (ITF) has outlined a set of policy recommendations for achieving the 2030 transport goals, focusing on three main areas: technology and innovation, infrastructure, and behavioural change (ITF, 2017). Key recommendations include promoting the adoption of low- and zero-emission vehicles, investing in clean public transport systems, improving the energy efficiency of transport infrastructure, and encouraging sustainable travel behaviours through pricing mechanisms and public awareness campaigns.

The 2030 transport goals in Ireland and around the world represent a bold and necessary step towards addressing the urgent challenges posed by climate change and unsustainable development. To achieve these goals, concerted efforts must be made to overcome the technological, financial, and behavioural challenges associated with the transition to sustainable transport systems. By doing so, we can pave the way for a cleaner, healthier, and more resilient future for all.

2.5 The Effectiveness of Educational Microworlds in Enhancing Learning

Educational microworlds are interactive, computer-based learning environments designed to provide learners with opportunities to explore and construct knowledge in specific domains. By encouraging active engagement and problem-solving, microworlds have the potential to enhance learning and promote deeper understanding of complex topics.

Studies have demonstrated the potential of educational microworlds to enhance students' understanding of environmental issues, such as climate change, by engaging them in problem-solving, decision-making, and reflection (Gomes et al., 2018). For instance, Gomes et al. (2018) developed a microworld to teach high school students about the role of renewable energy sources in mitigating climate change. Their study found that the microworld was effective in improving students' understanding of renewable energy concepts and fostering positive attitudes towards renewable energy sources. Similarly, Dede (2017) introduced EcoXPT, an immersive, inquiry-based digital environment that simulates complex ecosystems to help middle school students understand ecosystem concepts. The findings suggested that students who used EcoXPT showed improved understanding of the relationships and mechanisms within ecosystems.

Despite the growing body of evidence supporting the effectiveness of microworlds in education, there are still areas that require further exploration. For instance, more research is needed to investigate the potential of microworlds to support learning in a broader range of educational contexts, including informal learning environments and online settings.

Considering the extensive research and evidence supporting the efficacy of educational microworlds in fostering learning, critical thinking, and problem-solving skills, the decision to implement a microworld into this project as a means of teaching students about their transportation choices is well-founded. As highlighted in the studies mentioned above, microworlds have consistently proven to be effective tools in enhancing students' understanding of complex issues and promoting positive attitudes towards sustainable practices.

2.6 Summary

Transportation's impact on the world is a complex and crucial topic that requires education at all levels. When done correctly, educational microworlds can greatly influence the behaviour of learners. With this research we can now create learning environments where students can actively engage in world issues and feel like they can make world-changing decisions.

3 Design

3.1 Project considerations

To ensure the successful development and implementation of the microworld, several design project considerations were considered. These include target audience, learning objectives, technological constraints, and evaluation strategies.

Target Audience: The target audience for the microworld tool is Transition Year students participating in the Bridge2College program, the project’s content aligns with their curriculum, and they are at a critical age where they can grasp the complexities of climate change and sustainable transportation. Designing the tool for this specific audience ensures that the content, language, and user interface are appropriate and engaging for their age group.

Learning Objectives: The primary learning objectives for the microworld are to enhance students' understanding of the impact of transportation choices on Ireland's carbon emissions, promote sustainable transportation behaviours, and increase their awareness of climate change and sustainability issues. To achieve these objectives, the microworld employs constructivist and constructionist educational approaches, providing students with an interactive, immersive, and hands-on learning experience.

Technological Constraints: The design and development of the microworld tool required the selection and integration of various technologies, such as web-based programming languages, data visualization libraries, and interactive user interface components. These technologies needed to be compatible, user-friendly, and engaging to create a seamless and impactful learning experience.

Evaluation Strategies: The effectiveness of the microworld tool was assessed through a combination of research methods, including surveys, feedback, and interviews. The evaluation process aimed to measure the usability, pedagogical effectiveness, and overall impact of the tool on students' understanding of sustainable transportation and greenhouse gas emissions. This comprehensive evaluation strategy allowed for the identification of the microworld's strengths and areas for improvement, informing future iterations and potential extensions of the project.

By addressing these design project considerations, the microworld tool can successfully achieve its primary goal of educating Transition Year students about the impact of transportation choices on Ireland's carbon emissions and foster a deeper understanding of climate change and sustainable development.

3.2 Project Scope

Objectives

- Develop an engaging and informative microworld website presenting statistics, diagrams, and analyses of various transportation modes and their environmental impact.
- Create an interactive calendar system, enabling users to allocate their carbon emissions for current time and in line with goals for 2030 and 2050.
- Incorporate motivating elements to encourage users to adopt sustainable transportation choices.

- Assess the microworld's effectiveness in improving students' understanding and knowledge of transportation emissions and sustainable alternatives.

Methodology.

- Website development: Create the microworld website, ensuring it is engaging, informative, and user-friendly.

- Content creation: Develop accurate and up-to-date content on transportation emissions and sustainable alternatives, using reliable sources and data visualization techniques to facilitate understanding and engagement.

- Interactive features: Design and implement the calendar system to create an immersive and personalized learning experience.

- Feedback and refinement: Gather user feedback on the website's usability, content, and overall experience, and incorporate improvements based on the feedback.

Deliverables.

- A fully functional, user-friendly, and informative microworld website, including interactive statistics, interactive calendar system, and motivating elements.

- An evaluation report detailing the microworld's effectiveness in improving students' understanding and knowledge of transportation emissions and sustainable alternatives, along with recommendations for further improvements.

- A final project report summarizing the development process, findings, and recommendations.

The development and evaluation of the proposed microworld website aims to create a valuable educational tool that fosters understanding and awareness of transportation emissions and sustainable alternatives. By engaging users and offering personalized learning experiences, this project strives to promote responsible transportation choices and contribute to global climate change mitigation efforts.

3.3 Functional requirements

- The user must be able to investigate up-to-date statistics with a data visualization page
- The website should have two challenges for the user
- The user must be able to navigate to the different components of the website easily switching between challenges
- The user must be able to able to plan their yearly transportation choices by dragging certain transportation mode only specific months of the year
- The user must have a wide range of transportation modes available to select
- The user must be able to configure variables of the transportation mode in real time, which will have a clear visual impact on the outcome of the simulation.
- The user must have clear and concise instructions on how to use the simulation presented to them
- The user must be able to see there CO_2 emissions update in real time as they add to their calendar

- The user must be able to compare their CO_2 emissions with the national average, 2030 goals and 2050 goals.
- Once the user reaches 2030 or 2050 goals the user is blocked from adding more transport choices to the calendar unless another option is removed
- The user must be able to remove transport journeys from the calendar The user should be able to clearly visualise and easily understand the task and information on the screen.

3.4 Non-Functional requirements

Availability and Performance:

- Users can access the microworld from a PC or laptop device
- The microworld must be accessible from the world's main browsers (Chrome, Firefox, Safari, Edge)
- Ensure that the microworld website loads quickly and responds to user interactions with minimal delay.
- Design the website architecture to handle an increasing number of users without compromising performance or reliability.

Usability:

- Create a user-friendly interface that is easy to navigate and understand for users of all levels of technical proficiency.
- The website should be easy to understand by Transition Year students
- The website should be easy to navigate from challenge to challenge.
- The microworld should give feedback on the interaction of the calendar so that users understand the impact of their decisions.

Security:

- Ensure that the website complies with applicable privacy regulations, such as the General Data Protection Regulation (GDPR) and provides users with appropriate privacy controls and disclosures.

Maintainability:

- Design a modular website with components to facilitate easy updates, maintenance, and expansion of features.
- Adhere to best practices for code quality and organization to enable collaboration and maintainability.
- Create a UI skeleton for the microworld that can be easily modified to change the input data to suit any emissions context.

Documentation:

- Offer user documentation, such as an introduction page and an instruction page to explain the website and the microworld's objectives.
- Provide clear and comprehensive technical documentation in the development process to assist in understanding, maintaining, and extending the website.

Aesthetics:

- Ensure that the website's design and visual elements align with the project's messaging, ensuring consistent design

- Design a visually appealing website that effectively communicates the purpose and value of the microworld to the users.
- Responsive design: Implement responsive design techniques to ensure that the website's layout and content adapt to different screen sizes and resolutions.

By addressing these non-functional requirements, the project will deliver a reliable, secure, and user-friendly educational platform that promotes sustainability and climate change awareness related to transportation and greenhouse emissions.

3.5 Initial technology choices

Considering the requirements of the tool, it was decided that developing a web application would be the most beneficial. A web application offers a convenient user experience, allowing users to access the tool from any location with minimal issues. This ease of access is particularly beneficial for Bridge2College students, as it enables them to explore the tool both at home and in the classroom.

To build the microworld, I chose to work with technologies that I was already familiar with. ReactJS was my preferred choice, as I had previously worked with it and found it to be seamless to work with. Additionally, I was well-versed in CSS, HTML, and JavaScript, having completed multiple projects in the past using these technologies.

I had planned to create the interactive calendar using a calendar API; however, I found that it did not meet my specific needs. Consequently, I opted for the React DnD library to develop it instead. After researching various data visualization libraries, I decided on Nivo, which would allow me to effectively display data and statistics on the opening page.

Furthermore, I have had experience working with Material-UI (MUI) and believed that incorporating it into the project would enhance the user-friendliness of the website. By utilizing these technologies and libraries, I aimed to create a comprehensive and engaging web application tailored to the needs of Bridge2College students. Below I will go into more detail on why these technologies suited my needs.

3.5.1 React

React, developed by Facebook, is an open-source JavaScript library for building user interfaces (UIs) and single-page applications (SPAs). React is based on a component-based architecture, which allows developers to create reusable and modular UI components. This modularity promotes better code organization, maintainability, and scalability. React's virtual DOM allows efficient updates and rendering of components, leading to improved performance and responsiveness (React, 2023).

React was chosen for the Microworld website due to its strong community support, extensive documentation, and wide range of available third-party libraries. Furthermore, React's performance will ensure a smooth user experience, while its component-based architecture facilitates simple implementation and maintenance of the website.

3.5.2 CSS, HTML and JavaScript

Cascading Style Sheets (CSS), Hypertext Markup Language (HTML), and JavaScript are technologies for building web applications. HTML provides the structure and content of the website, while CSS is used for styling and layout. JavaScript adds interactivity and active behaviour to the website.

In the microworld, HTML and CSS will be used to create the basic structure and visual design of the website, ensuring cross-platform compatibility and responsive design. JavaScript will be employed to handle user interactions, data fetching, and the logic behind the website's features. These core web technologies are essential for creating an accessible, responsive, and interactive web application.

3.5.3 React-dnd

React-dnd is a high-level drag-and-drop (dnd) library for React applications. It uses the HTML5 drag-and-drop API and provides a high degree of customization to suit different use cases. The library is designed to handle complex dnd scenarios involving drop targets and multiple draggable items (React-dnd, 2023).

In the microworld, react-dnd will be utilized to create interactive elements, such as the calendar challenges for dragging and dropping images of different modes of transportation on specific months. The library will ensure a seamless and engaging user experience while interacting with these elements.

3.5.4 Nivo

Nivo is a collection of data visualization components for React applications. It offers pre-built, customizable components for creating interactive charts and diagrams, such as bar charts, pie charts, and line graphs. Nivo is built on top of D3.js, a data visualization library, and provides additional features, such as animations (Nivo, 2023).

The Microworlds Website will use Nivo to create visually appealing and informative charts and diagrams for presenting transport emission data and other relevant statistics on the introduction page. These data visualizations will help users understand the impact of their transportation choices and the broader context of transportation-related emissions.

3.5.5 MUI (formerly Material-UI)

MUI is a React framework that implements Google's Material Design principles. MUI provides a comprehensive set of customizable components, such as buttons, sidebars, and forms, as well as functions for handling styling and layout. MUI's components are designed with usability and accessibility in mind, ensuring a consistent and intuitive user experience across various devices and platforms (MUI, 2023).

For the microworld website, MUI will be used to create a visually appealing and user-friendly interface.

3.5.6 Development Environment and Tools

In addition to the technologies mentioned, the development environment and other tools play a central role in the project's success. The following tools will be utilized to streamline the development process and ensure high-quality code:

- **Node.js**: A JavaScript runtime built on Chrome's V8 JavaScript engine, Node.js enables the use of JavaScript on the server-side and is essential for installing and managing the project's dependencies.
- **npm**: Package managers for Node.js, npm was used to manage and install the required libraries and dependencies for the project.

- **Create React App:** A command-line tool for setting up a new React project with a pre-configured development environment, Create React App will be employed to jumpstart the project and provide a solid foundation for development.
- **Visual Studio Code:** A popular, lightweight, and powerful source code editor, Visual Studio Code offers built-in support for JavaScript, CSS, and HTML, as well as a vast array of extensions for React development, such as syntax highlighting, autocompletion, and linting.
- **Git and GitHub:** A distributed version control system, Git will be used to manage the project's source code, track changes, and collaborate with other developers. GitHub will serve as the remote repository for the project.

3.5.7 Overview

The development of the website utilized a combination of powerful and versatile technologies to create a user-friendly, interactive, and visually appealing web application tailored to Bridge2College students. React, with its component-based architecture and strong community support, served as the foundation for the website. Web technologies, like CSS, HTML, and JavaScript, were used to ensure cross-platform compatibility and responsive design.

The use of specialized libraries, such as React-dnd for creating interactive calendar elements, Nivo for data visualizations, and MUI for implementing a modern user interface, contributed to an engaging and informative user experience. Integration of these technologies allowed for the creation of a cohesive and robust platform that is easy to maintain and update.

The development environment and tools played an important role in contributing to the development process and ensuring high-quality code. Create React App provided a pre-configured development environment. Visual Studio Code facilitated efficient code editing, and Git and GitHub enabled version control.

Overall, the selection and integration of these technologies and tools led to the successful development of a comprehensive and engaging Microworld website, allowing Bridge2College students to explore and understand the impact of their transportation.

3.6 User Interface Design

Creating a user interface (UI) that appeals to 15-16-year-old students is vital to ensure the success of the Microworld project. This age group has grown up with technology and is accustomed to high-quality, intuitive, and engaging digital experiences. To capture their attention and promote learning, the UI must be designed with a focus on visual appeal, interactivity, and usability.

Design Element	Decision	Rationale
Colour Scheme	Vibrant, youthful, and approachable colours	To create a visually engaging and inviting platform
Typography	Clear, readable, and modern typefaces	To ensure readability and a contemporary look
Imagery	Relevant, high-quality images, and icons	To support content and make the platform visually appealing
Layout	Grid-based, clean, and well-organized	To provide a logical structure and make

Design Element	Decision	Rationale
	layout	content easy to find
Navigation	Clear, intuitive, and consistent navigation	To enable students to easily find their way around the platform
Interactivity	Animations, and interactive elements	To foster deeper engagement and promote learning outcomes
Gamification	Challenges, rewards, and progress indicators	To motivate students to participate and learn more effectively
Data Visualization	Interactive charts, graphs, and infographics	To present complex data in a visually appealing and easy-to-understand format
Responsiveness	Laptop-friendly and adaptable to various screen sizes	To ensure a seamless user experience across devices
Accessibility	Compliance with accessibility guidelines	To create an inclusive environment for all users

Figure 2: Table of UI Design elements

This table outlines the key UI design decisions for the microworld website, which were made to ensure that the platform is visually engaging, user-friendly, and accessible to 15-16-year-old students. By carefully considering and implementing these design choices, the platform will be well-positioned to engage and educate its target audience on the topics of sustainability and climate change.

4 Implementation

This chapter gives an overview of the various complexities involved in implementing the Microworld simulation and its accompanying website, from the design and development of the user interface to the back-end architecture and the website deployment. This chapter will also feature an analysis of the challenges faced during the implementation as well as important omissions. Furthermore, the chapter discusses not only the development of the core functionalities, but also the justification behind decisions made throughout the implementation of the microworld and website.

4.1 System Architecture

The system architecture for this project is designed to support a seamless, engaging, and interactive learning experience for users. The system architecture of the microworld project consists of two primary layers: the front-end, the back end.

<u>Front-end</u>

The front-end layer is responsible for providing an interactive and visually appealing user interface (UI) for students to explore the microworld. The front-end is built using React, a JavaScript library for building user interfaces. React allows for the creation of reusable UI components.

The Material-UI (MUI) library is utilized to ensure a consistent and responsive design across different devices and screen sizes. MUI provides a collection of pre-built UI components offering a modern, and visually appealing design for users.

React-DnD is used to enable drag-and-drop functionality, enhancing the interactivity of the challenges, and facilitating a more engaging experience for users. Nivo, a data visualization library, is employed to create visually appealing charts and graphs, which are essential for presenting complex information in an easy-to-understand format.

<u>Back End</u>

The back-end layer is responsible for processing user input, managing data, and serving dynamic content to the front-end. The back end is built using Node.js, a JavaScript runtime environment that allows for the execution of server-side JavaScript code. This choice of technology ensures consistency between the front-end and back-end development, which simplifies maintenance and reduces the learning curve for developers. The data storage is a crucial aspect of the microworld project, as it requires the storage and retrieval of information related to transportation emissions, sustainable transportation options, and user progress. A local database was maintained in the local storage of the browser to manage data storage efficiently.

4.2 CO_2 emission algorithm

Ensuring the accuracy of the emissions algorithm was crucial for the credibility of the microworld
Ensuring the accuracy of the emissions algorithm was crucial for the credibility of the microworld
simulation. This required thorough research into emissions data for different transport modes. This process involved cross-referencing multiple sources and verifying the correctness of the calculations, ultimately providing users with trustworthy values.

```
const calculateCO2Total = (id, datavaluekm, datavaluefreq) => {
  let CO2total = 0;
  if (id === "Medium Haul Flight") {
    CO2total = datavaluekm * datavaluefreq * 0.255;
  }
  if (id === "Long Haul Flight") {
    CO2total = datavaluekm * datavaluefreq * 0.150;
  }
  if (id === "Electric Car Irish Grid") {
    CO2total = datavaluekm * datavaluefreq * 0.0553;
  }
  if (id === "Electric Car 2030 Grid") {
    CO2total = datavaluekm * datavaluefreq * 0.01;
  }
  if (id === "Large Car") {
    CO2total = datavaluekm * datavaluefreq * 0.280;
  }
  if (id === "Medium Car") {
    CO2total = datavaluekm * datavaluefreq * 0.192;
  }
  if (id === "Small Car") {
    CO2total = datavaluekm * datavaluefreq * 0.154;
  }
  if (id === "Electric Train") {
    CO2total = datavaluekm * datavaluefreq * 0.029;
  }
```

Figure 8: How the emissions algorithm was implemented

The microworld simulation required users to input three data points by right-clicking on the image of the transportation type. These data points included the title of the trip (to keep track of the trip while it was placed on the calendar), the distance of the trip (the user is required to search up the distance online using Google Maps or other ways), and the frequency of the trips per month (for example, if the user was to enter their school trip details, they would have to input that they made that trip and back 20 times a month, which is 40 total trips of that distance). Users would then be able to drop the transportation type onto the specific month.

To calculate the total emissions displayed in the progress bar, the backend algorithm followed this formula: CO2 emissions per km of vehicle/transport type * number of km travelled * frequency. This calculation was then added to the count and displayed in the progress bar.

The implementation of accurate emissions calculations was essential for the overall success and educational value of the Microworld website. A well-tested calculation algorithm was used for microworld simulation and was able to provide users with an accurate representation of their transportation choices' environmental impact. This information allowed users to better understand the consequences of their actions and make more informed decisions regarding their transportation habits, ultimately contributing to the microworld simulation's effectiveness as an educational tool.

4.3 User Interface (UI)

A progressive, three-step user interface enables learners to engage in a structured learning journey where the complexity of the learning gradually increases. By implementing these challenges in the UI, the website will effectively guide students through the learning process, while maintaining their interest. Each challenge builds upon previous concepts, ensuring a complete understanding of transport's impact on emissions.

The UI of the Microworld website was implemented using a combination of React, CSS, HTML, and JavaScript, along with specialized libraries such as React-dnd, Nivo, and MUI. The UI is divided into three main sections: the Statistics Page/Home Page, Challenge 1, and Challenge 2.

4.3.1 Statistics Page/Home Page

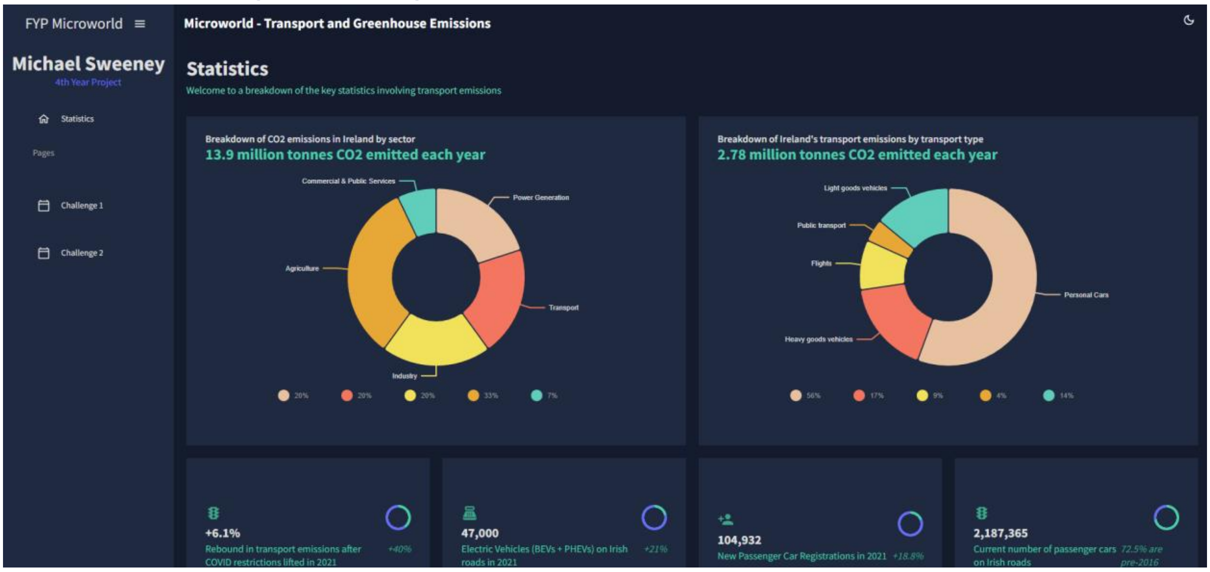

Figure 9: Landing page of the website, interactive statistics and data

The Statistics Page, which also serves as the Home Page, presents users with an overview of transportation-related statistics. Using Nivo, various interactive data visualizations, such as bar charts, pie charts, and line graphs, were created to showcase the emissions of different modes of transportation. These visualizations are designed to engage users and provide valuable insights into the broader context of transportation-related emissions.

The Home Page also features a navigation menu, implemented using MUI, which directs users to the different challenges available on the website. The layout and design of the page ensure a visually appealing and user-friendly experience.

4.3.2 Challenge 1

Challenge 1 is an interactive drag and drop calendar that encourages users to explore the impact of their transportation choices on emissions. Using React-dnd, users can drag and drop various transportation options on to a calendar, simulating their monthly transportation choices over a year. As users drop choices on to the calendar, the CO_2 emission algorithm in the backend calculates the total emissions generated by their chosen transportation methods and compares it to the national average while a progress bar signifies how far they are from reaching those figures.

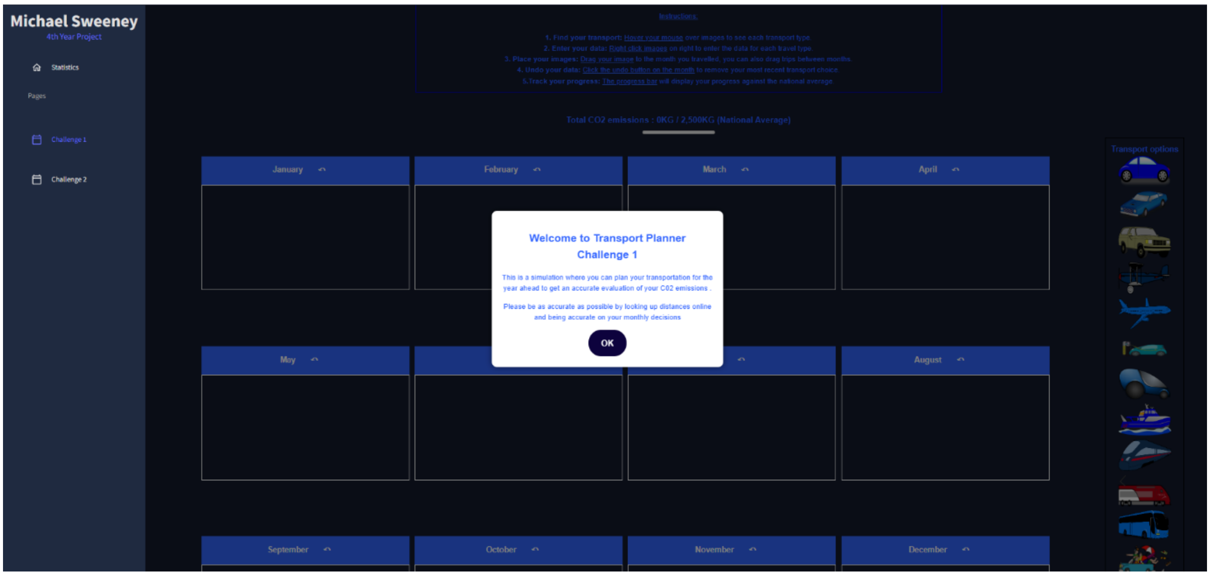

Figure 10: Challenge 1 landing page popup instructions

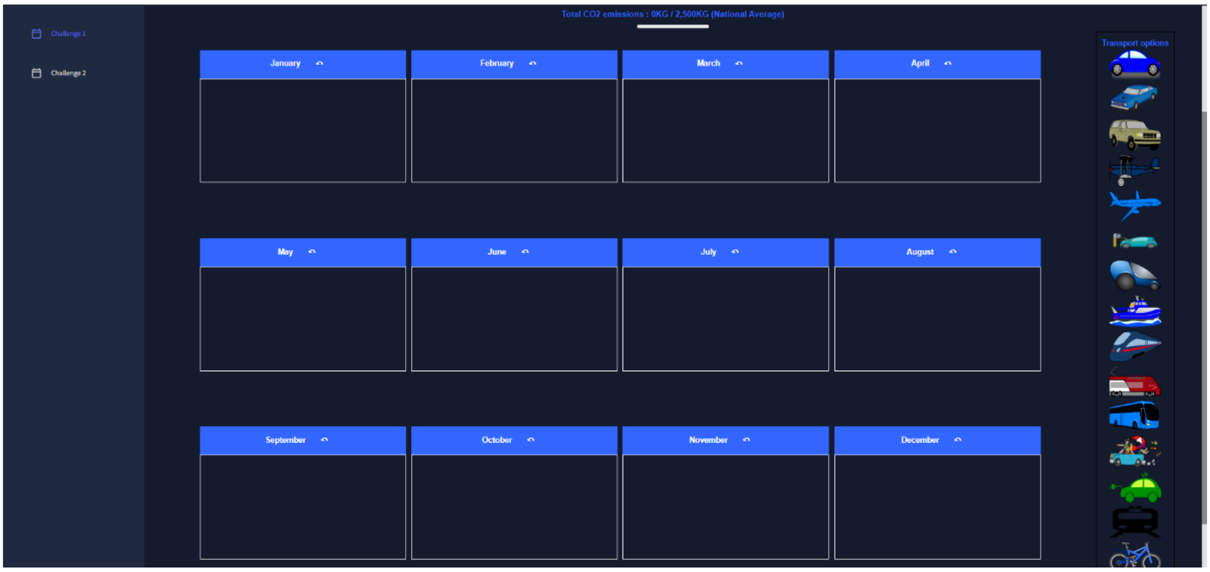

Figure 11: Challenge 1 drag and drop calendar based interactive microworld

4.3.3 Challenge 2

Challenge 2 focuses on educating users about future transportation choices. In this challenge, users are again presented with various transportation options but are tasked with making decisions that can help reduce overall emissions in line with the 2030 and 2050 emission goals. When the user reaches that emissions goal, a popup appears to inform them that the limit had been reached and that they had to remove some of their transportation choices. This activity is designed to encourage future critical thinking and understand the sacrifices needed to reach our 2030 and 2050 transportation goals.

Like Challenge 1, React-dnd was used to create interactive elements, while MUI components were employed to ensure a consistent and intuitive user experience. The visual design and layout of Challenge 2 were implemented using CSS, HTML and JavaScript, maintaining the responsive and visually appealing design found throughout the website.

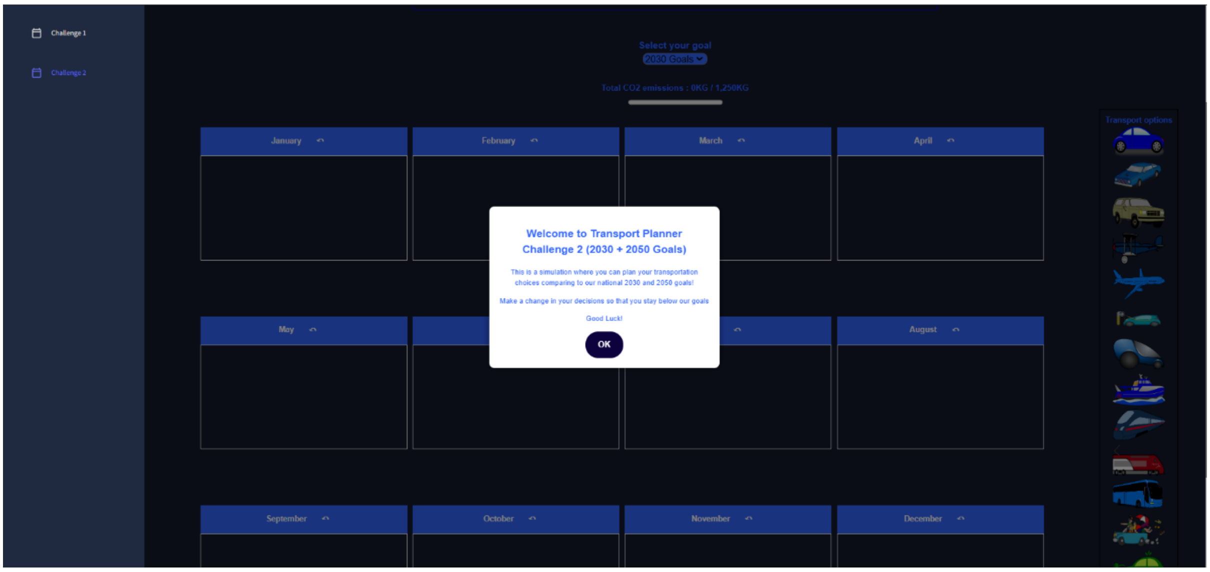

Figure 12: Challenge 2 landing page popup instructions

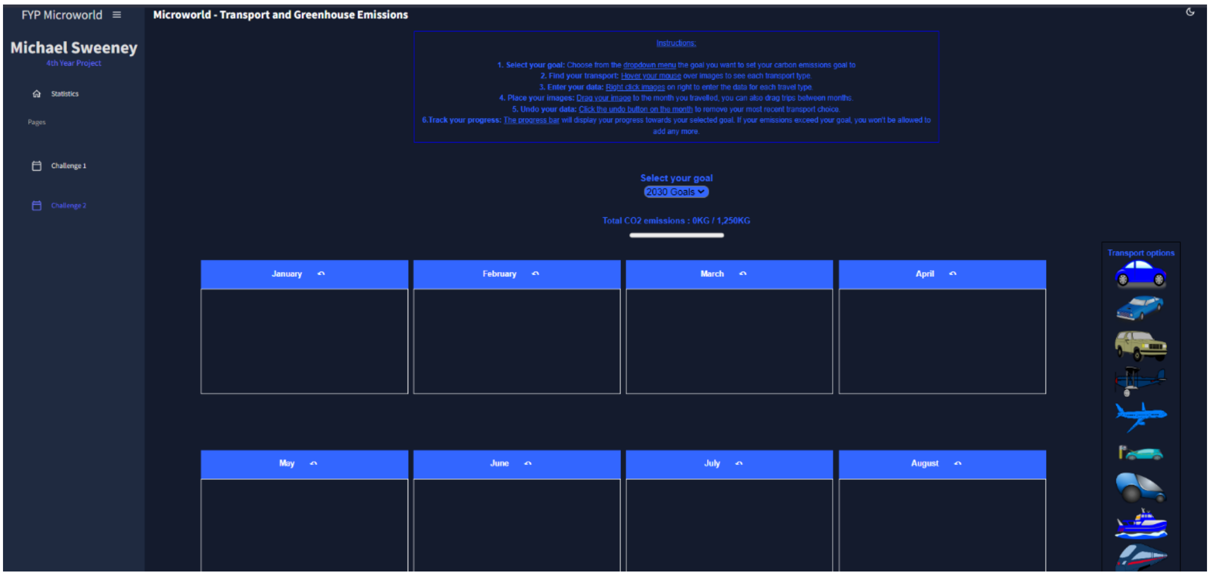

Figure 13: Challenge 2 UI with the option to select a emission goal

By implementing these three main sections of the UI, the Microworld website provides an engaging, informative, and interactive experience for students and other users, allowing them to explore the impact of their transportation choices and better understand the broader context of transportation-related emissions.

4.3.4 UI Skeleton

An important aspect of the website's development was the creation of a flexible UI skeleton. The goal of this development was to provide an adaptable foundation that could be utilized in various situations, not just limited to transportation-related carbon emissions. The code can be easily customized to accommodate different use cases involving carbon emissions or other environmental impact assessments. For example, it could be modified to visualize the carbon emissions of household items over a year, to see how much energy is wasted when a fridge is left on all year or a kettle is turned on twice a day every day for a year. The transport emissions per kilometre data could simply be substituted for the KWH of an appliance.

The implementation of the UI skeleton for the website provides an adaptable template that can be easily customized. By leveraging the strengths of React, MUI, CSS, and HTML, the UI skeleton offers a responsive, visually appealing, and user-friendly interface that can be adapted to suit different use cases. This versatility ensures that the UI skeleton can serve as a valuable tool for educating users and fostering greater awareness and understanding of the environmental consequences of their choices, regardless of the specific context.

4.4 Deployment

The deployment of the website was a crucial step in ensuring the application was accessible to Bridge2College students and other potential users. To ensure a seamless and reliable hosting experience, the website was deployed on a domain purchased from NameHero, a reputable and trusted hosting provider. Before deploying the website, the front-end and back-end code were thoroughly tested and optimized to guarantee optimal user experience. Once the code was ready for deployment, the necessary files were uploaded to the NameHero server.

For the website, The Turbo Cloud plan was selected based on the expected traffic, performance requirements. It was the ideal plan to select since the plan allows hosting an unlimited number of websites under a single account. This flexibility is advantageous for the website, as it enables the addition of more related websites or projects in the future without incurring extra hosting costs. The plan could handle a considerable amount of traffic, ensuring that the website remains accessible and performed well. The plan also includes a free domain, cPanel for easy management, Auto SSL for securing the website, and a comprehensive security suite for protection against potential threats. The plan also offers free website migrations, which is beneficial if the website needs to be moved to another hosting provider.

The deployment of the website on the www.michaelsweeney.work domain, hosted by NameHero, was a crucial step in making the application accessible to Bridge2College students. The deployment of the website allows Bridge2College students and other users to access and explore the application, gaining valuable insights into the impact of their transportation choices on carbon emissions and the environment.

4.5 Technical Challenges and Solutions

Throughout the implementation of the Microworld website, several technical challenges were encountered, necessitating innovative solutions and adjustments to the initial plan. Some of these challenges included switching from a calendar API to react-dnd, obtaining suitable images for transport options, handling image drops and site updates, calculating accurate emissions data, ensuring enough transport options, scaling the website for different screen sizes, and enabling the removal of images from the calendar.

- **Switching from a calendar API to react-dnd:** Initially, the plan was to use a calendar API (react-calendar) for the interactive calendar. However, after attempting to implement the custom functionality for the interactive simulation, it became clear that the API was not suitable for the project. Consequently, the decision was made to switch to react-dnd, a more flexible and customizable drag-and-drop library. With this the calendar could be built from scratch and create a more customizable experience. This change required additional time but ultimately resulted in a more engaging and interactive user experience.

- **Handling transportation image drops and site updates:** Another challenge faced during the development process, involved managing the behaviour of dropped images on the calendar. Initially, when an image was dropped on a month on the calendar and the site needed to be updated, the useEffect hook would refresh the site, causing the image to disappear from the calendar. This issue was resolved by refining the logic within the useEffect hook and implementing a more efficient state management system to prevent unnecessary refreshes.
- **Ensuring enough transport options:** To make the microworld a useful and engaging tool, it was essential to provide users with a wide variety of transport options to choose from. This challenge involved researching and selecting appropriate transport modes that were both relevant to the target audience and diverse enough. The final list of transport options was carefully selected to balance realism, variety, and educational value.
- **Scaling the website for different screen sizes:** Creating a responsive design that adapts seamlessly to various screen sizes and devices was another technical challenge faced during the implementation process. This challenge required testing across multiple screen sizes, operating systems, and browsers, ensuring a consistent and enjoyable user experience for all visitors.
- **Enabling the removal of transport images from the calendar:** Users needed the ability to remove images from the calendar in case of mistakes or changes in their plans. Implementing this functionality proved challenging, as it required the development of an efficient method for users to interact with the calendar and remove images without causing disruptions to other elements on the page. This challenge was overcome by adding an undo button on each month that took the image off the image stack.

The implementation of the website presented several technical challenges discuss **such as the ones listed above**, which were ultimately addressed through debugging, research, and perseverance. Overcoming these challenges resulted in a more robust, engaging, and user-friendly application that effectively communicates the impact of transportation choices on carbon emissions and the environment, and I overall become a better developer because of this.

4.6 Omissions

During the development of the microworld, certain features and aspects were omitted from the initial plan for various reasons, including redundancy or a shift in focus. These omissions include the quiz/questionnaire, the translation from CO2 emissions to carbon tokens, the introduction of fun tokens, and the dedicated introduction page.

- **Introduction page:** An introduction page was initially planned to provide users with a comprehensive overview on using the microworld. However, it was determined that a PowerPoint presentation would be sufficient for introducing students to the tool in the context of Bridge2College. The introduction page was therefore omitted from the current implementation. It is worth saying though that if the Microworld website were to be used in other schools, an introduction page will be necessary to ensure that users fully understand the purpose and functionality of the tool.
- **Quiz/Questionnaire:** In the original concept, a quiz or questionnaire was intended to provide students with an estimated idea of their emissions by answering a series of questions. However, this feature was ultimately removed as it was deemed unnecessary. With Challenge One, students were already able to gain an accurate understanding of their emissions more accurately. Removing the quiz/questionnaire helped streamline the user

experience and allowed students to focus on the core challenges and lessons provided by the microworld.

- **Translation from CO_2 emissions to carbon tokens:** This idea involved translating CO2 emissions into carbon tokens as a way of gamifying the experience and making the information more understandable to students. However, it was decided that converting emissions data into a token system would not provide tangible, real-world value. Presenting CO2 emissions directly in the progress bar proved to be more useful, as it allowed students to develop a clearer understanding of the actual impact of their transportation choices on the environment.
- **Fun tokens:** Fun tokens were initially proposed as a means of motivating students to explore a variety of transportation options and make their choices more realistic. However, during the development process, it became evident that students would be intrinsically motivated to make accurate choices and fully engage with the Microworld's challenges without dun tokens. In the end, the fun token system was deemed unnecessary and removed from the final implementation.

The process of refining the microworld involved several omissions from the initial idea. These changes were made to focus on the core educational goals of the project and avoid unnecessary features. By removing extraneous features, such as the quiz/questionnaire, carbon tokens, and fun tokens, the Microworld website became a more focused and effective educational tool. These omissions ultimately contributed to the creation of a more engaging and user-friendly tool that effectively communicates the impact of transportation choices on carbon emissions and the environment.

4.7 Summary

In conclusion, the implementation of the Microworld simulation and its accompanying website presented numerous challenges and complexities, ultimately resulting in a comprehensive educational tool for Bridge2College students and other users. Through the use of a CO2 emission algorithm, an engaging user interface, and carefully considered deployment strategy, the microworld offers a valuable resource for students and educators.

The implementation process involved addressing various technical challenges, such as the choice of suitable calendar implementation, handling of transportation image drag and dropping, ensuring a variety of transport options, and creating a responsive design for different screen sizes. Additionally, certain features were omitted from the initial plan to streamline the user experience and focus on the core educational goals of the project.

Moreover, the development of a flexible UI skeleton allows for the customization and adaptation of the website to suit different use cases, further enhanced it as an educational resource. With the successful implementation of the simulation and website, students now have access to a customizable interactive tool that encourages critical thinking, environmental awareness, and informed decision-making regarding environmental choices.

By engaging users in interactive challenges and providing accurate, research-backed data on CO2 emissions, the Microworld website serves as an effective tool for inspiring positive change and promoting sustainable transportation habits for a better future.

5 Testing and Evaluation

This chapter explores the various testing and evaluation methodologies, delving into the importance of data analysis and interpretation to extract valuable insights and make informed decisions on whether the project was successful in its goal to successfully teach the impact of transport on Ireland's carbon emissions.

5.1 Bridge2College Workshop

The Bridge2College program, administered by Trinity College Dublin, is an extracurricular educational program designed for students during their Transition Year. A two-day session focusing on Environmental Science and Sustainability, in partnership with Bridge2College was created. The author, along with three other microworld project Computer Science students, tested the microworld tool developed in this report to educate the Bridge2College students about transportation's impact on climate change.

5.1.1 Workshop Structure

For the project, an initial presentation focusing on transport emissions was delivered, followed by some verbal questions with the students to evaluate their existing knowledge. Subsequently, students were then given a demo on the microworld and later spilt into groups and went into the computer lab to collaborate on the microworld challenges.

Challenge 1:

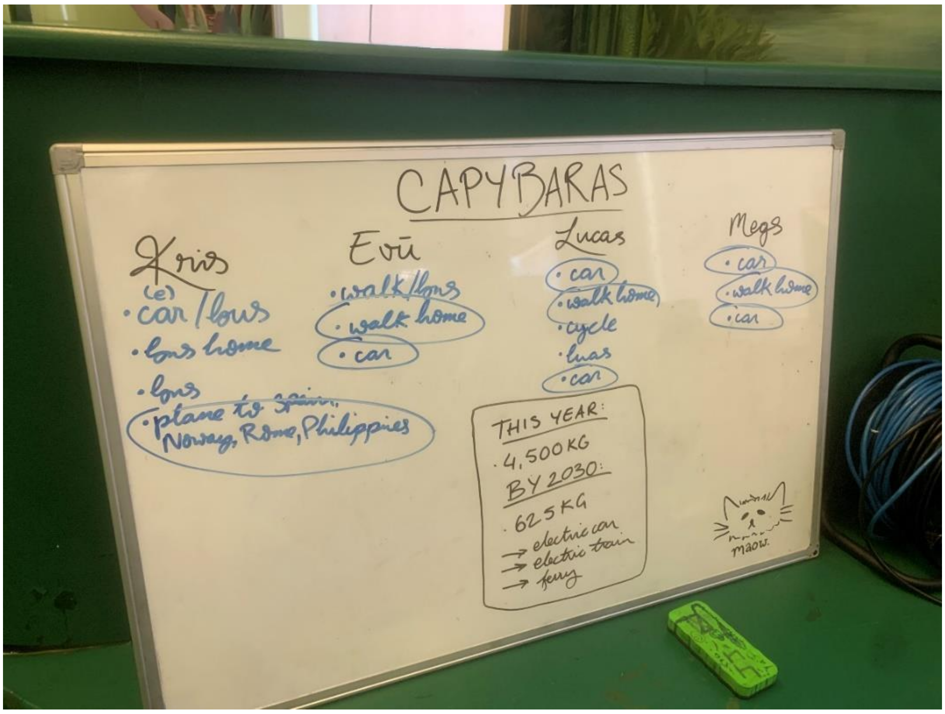

Figure 14: Students split into groups to work out the average of their transport emissions for the year

In a collaborative effort, students gathered in groups and engaged in discussions about their annual transportation habits. Through this process, they were encouraged to work together and take an average of their group's habits to use as a reference point for Challenge 1. This allowed them to gain a better understanding of where their individual transportation emissions stood in comparison to the national average, emphasizing the importance of collective action towards a more sustainable future.

Figure 15: Students broke into groups to break down their yearly transport habits

Challenge 2:

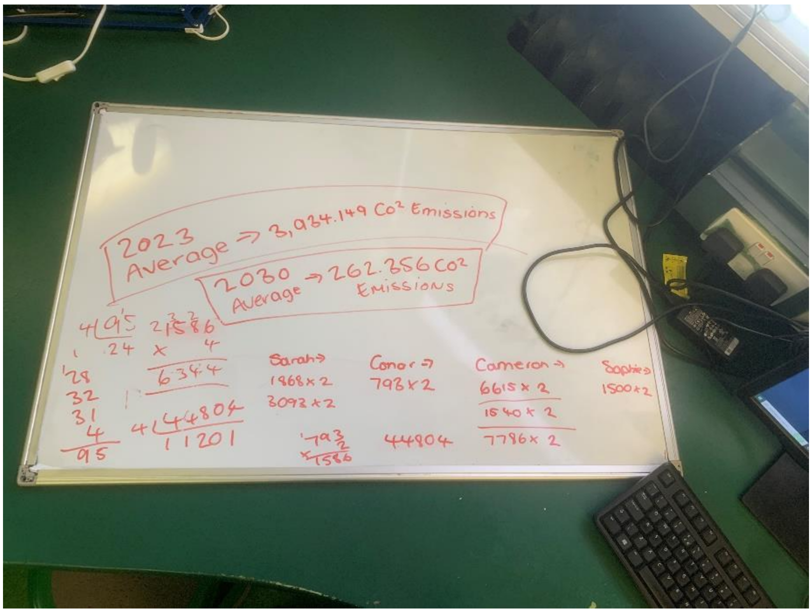

Figure 3: Adjustments made to their group average to reach 2030 goals

In the second challenge, students were tasked with adjusting their transport habits from the year 2023 and choosing more environmentally friendly options to reach 2030 goals. It was encouraging to see that many students opted for closer holiday destinations and the purchase of electric vehicles. Notably, a particularly interesting takeaway was that most students indicated a willingness to choose journeys that involved ferries and public transport instead of flights to nearby countries. This highlights a growing awareness of sustainable transportation options and a willingness to make changes that benefit the environment.

Figure 17: Students researching distances travelled for different modes of transportation

5.1.2 Student Discussion

Upon completing both challenges within their groups, students reconvened in the main room for a discussion with the educators. The conversation was lively, with students demonstrating high levels of engagement and asking numerous questions. Overall, they expressed satisfaction with the simulation and agreed that it made them contemplate their future choices.

A recurring theme during the discussion was the students' realization of the significant environmental impact of travel. Many admitted they had not previously understood the extent of this issue. Additionally, the conversation touched on the limited options available to those on tight budgets, highlighting the socioeconomic factors influencing sustainable choices.

Several students mentioned their intention to show the microworld to their teachers upon returning to school, advocating for a class discussion on the topic. One student emphasized the need for more education about carbon emissions, expressing that their age group often feels powerless when it comes to taking action or influencing climate policies.

When exploring ways to modify their emissions to achieve the 2030 reduction goals, the students proposed numerous strategies. A majority of the groups chose to replace their diesel or petrol cars with electric vehicles (EVs). All groups opted for shorter vacations involving air travel or decided to take ferries to mainland Europe instead. They also committed to using public transportation in the future to further reduce their overall emissions.

Figure 48: A word visualisation of the students' feedback

Some notable quotes from the students include:

- *"Being sustainable and eco-friendly is not as difficult and impossible as everyone makes it out to be. Take it one step at a time, and you will make a difference."*
- *"I learned about how my decisions impacted the world, the different amounts of carbon emissions people produce, and how I can reduce them."*

This interactive discussion allowed students to reflect on their experiences with the transport microworld and stimulated critical thinking about the environmental consequences of their choices. The students' enthusiasm for sharing the microworld with their teachers and classmates highlights the potential for such educational tools to reach a wider audience and foster meaningful conversations on sustainability.

Furthermore, the various strategies proposed by the students to reduce emissions demonstrate their capacity for creative problem-solving and their willingness to make positive changes in their lives. By encouraging young people to think critically about their actions, the transport microworld has not only enhanced their understanding of the environmental impacts of transportation choices but also inspired them to adopt more sustainable habits.

The discussion of the transport microworld with a group of students provided valuable insights into its usability and effectiveness as an educational tool. The engaging discussions and positive feedback from the participants indicate the potential for this microworld to foster a deeper understanding of sustainability and to motivate individuals to make more environmentally conscious decisions.

5.1.3 Student Feedback

After the students' workshop we gathered feedback from the students with a survey. A total of 24 students provided feedback, with ages ranging from 15 to 16 years old, from various schools. A majority of the participants agreed or strongly agreed that the simulation was easy to use and informative. They also indicated that they learned more using the simulation compared to reading statistics in the presentation and the home page. Most students agreed that the simulation provided sufficient feedback on the environmental impact of each transport choice and had a satisfactory variety of transport options. The students generally appreciated the interface and found the tool to be engaging.

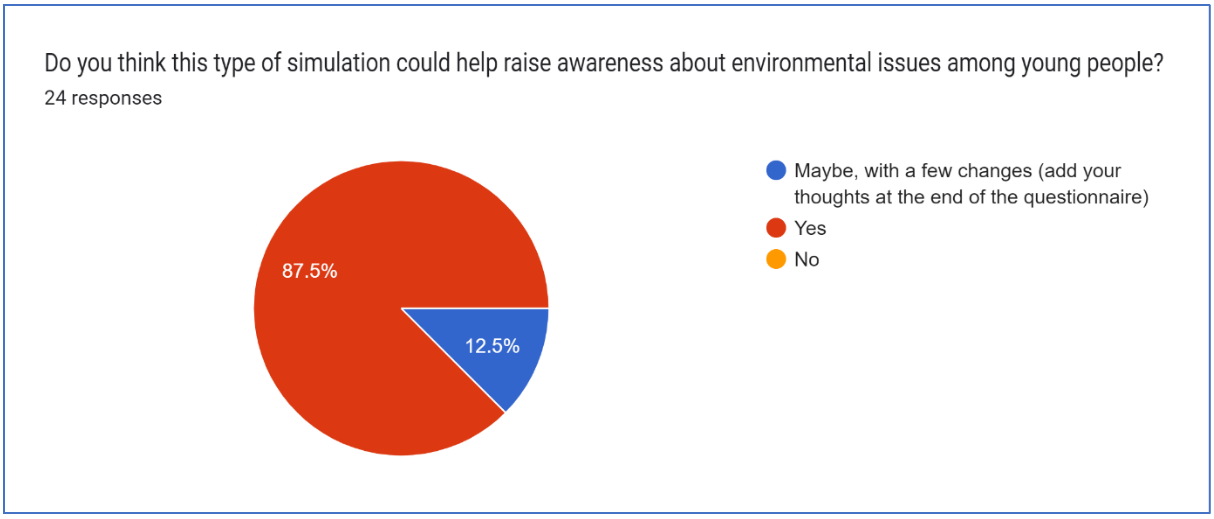

Figure 20: Students' feedback on if the microworld has potential to raise awareness

The students highlighted numerous key takeaways from the session. They learned about the impact of transportation on carbon emissions, the significant role of planes in emitting CO2, the benefits of electric vehicles, and the need for more sustainable transport options in Ireland. Students also gained insight into their own carbon emissions and potential ways to reduce them.

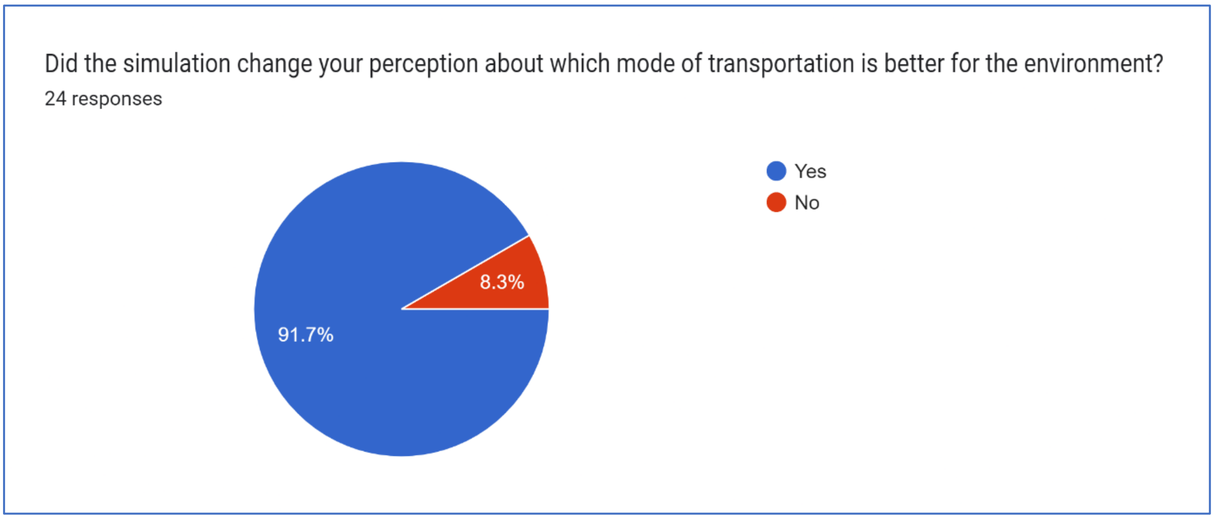

Figure 21 Students' feedback on their opinions on which mode of transportation is most sustainable

Most of the participants found the information presented in the simulation easy to understand and believed that the simulation could help raise awareness about environmental issues among young people. As a result of the session, many students reported increased interest and knowledge about climate change. Furthermore, several participants stated their intention to change their behaviour to reduce their carbon emissions.

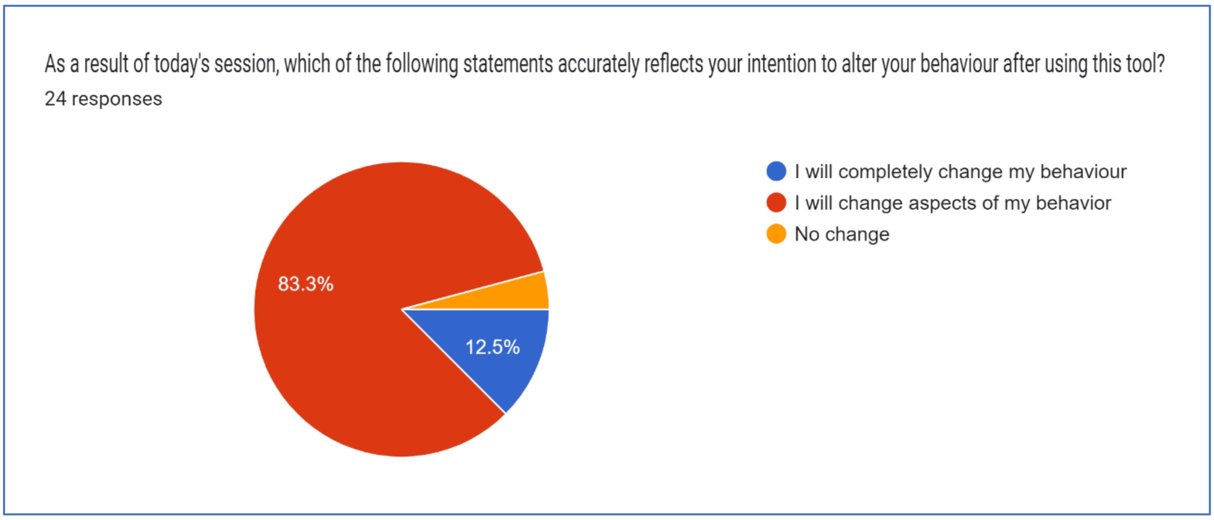

Figure 5: Students' feedback on behavioural change after simulation

The feedback on the usability of the microworld was positive, hhowever, students suggested improvements to the simulation. One participant recommended making the interface more user-friendly and visually appealing, while another suggested including a pop-up displaying the increase in emissions after each input. A few students believed that the simulation could be more engaging and interesting for young people with a few changes. Students considered the tool to be unique and beneficial, especially for classrooms; but said it might need some adjustments to engage more young people and raise awareness effectively.

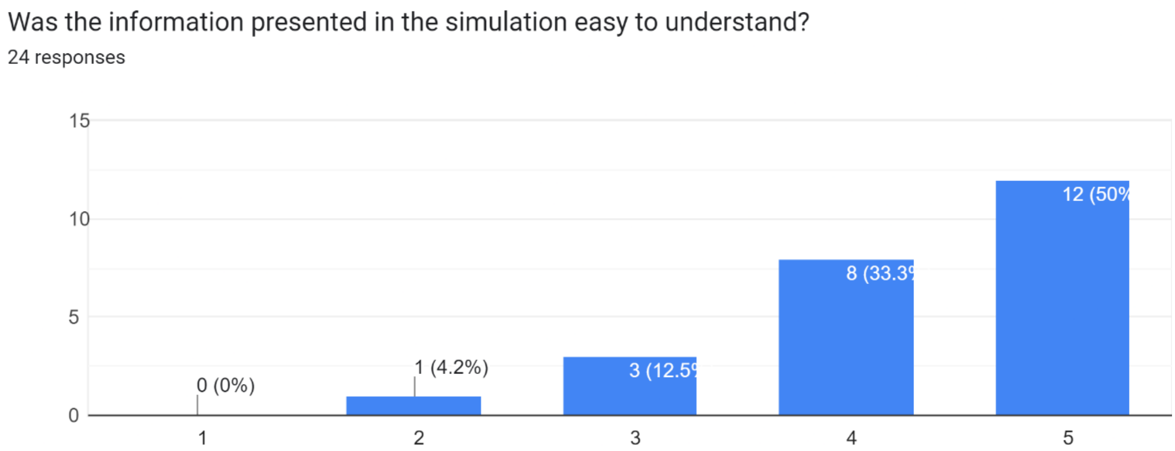

Figure 6: Survey results on if the information was easy to understand (1 being poor and 5 being very good)

Overall, the feedback received from the students was positive, with the majority finding the simulation engaging, informative, and effective in raising environmental awareness. The suggestions for improvement could be considered for future iterations of the simulation to enhance its impact on young people's understanding of and engagement with climate change issues.

6 Conclusions

The successful development and implementation of the microworld simulation and website presented in this paper, provided students with an engaging and interactive educational experience that addresses the pressing global issues of transport’s impact on climate change. The overwhelmingly positive feedback from students attests to the effectiveness of the microworld in raising awareness and deepening their understanding of the impact of transportation choices on the environment.

The combination of interactive data visualization, personalized carbon emission calculations, and calendar-based planning allowed students to explore, experiment, and discover the consequences of their transportation choices. This immersive learning experience not only captured their attention but also encouraged a sense of ownership in making more sustainable transportation decisions. By bridging the knowledge gap, the microworld empowered students to act and contribute to the global effort to reduce greenhouse gas emissions and mitigate the effects of climate change.

The study highlights the importance of incorporating effective human-computer interaction and user interface design principles in the development of educational microworlds for the target audience. By prioritizing age-appropriateness, visual appeal, and simplicity the microworld created an accessible and engaging platform that facilitated learning and promoted behavioural change.

This study demonstrates the potential of educational microworlds as powerful tools in addressing climate change and sustainability challenges. The positive outcomes suggest that similar microworlds could be developed to tackle other complex issues, further expanding the scope of experiential learning and inspiring future generations to take meaningful action towards a more sustainable world.

6.1 Future Work

While the present study demonstrates the potential of educational microworlds in addressing pressing global issues like climate change and sustainability, there remains a wealth of opportunities for future research and development in this area. By building upon the success of the current microworld, we can continue to engage students and inspire them to take action in addressing environmental and social challenges.

One avenue for future work could involve the expansion of the microworld with the skeleton UI to encompass additional dimensions of sustainability beyond transportation. By incorporating topics such as energy consumption, waste management, and food production, the microworld could provide students with a more comprehensive understanding of their environmental footprint and the potential consequences of their everyday choices. This holistic approach could help to foster a greater sense of personal responsibility and empower students to make more informed decisions across different aspects of their lives.

Another potential direction for future research is the investigation of the long-term effects of the microworld on students' attitudes and behaviours. While the current study focused on immediate feedback and learning outcomes, it would be valuable to examine whether the microworld has a lasting impact on students' transportation choices and overall commitment to sustainability. Longitudinal studies could be conducted to track changes in students' habits and attitudes over time, providing insight into the sustained effectiveness of educational microworlds in promoting behaviour change.

In addition to these research directions, future work could also involve the development of additional resources and tools to support educators in implementing the microworld in their classrooms. This could include the creation of lesson plans, assessment materials, and teacher training programs to facilitate the effective integration of the microworld into existing curricula. By providing educators with comprehensive support, the microworld could be more readily adopted in schools and have a broader impact on students' learning and attitudes towards sustainability.

The success of this microworld in raising awareness and promoting sustainable transportation habits among students highlights the potential of educational microworlds as powerful tools in addressing complex global issues. By pursuing the various research directions outlined above, future work can continue to build upon this success and explore new ways to engage learners, inspire action, and contribute to a more sustainable and resilient world.

6.2 Author’s Reflection

As the author of this report, I am pleased with the results and the positive feedback from the students who participated in the study. The project's success demonstrates the potential of educational microworlds in encouraging understanding and inspiring action in addressing pressing global challenges such as climate change and sustainability.

Throughout the development process, I encountered several technical challenges, which led to valuable learning experiences that ultimately shaped the final design of the microworld. Overcoming these obstacles, I successfully developed an engaging and user-friendly tool that effectively communicated the relationship between transportation choices and greenhouse gas emissions to Transition Year students.

The feedback gathered from the cohort of 26 students participating in the Bridge2College program revealed an overwhelmingly positive response, attesting to the microworld's success in achieving its primary aim. Additionally, the study highlighted the importance of incorporating effective human-computer interaction and user interface design principles in the development of educational microworlds for the target audience.

The success of this microworld in raising awareness and promoting sustainable transportation habits among students underlines the potential of educational microworlds as powerful tools in addressing complex global issues. The insights gained from this project encourage the exploration of new ways to engage learners, inspire action, and contribute to a more sustainable and resilient world.

7 Appendix

A working version of the microworld can be found at the following links:
https://www.michaelsweeney.work

The source code for this project and active deployment can be found on GitHub:
https://github.com/mikeysweeney/fyp

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

https://forms.gle/MkTcsDdDLhZ99PXc9

8 Bibliography

Gomes, J. C., Figueiredo, M., & Amorim, M. (2018). Educational microworlds: A qualitive and quantitative study on attitudes and learning impact. International Journal of Emerging Technologies in Learning (iJET), 13(1), 4-20.

Kevin Sullivan, Aibhín Bray & Brendan Tangney (2021) *Developing twenty-first-century skills in out-of-school education: the Bridge21 Transition Year programme*, Technology, Pedagogy and Education, 30:4, 525-541, DOI: 10.1080/1475939X.2020.1835709

Intergovernmental Panel on Climate Change (IPCC). (2021). Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

International Energy Agency (IEA). (2019). CO2 Emissions from Fuel Combustion 2019. OECD Publishing.

UN Environment Programme. (2023). Transport. Retrieved from https://www.unep.org/explore-topics/energy/

Beijing Normal University. (2021). Climate change threatens rail infrastructure, study finds. Retrieved from https://eandt.theiet.org/content/articles/2021/05/climate-change-threatens-rail-infrastructure-study-finds/

United Nations Framework Convention on Climate Change. (2015). Paris Agreement. UNFCCC.

Ritchie, H. (2020, October 6). Cars, planes, trains: where do CO2 emissions from transport come from? Our World in Data. Retrieved from https://ourworldindata.org/co2-emissions-from-transport

DfT (2021). Environmental sustainability on the railway: stating our priorities. Retrieved from

Lee, D. S., Fahey, D. W., Skowron, A., Allen, M. R., Burkhardt, U., Chen, Q., ... & Gettelman, A. (2021). The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018. Atmospheric Environment

Warren, K. J., Winiwarter, V., & Cao, G. Y. (2014). Teaching sustainable development in higher education: Building a multi-disciplinary pedagogy. Journal of Environmental Studies and Sciences, 4(3), 244-253.

Gomes, J. C., Bogner, F. X., & Costa, J. M. (2018). Investigating climate change mitigation and adaptation: The role of renewable energy on environmental consciousness of adolescents. Environmental Education Research, 24(9), 1377-1396.

Dede, C. (2017). EcoXPT: Designing and validating an immersive, inquiry-based digital environment to foster ecosystems learning. Journal of Science Education and Technology, 26(4), 379-394.

Banister, D. (2008). The sustainable mobility paradigm. Transport Policy, 15(2), 73-80.

Department of Communications, Climate Action & Environment. (2019). Climate Action Plan 2019: To Tackle Climate Breakdown. Retrieved from https://www.gov.ie/en/publication/ccb2e0-the-climate-action-plan-2019/

Department of Transport, Tourism and Sport. (2019). Sustainable Mobility Policy – Public Consultation. Retrieved from https://www.gov.ie/en/consultation/f5b503-public-consultation-on-sustainable-mobility-policy/

Fulton, L., & Eads, G. (2014). IEA Mobility Model (MoMo) and its use in the ETP 2014. International Energy Agency.

Gössling, S., Cohen, S., & Higham, J. (2016). Climate change and transport: an introduction. Journal of Transport Geography, 52, 1-3.

International Energy Agency (IEA). (2019). Global energy & CO2 status report 2019. Retrieved from https://www.iea.org/reports/global-energy-co2-status-report-2019/emissions

International Transport Forum (ITF). (2017). ITF Transport Outlook 2017. OECD Publishing.

Rogelj, J., Shindell, D., Jiang, K., Fifita, S., Forster, P., Ginzburg, V., Handa, C., Kheshgi, H., Kobayashi, S., Kriegler, E., Mundaca, L., Séférian, R., & Vilariño, M. V. (2018). Mitigation pathways compatible with 1.5°C in the context of sustainable development. In Global Warming of 1.5°C. An IPCC Special Report.

Sims, R., Schaeffer, R., Creutzig, F., Cruz-Núñez, X., D'Agosto, M., Dimitriu, D., Figueroa Meza, M. J., Fulton, L., Kobayashi, S., Lah, O., McKinnon, A., Newman, P., Ouyang, M., Schauer, J. J., Sperling, D., & Tiwari, G. (2014). Transport. In Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

United Nations Framework Convention on Climate Change. (2015). Paris Agreement. Retrieved from https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

Andersen, O., Gössling, S., & Cohen, S. A. (2018). Climate change and the mobilities turn: Implications for transport and the environment. Journal of Transport Geography, 71, 184-196.

Banister, D. (2005). Unsustainable transport: City transport in the new century. Routledge.

Banister, D. (2008). The sustainable mobility paradigm. Transport Policy, 15(2), 73-80.

Batty, M., Axhausen, K. W., Giannotti, F., Pozdnoukhov, A., Bazzani, A., Wachowicz, M., ... & Portugali, Y. (2010). Smart cities of the future. The European Physical Journal Special Topics, 214(1), 481-518.

Bulkeley, H., & Betsill, M. M. (2005). Rethinking sustainable cities: multilevel governance and the "urban" politics of climate change. Environmental Politics, 14(1), 42-63.

Cervero, R., & Kockelman, K. (1997). Travel demand and the 3Ds: Density, diversity, and design. Transportation Research Part D: Transport and Environment, 2(3), 199-219.

Creutzig, F., Lohrey, S., Bai, X., Baklanov, A., Dawson, R., Dhakal, S., ... & Pichler, P. P. (2019). Upscaling urban data science for global climate solutions. Global Sustainability, 2.

Geels, F. W., Sovacool, B. K., Schwanen, T., & Sorrell, S. (2017). Sociotechnical transitions for deep decarbonization. Science, 357(6357), 1242-1244.

Hardman, S., Jenn, A., Tal, G., Axsen, J., Beard, G., Daina, N., ... & Sovacool, B. K. (2019). A review of consumer preferences of and interactions with electric vehicle charging infrastructure. Transportation Research Part D: Transport and Environment, 62, 508-523.

Hawkins, T. R., Singh, B., Majeau-Bettez, G., & Strømman, A. H. (2013). Comparative environmental life cycle assessment of conventional and electric vehicles. Journal of Industrial Ecology, 17(1), 53-64.

IEA. (2020). Global EV Outlook 2020: Entering the decade of electric drive? International Energy Agency.

Lucas, K., Mattioli, G., Verlinghieri, E., & Guzman, A. (2016). Transport poverty and its adverse social consequences. Proceedings of the Institution of Civil Engineers-Transport, 169(6), 353-365.

Newman, P., & Kenworthy, J. (1999). Sustainability and cities: Overcoming automobile dependence. Island Press.

Nykvist, B., & Nilsson, M. (2015). Rapidly falling costs of battery packs for electric vehicles. Nature Climate Change, 5(4), 329-332.

Pucher, J., & Buehler, R. (2017). Cycling towards a more sustainable transport future. Transport Reviews, 37(6), 689-694.

Rogelj, J., Shindell, D., Jiang, K., Fifita, S., Forster, P., Ginzburg, V., ... & Vilariño, M. V. (2018). Mitigation pathways compatible

Barrett, S. (2013). Climate treaties and approaching catastrophes. Journal of Environmental Economics and Management, 66(2), 235-250.

Buehler, R., Pucher, J., & Dill, J. (2017). Walking, cycling, and public transportation use among adults: a cross-sectional study from the United States, Canada, and Germany. Journal of Transport & Health, 5, 1-11.

OECD. (2020). COVID-19 and the low-carbon transition: Impacts and possible policy responses. Retrieved from https://oecd.org/coronavirus/policy-responses/covid-19-and-the-low-carbon-transition-impacts-and-possible-policy-responses-749738fc/

Creutzig, F., Baiocchi, G., Bierkandt, R., Pichler, P. P., & Seto, K. C. (2015). Global typology of urban energy use and potentials for an urbanization mitigation wedge. Proceedings of the National Academy of Sciences, 112(20), 6283-6288.

Doll, C., Trinks, C., Sedlacek, N., Pelikan, V., Comes, T., & Schultmann, F. (2014). Adapting rail and road networks to weather extremes: case studies for southern Germany and Austria. Natural Hazards, 72(1), 63-85.

Faria, R., Marques, P., & Moura, P. (2013). A sustainability framework for the European electric vehicle system. Energy Policy, 61, 1021-1032.

Fischer, G., Winiwarter, W., Ermolieva, T., Cao, G. Y., Qui, H., Klimont, Z., ... & Schöpp, W. (2015). Implications of population growth and urbanization on agricultural risks in China. Population and Environment, 36(3), 243-261.

React. (n.d.). Retrieved [February 2023], from https://reactjs.org/

React-dnd. (n.d.). Retrieved [February 2023], from https://react-dnd.github.io/react-dnd/about

Nivo. (n.d.). Retrieved [insert date of retrieval], from https://nivo.rocks/

MUI. (n.d.). Retrieved [insert date of retrieval], from https://mui.com/

Fuglestvedt, J., Berntsen, T., Myhre, G., Rypdal, K., & Skeie, R. B. (2008). Climate forcing from the transport sectors. Proceedings of the National Academy of Sciences, 105(2), 454-458.

Fulton, L., & Eads, G. (2014). IEA Mobility Model (MoMo) and its use in the ETP 2014. Energy Policy, 73, 322-332.

Gakis, K., Pafi, K., Siskos, E., & Botzoris, G. (2018). An analysis of the potential of intelligent transport systems to reduce CO2 emissions: The case of Thessaloniki, Greece. Transportation Research Part D: Transport and Environment, 63, 569-583.

Litman, T. (2014). Evaluating public transit benefits and costs: Best practices guidebook. Victoria Transport Policy Institute.

National Research Council (NRC). (2008). Potential impacts of climate change on US transportation. Transportation Research Board Special Report 290. Washington, DC: National Academies Press.

Nykvist, B., & Nilsson, M. (2015). Rapidly falling costs of battery packs for electric vehicles.

References

Cambridge Systematics. (2007). National Rail Freight Infrastructure Capacity and Investment Study. Association of American Railroads.

Chester, M., & Horvath, A. (2010). Life-cycle assessment of high-speed rail: the case of California. Environmental Research Letters, 5(1), 014003.

Chester, M., Horvath, A., & Madanat, S. (2013). Parking infrastructure: energy, emissions, and automobile life-cycle environmental accounting. Environmental Research Letters, 7(3), 034001.

Eyring, V., Isaksen, I. S. A., Berntsen, T., Collins, W. J., Corbett, J. J., Endresen, O., ... & Stevenson, D. S. (2010). Transport impacts on atmosphere and climate: Shipping. Atmospheric Environment, 44(37), 4735-4771.

Lee, D. S., Fahey, D. W., Forster, P. M., Newton, P. J., Wit, R. C. N., Lim, L. L., ... & Sausen, R. (2009). Aviation and global climate change in the 21st century. Atmospheric Environment, 43(22-23), 3520-3537.

Lopez, I., Hendrickson, C., & Matthews, H. S. (2016). Assessing energy and environmental impacts of the US rail system. In 2016 TRB Annual Meeting.

Owen, B., Lee, D. S., & Lim, L. (2010). Flying into the future: aviation emissions scenarios to 2050. Environmental Science & Technology, 44(7), 2255-2260.

Psaraftis, H. N., & Kontovas, C. A. (2016). Ship speed optimization: concepts, models and combined speed-routing scenarios. Transportation Research Part C: Emerging Technologies, 68, 181-198.

Schäfer, A. W., Barrett, S. R., Doyme, K., Dray, L. M., Gnadt, A. R., Self, R., ... & Wilkerson, J. T. (2016). Cost and environmental assessment of technologies to address aviation emissions. Environmental Science & Technology, 50(1), 70-85.

Sims, R., Schaeffer, R., Creutzig, F., Cruz-Núñez, X., D'Agosto, M., Dimitriu, D., ... & Fulton, L. (2014). Transport. In Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

Smith, T. W., Jalkanen, J. P., Anderson, B. A., Corbett, J. J., Faber, J., Hanayama, S., ... & Pandey, A. (2014). Third IMO GHG Study 2014. International Maritime Organization (IMO), London, UK.

Williams, V., Noland, R. B., & Toumi, R. (2013). Reducing the climate change impact of aviation by restricting cruise altitudes. Transportation Research Part D: Transport and Environment, 25, 62

Bandivadekar, A., Bodek, K., Cheah, L., Evans, C., Groode, T., Heywood, J., ... & Weiss, M. (2008). On the road in 2035: Reducing transportation's petroleum consumption and GHG emissions. Laboratory for Energy and the Environment Report No. LFEE 2008-05 RP.

Cervero, R., & Guerra, E. (2011). Urban density and transit-oriented development. In Parking: issues and policies (pp. 121-142). Emerald Group Publishing Limited.

Ewing, R., & Cervero, R. (2010). Travel and the built environment: A meta-analysis. Journal of the American Planning Association, 76(3), 265-294.

Faria, R., Marques, P., & Moura, P. (2013). A sustainability framework for the European electric vehicle system. Energy Policy, 61, 1021-1032.

Litman, T. (2014). Evaluating public transit benefits and costs: Best practices guidebook. Victoria Transport Policy Institute.

Metcalf, G. E. (2009). Market-based policy options to control US greenhouse gas emissions. Journal of Economic Perspectives, 23(2), 5-27.

Nykvist, B., & Nilsson, M. (2015). Rapidly falling costs of battery packs for electric vehicles. Nature Climate Change, 5(4), 329-332.

Pucher, J., Dill, J., & Handy, S. (2010). Infrastructure, programs, and policies to increase bicycling: An international review. Preventive Medicine, 50, S106-S125.

Sorrell, S. (2010). Global oil depletion: A review of the evidence. Energy Policy, 38(9), 5290-5295.

References

Ahern, A., Boyle, I., & Stokes, J. (2017). Land use, transport and energy infrastructure integration in Ireland: A research and policy agenda. Energy Research & Social Science, 32, 85-97.

Caulfield, B. (2014). Re-thinking the effectiveness of parking policy in Dublin city. Case Studies on Transport Policy, 2(2), 63-69.

Caulfield, B., Brazil, W., & Weldon, P. (2017). Public transport – A viable alternative to the private car in Ireland? Transportation Research Procedia, 25, 4254-4265.

Curtis, C. (2017). Land use and public transport integration in Ireland. European Transport Research Review, 9(3), 1-14.

Curtis, C., & Caulfield, B. (2018). Public transport provision in dispersed rural areas: A case study of Ireland. Research in Transportation Economics, 69, 420-427.

Department of Transport, Tourism and Sport. (2009). Smarter Travel: A Sustainable Transport Future. Government of Ireland.

Environmental Protection Agency (EPA). (2021). Ireland's Greenhouse Gas Emissions. Retrieved from https://www.epa.ie/ghg/

Government of Ireland. (2018). Project Ireland 2040: National Planning Framework. Retrieved from https://www.gov.ie/en/campaigns/09022006-project-ireland-2040/

Government of Ireland. (2019). Climate Action Plan 2019: To Tackle Climate Breakdown. Retrieved from https://www.gov.ie/en/publication/ccb2e0-the-climate-action-plan-2019/

Kenny, P., Caulfield, B., & Brady, J. (2018). Electric vehicle charging infrastructure in Ireland: The role of car parks. Transportation Research Part D: Transport and Environment, 63, 288-301.

Ryder, H., Brazil, W., & Caulfield, B. (2020). The impact of walking and cycling infrastructure on travel behaviour in Ireland. Transportation Research Procedia, 46, 90-97.

Antle, A. N., Droumeva, M., & Corness, G. (2011). Human-computer-intuition? Exploring the cognitive basis for intuition in embodied interaction. International Journal of Arts and Technology, 4(3), 235-254.

Deterding, S., Dixon, D., Khaled, R., & Nacke, L. (2011). From game design elements to gamefulness: defining "gamification". In Proceedings of the 15th International Academic MindTrek Conference: Envisioning Future Media Environments (pp. 9-15).

Fails, J. A., Guha, M. L., & Druin, A. (2013). Methods and techniques for involving children in the design of new technology for children. Foundations and Trends® in Human–Computer Interaction, 6(2), 85-166.

Guha, M. L., Druin, A., & Fails, J. A. (2013). Cooperative inquiry revisited: Reflections of the past and guidelines for the future of intergenerational co-design. International Journal of Child-Computer Interaction, 1(1), 14-23.

Hart, J. K., Staveland, L. E., & Gunn, W. (2016). Using interactive graphics to teach about climate change. Journal of Educational Multimedia and Hypermedia, 25(4), 381-397.

Kafai, Y. B., & Resnick, M. (1996). Constructionism in practice: Designing, thinking, and learning in a digital world. Routledge.

Lankow, J., Ritchie, J., & Crooks, R. (2012). Infographics: The Power of Visual Storytelling. John Wiley & Sons.

Markopoulos, P., Read, J. C., MacFarlane, S., & Höysniemi, J. (2008). Evaluating children's interactive products: Principles and practices for interaction designers. Morgan Kaufmann.

Norman, D. A. (2013). The Design of Everyday Things: Revised and Expanded Edition. Basic Books.

Uttal, D. H., Meadow, N. G., Tipton, E., Hand, L. L., Alden, A. R., Warren, C., & Newcombe, N. S. (2013). The malleability of spatial skills: A meta-analysis of training studies. Psychological Bulletin, 139(2), 352-402.