PERSUASIVE DATA VISUALIZATION AND INTERACTIVE NARRATIVE FOR CLIMATE CHANGE AWARENESS

by

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Abstract

Climate change is a global phenomenon that affects every living being on our planet. We have been observing drastic changes to our climate since the last few decades. This has raised concerns among people from all works of life to address this issue which requires collective effort in mitigating the threats. Climate researchers have emphasized the human involvement in the acceleration of climate change, especially due to the drastic increase in warming trend since the industrial revolution. There are numerous climate actions that each individual performs in their day-to-day lives, and these actions collectively impact the climate in the short and long run. Raising awareness among people about climate change and helping them realize the consequences of their actions is key to mitigating climate change problems. Our research aimed to achieve this by building a persuasive intervention that combines visualization of climate change data and an interactive narrative that demonstrates how our actions can impact the climate. We conducted a user study with 100 participants and found evidence showing that our system was effective in significantly promoting behavior change to mitigate climate change. We found defensive responses as a key factor that is negatively influencing the effect of our intervention on the participants. Compelling visuals and multiple interaction options, simulating climate actions and their consequences, and reducing the effort to learn about the phenomenon were significant positive techniques used in the intervention. Additionally, the social elements of our intervention played a major role in promoting participants' willingness to perform pro-environmental behavior. Participants were able to learn from and compare their behavior with other participants, and they were also able to contribute together to fight this collective-problem, which contributed to the effectiveness of the intervention. Our work contributes to the field of persuasive technology, data visualization, interactive narratives and climate research by introducing a new persuasive way of communicating climate change information to the general public using a combination of data visualizations and interactive narratives.

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Chapter 1

Introduction

Climate is defined as long-term averages and variations in weather measured over a period of several decades [83]. Climate affects every aspect of the lives of all the living beings on this planet, and changes to it can have unexpected effects globally. The warming of the climate we are experiencing since the last couple of decades is phrased as "global warming", which is the current ongoing trend in climate change. This research aims to raise awareness and promote positive behavior change towards climate change through a persuasive intervention.

1.1 Motivation

Intergovernmental Panel on Climate Change's (IPCC) fourth assessment report stated that global mean air temperature greatly increased after 1950's, which can be related to the increasing amount of carbon-based gases emitted through human activities ever since the beginning of industrial revolution [129]. We are experiencing hotter temperatures each year, where in the last year (2021), the global mean annual temperature anomaly was 1.4 °C, that tied with the year 2019 in being the third warmest year over the period 1961–2021 [45]. Moreover, 2020 was the warmest year in instrumental record (1.7 °C global mean temperature increase), whereas in the past decade (2011–2020) the global mean annual temperature change was 1.31 °C, scoring well above any earlier periods in record [43]. For these statistics, the anomalies are compared to the climatology of the period 1961–1980 which is represented as the climatic normal [45], that provides us with the perspective on the changing climate over the last 60 years. Considering the notable increase we are experiencing over the last decade, it has become a burning topic in the research community to encourage taking steps to mitigate climate change.

The rapid changes in the climate that is being observed since the last decade, warmer years being experienced more frequently, and widespread agreement on human

involvement in the warming trend of the climate: these factors motivated this research to build a persuasive intervention that would help the general public understand this global phenomenon and show how our day-to-day activities contribute to the issue. By raising awareness about climate change, and motivating a positive behavior change towards mitigating climate change, we aim to address this global phenomenon with the goal to prevent adverse changes to our world that may impact generations to come. To achieve this, our objective of this research is to combine the persuasive power of data visualizations, interactive narratives, and gamification to raise awareness and promote behavior change towards this global issue.

1.2 Problem Statement

While many argue climate change being a natural phenomenon [40] and that there is little to be done to stop these changes, the majority of climate scientists (90-100%) agree that human activities are causing the recent global warming [26]. Stocker [121] argues that, since the mid-20th century, human influence has been the dominant cause of the observed global warming. John et al. [26] performed a synthesis of research which surveyed the consensus among researchers that humans are causing recent global warming. They concluded that 90-100% of publishing climate scientists believe that human activities have impacted climate change. The overwhelming agreement on the fact that humans are influencing climate change draws urgency to the development of interventions that convey correct information and raises awareness about climate change, since a common counter argument is often presented that there is no consensus on human causing global warming [40].

Moreover, illiteracy about climate change is caused by misinformation about the phenomenon that is spread across the general public [82]. Hence, it is important to properly educate people about this global phenomenon and in ways that is understandable to a wider audience. Presenting information regarding climate change in a way that is understandable to the general public is not an easy task, since climate information spans across spatio-temporal data [76] that needs observation and exploration to have an understanding of the phenomenon. Thus, it is a challenge to present correct climate change information in an understandable manner to raise awareness about climate change among the general public.

1.3 Solution

To make learning from data easier that is also understandable to a wider audience, visualizations are a powerful tool that helps visually detect patterns from complex structures, and in some cases can reveal information from data that cannot be observed in any other way [73]. Graphical representation of data also possesses the power of positively influencing its readers into finding the scientific content more credible, regardless of the triviality of the visualization [126]. Thus, it is desirable to convey messages regarding climate change using data visualizations that consists of spatio-temporal data [76].

Using visualization to make sense of various phenomena with a view to solving problems go back to more than a hundred years. In 1854, John Snow's visualization of the spread of cholera in an area of London saved many lives which is an astounding achievement in the field of data visualization [105]. Moreover, visualizations can be a mean to tell a story that is driven by data, which can be powerful in expressing how our climate has been changing over the years. An early and notable example of telling a story with data visualization is the "Napoleon's March" by Minard, which captured the losses of Napoleon's army in his Russian campaign [55]. This simple representation of spatio-temporal information tells the story of Napoleon's journey to force Russia back into the Continental Blockade of United Kingdom that lasted for about 6 months [138]– which some have claimed to be "the best graphic ever produced" [55] due to its success in displaying multidimensional data while hiding all the complexities to its viewers [55].

Depicting outcomes of climate changes has been practiced across multiple mediums. In fact, the documentary film, "An Inconvenient Truth" stirred attention among the general public through its vivid portrayal of the grim visuals (such as, strong hurricanes and floods destroying communities and parts of different countries getting submerged due to rising sea levels) of global warming [57], and mass media coverage about environmental issues have been found to be effective in raising environmental concerns [63]. Although climate problems are mostly researched among academics in finding factors related to the phenomenon [65] [110] [8] [76], reaching out to the general public and educating them about its causes and effects remains an area open for research.

On the other hand, gamification is defined as "the application of game design elements to non-game activities" [35], and among the many different ways to educate people, learning through games, or gamification in education is being introduced to various topics. Learning through gamification has been found to be more effective than traditional learning methods, due to their ability to engage the learner, and allowing them to learn in ways beyond simply reading [16] [75]. Therefore, to tackle climate problem by raising awareness about climate change among the general public, we also employ gamification.

Furthermore, the advancement in computer technology has paved the way in introducing new ways of learning, where both teaching and learning experiences are getting enhanced by new modes of interactions. Application of digital games for education has been envisioned since the dawn of digital games, as even found in Orson Scott Card's 1985 science fiction novel "Ender's Game", where he demonstrated a world in which the brightest of minds learn only through playing games [119]. Although we have not seen adaption of games for learning to such extent, games as a means of learning has received much research attention [32] [66]. Emotions experienced while playing games, such as excitement, triumph, dejection, relief, frustration, relaxation, curiosity, and amusement [72], are generally self-directed as they encompass our progress and interest in the game. However, interactive narratives have a unique power to generate emotions directed towards others, in other words, to feel empathy towards the in-game content (e.g., characters and environment) [114]. This characteristic of interactive narratives can be harnessed to target issues that require people to feel responsible and act accordingly [131], such as climate change which is a global phenomenon that demands participation of individuals collectively due it being a collective-action problem [21].

Thus, to raise awareness and promote positive behavior change to mitigate climate change among the general public, our solution is to combine the persuasive power of data visualizations, gamification and interactive narratives.

1.4 Contributions

With the research objectives in mind to raise awareness and promote positive behavior change towards climate change, and in a way that is accessible and understandable

by the general public: we developed a web application comprising of visualizations of climate change data, and an interactive narrative game where the player drives the story by taking decisions that impacts and determines the future of the game's world, reflecting the impact of our real-life choices and behaviours on the climate.

To determine whether the intervention is effective in raising awareness and promote behavior change to mitigate climate change problems, we designed and conducted both a quantitative and qualitative study with a total of 100 participants where they rated various design aspects of the intervention and shared opinions about their awareness level and behavior towards climate change. By analyzing both quantitative and qualitative data, we found that the system was able to increase positive behavior change to mitigate climate change, but could not increase awareness about climate change. Moreover, we found a strong relation between participants' defensive responses against the system, and their level of awareness and willingness to change behavior to mitigate climate change. Our system was also perceived as significantly persuasive in promoting positive behavior change to mitigate climate change, where all the social features of the intervention that emphasized on dealing with climate change with collective effort received overall positive feedback from the participants.

The effectiveness of our system paves a new way of communicating and educating climate information to the general public. To the best of our knowledge, combining data visualizations, interactive narratives and gamification in an intervention to raise awareness about climate change is a novel way to address the climate change problem. Our intervention presented the two components: data visualization and interactive narrative game respectively to the participants with an aim to enhance the experience in motivating the user to engage in positive behaviour change and raise their climate change awareness. The system will benefit future researchers in combining the persuasive nature of visualizations, interactive narratives and gamification in mitigating complex issues such as the climate change.

Finally, based on the most effective design elements from our findings, we present design recommendations for interventions aimed towards mitigating climate change that include: incorporate compelling visuals, reduce effort in learning about the phenomenon, depict both positive and negative outcomes of the climate's future through

simulation, reinforce learning and observation of other's behavior through demonstration of collective participation of people, and provide options for exercising different choices and show how they can impact the climate.

1.5 Research Overview

The remainder of this thesis is organized as follows:

- In chapter 2, we reviewed background research in the field of data visualization, interactive narratives and design strategies to build persuasive interventions that formed the foundations for this research.
- In chapter 3, first, we define concrete objectives that we aim to fulfill through our research. Then, we explain the development of our intervention in details.
- In chapter 4, we discuss about the study that was designed to capture the effectiveness of our intervention.
- In chapter 5, we present the results from the conducted study.
- In chapter 6, we discuss about our findings in relation to existing research, reflect upon our research objectives, and share our design recommendations. Then, we address the limitations of our work and directions for future work.
- In chapter 7, we share our final thoughts and conclude our research.

Chapter 2

Background

Climate change being a burning issue has led to extensive research on this phenomenon that spans across multiple disciplines. However, our research mostly focuses on utilizing the persuasive nature of visualizations and interactive narratives to promote awareness and behavior change to mitigate climate change. This section presents background literature and reflects on their limitations that laid out the foundations for our work.

2.1 Climate Change Visualization

Visualizations allow the viewers to interpret visualized data in various ways, and depending on the purpose, the resultant visualization can provide different information. However, gaining insights from visualizations is one of the main purposes of information visualization, as Card et al. [20] stated "The purpose of visualization is insight, not pictures". The visualization research domain is a vast area that spans across discovering new means of visualizing data, exploration of data using visualizations, and analyzing their effectiveness: however, for our research we only focus on climate change visualizations. When it comes to climate change visualization, the intended insight to be gained from the visualization can vary depending on what the viewer is expecting to learn. Some visualizations target finding indicators and factors of climate change [9] [8] [132] [71] [76], some aim to define trends and models to predict the upcoming changes [110], while some have been designed to establish the fact that climate change is real by providing evidence [65] [104]. There has also been an increasing use of visualizations to demonstrate the future of the climate that help us become more aware of the situation and better prepare for the future [46] [81].

Xinbo et al. [65] used data visualization to assess climate trends for the continental United States and gain insight on climate extreme indices. Their research used the daily climate data from the Applied Climate Information System (ACIS), which was

used to derive climate extreme indices such as, maximum/minimum temperatures, high precipitation values, total annual precipitation and snowfall. They used choropleth maps and line charts to intuitively help users access the derived climate extreme data that has spatio-temporal characteristics. Through the help of visualizations and analysis, the researchers were able to find decreasing frequency of winter temperature and snowfall extremes in northern US, increasing trend in precipitation in inland areas and northeast region compared to the western coastal areas and southeast region.

Varma et al. [136] introduced an interactive visualization of the greenhouse effect, called Global Warming: Virtual Earth, with a view to help middle school students understand the science behind this phenomenon. The authors followed the principles from the knowledge integration (KI) framework [78] to design the learning activities and guide students virtual experimentation. Their learning unit included videos on introduction to global warming, calculating ecological footprint using an online tool and visualizations to learn about greenhouse gases, clouds, and albedo. The visualizations allowed the students to conduct experiments to learn about global warming, such as, using sliders to manipulate the population growth and see its effect on climate. Their study with 196 participants showed that the average overall learning scores improved from pre- to post-participation. In pre-participation questionnaire students had some understanding of the greenhouse effect, but it was mostly incomplete or incorrect. Students' responses in the post-participation questionnaire included more ideas about the interaction of the key factors in global warming, which shows that the students' ideas were now more normative and better integrated.

Kholid et al. [46] used Augmented Reality (AR) to provide information about global warming interactively. Using a paper printed map, the researchers projected 3D models of melting icebergs, rising sea levels, extreme weather, drought and other events of global warming to show their harmful effects. The user can select different locations on the map to see the visualizations. The application was tested on 30 users consisting of elementary to college students and older adults, and most users found that information on the application was complete and easy to understand and operate. The system had limitations to work only on flat surfaces with a distance of 40cm to project the models properly.

There have been more non-traditional approaches in visualizing data for climate

awareness such as *Eco-visualization* which aims to provide feedback on real-time energy consumption for more ecologically responsible behavior [64]. These visualizations include public art displays that show energy consumption for a building in terms of number of trees needed to be planted due to the amount of carbon emitted [64], or even smart wires that glow red during heavy load [60]. However, there has not been widespread implementation of such interventions in the real world. Daily or continuous feedback on energy load has been found to be effective in increasing energy conservation behavior [15], but attitudes toward conservation have also been found not linked directly to conservation behavior [64].

Nathan et al. [8] used high resolution CO_2 emission data that resulted from the Vulcan project which quantified fossil fuel CO_2 emissions at the scale of individual factories in the United States. Using the map of United States, the researchers created both 2D and 3D visualizations to analyze the CO_2 emission rates and its flow in the atmosphere. While the 2D visualization helped figure out that highly populated and industrial locations emit more CO_2, especially during daytime and evening, the 3D simulations allowed to get a glimpse of the transportation of CO_2 across the regions. The simulations showed CO_2 getting washed out over the gulf due to summer thunderstorm activity, which might also be responsible for middle- and late-summer elevated parcels of CO_2 rich air. Another study [9] also used the Vulcan project data to understand the complex space-time dimensions of fossil-fuel emissions (CO_2), and its relation to the human-induced climate change, and found similar results using 2D and 3D heat map visualization using the map of United States.

Prejmerean et al. [110] used map based visualization to simulate the current and future situation of global warming for the counties of Romania. Using a genetic algorithm, the expected value of carbon footprint for a settlement was calculated based on the current data on the carbon footprint by a population of a county. This would then be used to correlate carbon footprint with temperature change through comparison of current data from the localities. Using this proposed solution, the authors aimed to provide ways to assess risk factors associated with the increasing temperature such as, the increase in temperature may impact individuals who are prone to cardiac disease, high blood pressure and other chronic diseases.

Kinakh et al. [71] used spatial vector data on carbon dioxide, methane, nitrous oxide and other greenhouse gases emissions in Poland. The authors created a website for spatial analysis and visualization of green house gas emissions using Google Maps Javascript API and creating a heat-map of the emissions. The website provided user interaction to perform operations on the data such as, calculating total or specific emissions, maximum or average magnitudes of emissions. Using the created visualizations, the authors were able to identify highest emission regions. They also noticed high emission in resort areas where wood is mostly used as fuel, which has a higher emission coefficient compared to other energy sources.

Jie et al. [76] developed a visual analytical framework called Visimate: comprising of three visualization techniques for spatial and temporal patterns in a single view, time-series patterns, and anomaly detection. Using data collected from NOAA National Climate Data Center and China Meteorological Data Sharing Service System's land surface observations, the researchers performed K-Means clustering to divide all data stations into groups having similar climate change rates. The user can set the date range, number of clusters and variable (e.g., average temperature change) to be generated in the visualization. To evaluate Visimate, the researchers first used the visualization tool to confirm existing conclusions that had been proven, such as identifying the period (1975-1989) when China's climate change has been believed to have happened. Secondly, the visualization tool was evaluated by 15 experts from National Ocean Technology Center and Naval Marine Hydrometeorology Center. The participants scored the tool using a 10-point scale on seven aspects: aesthetics, visual design, interaction, learnability, performance, functionality, and scalability. Aesthetics and visual design were the highest rated aspects of the visualization tool, followed by scalability as the experts found the solution generic and applicable in climate change analysis across different parts of the world. The interaction aspect was rated low as some participants found the tool to be slower than existing GIS platforms. The learnability aspect was scored the lowest due to lack of time to get familiar with the system, and the complexity of using two different representations of global radial map. Most participants shared their concern that climate change is a complicated process affected by many factors, and without considering all factors the correctness of the findings can not be guaranteed.

Christian et al. [132] addressed the issue of under utilizing information visualization techniques in climate research as most climate researchers are not experts in visualization. Their informal interviews with 76 researchers at the Potsdam Institute for Climate Impact Research (PIK) surfaced that the state-of-the-art techniques are rarely applied, and integration of such solutions into the researchers workflow is not easily achievable. The results from their study clearly suggest that 2D visualizations are preferred more than higher dimensional techniques, with time charts, bar charts, basic maps and scatter plots being the most used visualization techniques respectively. 93% of the researchers use visualization for presenting results in publications and other scientific context, while 70% use them for verifying hypotheses. Moreover, 69% of the participants claimed to use visualization for finding unknown patterns and structures through data exploration. Office suites (spreadsheets, diagramming, presentation) were the mostly applied software to generate visualizations, while 38% used geographic information systems (GIS) (e.g., ArcGIS) to perform climate research tasks. Specialized systems such as, Ocean Data View and Vis5D were mentioned in only 20% of the feedback. For the desired features in visualization, appropriate labelling was mostly mentioned (88%), followed by faithfully representing geo-spatial aspects of the data e.g., different geographic projections (56%). High degree of interactivity was only mentioned by 14% of the participants as an important factor for visualizations. The authors of the paper believe that the lack of utilization of interactive visualizations in routine analyses work done by climate researchers can be attributed to sophisticated visualizations being less known and that different data types, scales, and climate scenarios are not covered in most systems which is important in climate research. Moreover, complex and high volume data requires elaborate data structures and caching mechanisms, for which researchers believe such data can not be handled by interactive analyses systems. Overall, there seems to be more trust in statistics and analytical computations, rather than in visual representations among the climate researchers.

Parvathy et al. [104] demonstrated effects of global warming with the help of AR to provide an engaging learning experience to students. AR can stimulate multiple sensory modalities: touch, sight and hearing, which can make students more actively involved in a learning process than conventional teaching methods. Using marker

technology, the authors showed how the radiation from the sun affects the earth by assigning a unique marker to each of the 3D representation of objects (e.g., sun or earth). The authors conducted a comparative study on their AR system with an ordinary video on a batch of students. Although the paper does not mention the demographics of its study's participants, nor does it discuss about its sample size- the results show that participants found the AR system 80% more interactive. Most students preferred the AR system and found the content in the said system 40% more understandable than traditional video content.

After a review of previous literature, it is clear that using maps to visualize climate change data is a common practice [65] [46] [8] [110] [71], and visualizing carbon emission is an integral part in most climate change visualizations [78] [8] [9] [110] [71]. Moreover, simple visualizations such as, scatter, bar and line charts are still preferred over complex high dimensional visualizations by non-visualization-experts [132]. Thus, for the general public it is more suitable to use visualizations that are widely known. In our research we used a choropleth map, line chart, and bar plot to present visualizations of climate change related data that are described in detail in section 3.2.

2.2 Interactive Narrative

Narratives or storytelling has an intrinsic receptive effect on humans. Its importance in human cognition has led to the development of a field within psychology called cognitive narratology [74]. Narratives as agents of learning has gained popularity in the research community, ranging from applications in teaching, raising awareness and behavior change. Interactive narratives have been around for a while, with Role Playing Games (RPG) like Adventure [31] and Dungeon's and Dragons [61] gaining popularity back in the 1970s, where the player drives the stories based on the decisions they take in these paper-based board games. Such interactive narrative games have evolved into more advanced computer and mobile platforms such as, Detroit: Become Human [38] and The Walking Dead [117] that provide extensive story interactions with complex storylines, and realistic graphics that can be harnessed to train empathy among its player base [103]. Another main advantage of interactive narratives is that it enables the reader to empathize with the protagonists as if the player were a part of

the story [101], and helps them to connect with unfamiliar situations and characters [86].

Micah et al. [32] used narrative learning game to teach and build interest in Object Oriented Programming (OOP) to middle school girls. The authors believed that a good narrative would aid in capturing the attention of its audience and thereby facilitate better learning experience. Using Ren'Py game engine, the authors developed a desktop application called Narrate: where the user goes through five episodes (one each day) involving scenarios that allows the user to progress by completing a series of pre- and post-participation questions related to OOP concepts of programming via multiple choice, drag and drop boxes, and keyboard input. Each episode in the game covers different aspects of OOP principles (i.e., basics, abstraction and encapsulation, inheritance and polymorphism) and finally a cumulative review which are presented in a story telling manner in the setting of a middle school. Although the game was targeted for middle school girls, due to the COVID-19 pandemic the researchers tested their game with 25 students from Baylor University, however, only 9 completely finished the study due to technical difficulties. Although none of the findings had statistical significance, there was a slight improvement in all of the episode's pre- and post-participation questionnaire (around 2-14% improvement in mean scores), showing effectiveness of interactive narratives in teaching complex programming concepts. Moreover, the game had high entertainment value as most subjects found the concept of learning to code using Narrate to be "cool". The solution highlights the effectiveness of such a tool not only in learning, but also as an assessment tool since the pre- and post-participation questionnaires can be catered to specific topics of any subject.

Elaine et al. [66] introduced a narrative focused RPG to promote visualization literacy in young children. With the increasing use of data visualization in academic, health informatics, societal topics, news and social media: visualization literacy is becoming one of the necessary skills in understanding the world around us, which was addressed in this research by helping to develop this skill at an early age which is largely overlooked in the field of research. Using Unity game engine [130], the researchers created a RPG game for the iPad Pro platform, targeting children aged between 11-13 years old. The game starts with an introduction to the main character

who studies in a magic school, and the story progresses as the hero helps other characters solve problems related to data visualization. Learning activities were presented as multiple choice questions such as, choose a best suited chart to solve a problem, or interpreting the contents of a chart. A total of 33 participants aged between 11-13 years old were separated to play a without-narrative (16 participants) and with-narrative (17 participants) versions of the game, where the with-narrative version had in-game character dialogues and story elements. After going through a pre-participation questionnaire to measure the understanding of pie charts and histograms, the participants played the game which was followed by a post-participation questionnaire with similar questions. Significant difference between the pre- and post-participation questionnaire was found for only one question between the with and without-narration versions, but participants were more engaged in the with-narrative version with significant statistical difference. Participants praised the usage of facial expressions on characters to express emotions, and liked that the problems were connected to each other through the story. However, some participants complained that the story was too short and found some characters to be shallow. Overall, the findings indicate a more engaged experience although the learning outcome was inconclusive, the researchers found that in most questions of the learning activity there were no room for improvement since most students correctly answered them in pre-participation questionnaire, thus more complicated topics may be introduced to further evaluate the narrative game.

Frey et al. [54] explored how the specific characteristics of interactive narratives can impact reader's experience, and how the physiological reaction of the users can act as as implicit input for interaction within the story. The researchers developed an application using Unity game engine [130] called Physiological Interactive Fiction (PIF) which can be used to build interactive narratives. Using PIF, the researchers built two short stories with two varying content for each, resulting in four different story scenarios to capture how the reader's perception of the story depends on their own experience and demographics. A user study conducted with 168 participants aged above 18 years showed that, the engagement of the narrative is positively correlated to the environment the reader grew up in. Results also showed that perceived similarity of the narrative is also associated with how similar the in-game character is to the user such as, if the in-game character reacts to something similarly as the

user would then the user's perceived similarity increases. Thus, adapting the story based on users' background and how they react to certain situations can have powerful impact in eliciting engagement or empathy. To further establish how the users' reaction can be measured while playing an interactive narrative, the researchers ran another study with 14 participants (aged 21-31 years). They measured the participants' physiological reactions using breathing belt, ElectroDermal Activity (EDA) nodes and eye-tracking head mounted display. Using Weka library, the researchers classified arousal (boring vs. exciting), difficulty (complicated vs. simple) and valence (happy vs. sad) constructs with the physiological data collected from reactions to different stories by the participants. The classification model reached highest accuracy in comparing boring vs. exciting (arousal) with 92.9% accuracy, followed difficulty (78.6%) and valence (64.3%). These results show that using physiological measurements and classification models, interactive narratives can be adapted to elicit maximum engagement and empathy. The researchers did not explore this aspect of adapting the story based on the measurements, but the findings show promise in automatic adaption of an entire story that can reinforce the sense of wonder for its viewer.

Thomas et al. [131] used virtual reality (VR) technology to create an immersive storytelling experience to raise awareness about a climate aspect: ocean pollution. Their VR application called "Oceans We Make" was developed for the computer platform with high resolution graphics for real-life like experience. In their narrative, the user is taken to a diving site where the user then plunges into the sea to see the beautiful underwater environment such as, sea corals, plants and fishes. Lighting and shading of the water were fine tuned for a better visual experience. The user then gradually encounters plastic bottles and trash along the journey, enabling them to collect the waste objects to get rewards. However, the number of waste increases with time and by the end of the journey the number of waste becomes too many to keep up with, that was programmed to help the user realize the scale of pollution that is being caused. The VR application was displayed in various exhibitions such as, MeshMinds and ArtxTechForGood where around 200 users tried the experience. Open-ended feedback from users showed how impactful the application was as users mentioned that they felt guilty about throwing plastic to the ocean and felt sad to see

fishes die while humans are saving themselves forgetting about innocent animals. The feedback shows the emotional impact an immersive narrative experience can have on its users.

Following up with the study by Thomas et al. [131], Kay et al. [137] extended the notion of ocean pollution and VR narrative experience to raise awareness about the effects of microplastics within the human body. The researchers wanted to address the effect of plastic pollution debris on humans themselves, as a 2019 study reported people could ingest 5g of microplastics every week, which is equivalent to the weight of a credit card [34]. The researchers built a similar VR application as Oceans We Make [131], but here the user is taken to a journey inside a virtual human stomach where microscopic marine creatures are ingesting plastic microfiber and swimming among colorful microplastics. The user can shoot the microplastics and collect them, and as they shoot the items, their sources such as, plastic bags, bottles or clothing are revealed to the user. At the end of the game, the user is presented with the items they collected and ways they can reduce microplastic pollution. A study on 20 participants revealed that, on a scale of 1-10 about how much aware the participant is about microplastics within their body: the average rating on post-VR experience went up to 9.2, from average rating of 5.05 from the pre-VR experience. Moreover, participants showed intention to make positive attitude changes such as, using recyclable cups (80% response rate), using reusable shopping bags (75%) and refusing plastic straws (70%). The overwhelmingly positive responses show the effectiveness of the narrative experience in raising awareness of microplastic within human body, however, the results lack statistical significance due to the small sample size.

Interactive narratives have also been used to address complex societal issues such as, social privilege. For example, Bhardwaj et al. [13] investigated using the nature of self-reflection that interactive narratives can elicit within its users to help understand complex intersectional social issues. The researchers designed a game called “Tread Together” built using Unity game engine [130] which runs on a big screen connected to a treadmill, and the user can interact with the game by walking or sprinting on the treadmill, and using two buttons. The game begins by asking the user questions to identify their own privilege, where the user presses one of the two buttons to indicate agreement or disagreement to different statements such as, “I grew up in an urban

setting.". Then, the game sets a lower privileged identity for the user to play as, and the player progresses by walking on the treadmill and making decisions that unfold different conflicts and sets the forward motion of the story. Players can overcome hindrances within the game by sprinting on the treadmill, which resembles struggles of real life. The game can either end by reaching the end of the story, or by giving up due to exhaustion. In the former case, the user is presented with how long it took them to finish the game in comparison to how long it would have taken had they played based on their own privilege. For the latter case, the game shows how much they would have achieved in the game had they been afforded the privilege they possess. The researcher built the scenario from a real life experience where in his home country migrant workers had to walk back back due to workplaces being shut down during the COVID-19 pandemic, while his friend had expressed displeasure at the inability to go to the gym for their daily treadmill sessions. Although a user study was not conducted to collect feedback on the system, its unique design and attempt at addressing a complex issue such as social privilege shows the promise in the variety of applications that interactive narratives can be useful for.

Federica et al. [103] performed a case study on two recent best-selling interactive commercial story games: Detroit: Become Human [38] and The Walking Dead [117] to discover the potential of such video games to foster empathy. Empathy is described as the ability to understand and share others emotional state or context [103], which is an essential characteristic of human interactions to share and understand other people's feelings. Thus, it is important to investigate how empathy can be learned and taught. In that context, video games can be an interesting approach due to their unique abilities in aspects of immersion, interactivity and widespread popularity among general population. Detroit: Become Human is set in a dystopian version of Detroit during the year 2038, where human like androids carry out important roles within the society such as, law enforcement and caretakers. The player in this game plays as androids as they face discrimination from the humans while trying to belong in the society, and are faced to take informed decisions as they play the role of victims of abuse. On the other hand, The Walking Dead is set on present-day Georgia, where a virus has led to a zombie apocalypse, and the protagonist Lee who is an ordinary man becomes a victim of circumstances as he tries to survive in a hostile

environment with scarce resources. Both games put the player in difficult situations with moral conflicts where the player must empathize with other characters or the character they are playing. By analysing the game content, the authors concluded that as these games allow players to act and think as the character within the game, it produces a strong effect on empathy elicitation. The high level of interactivity of such video games offer a method of observing our actions' consequences, as the player is responsible for the choices and how the story follows. Moreover, as the players can exercise different actions within the game, they are able to learn new values and experience various perspectives that integrates cognitive and emotional empathy. Exploration of multiple outcomes can also be encouraged by these games by offering rewards for reaching different endings, that enhances replayability of such games. The authors suggested that such commercially successful games due to their unique characteristics may serve as starting point of how interactive story games can be harnessed to have impact on empathy, ethics, politics and social issues that are integral parts of human-human interaction.

Paul et al. [28] designed an approach for building an interactive narrative game using the modes of rhetoric of empathy, logic, and credibility to encourage engagement and response to climate change challenges. Through a series of participatory design workshops with designers, researchers and climate scientists, the researchers developed an interactive narrative game with two modes: existence and dream mode. The existence mode takes place in a fictional universe where climate has been badly affected. In this mode, the weather of the world is amplified with worsening effects based on the player's current weather condition e.g., rain in real-time is reflected as acid rain in the game. The existence mode starts with the player getting familiarized with the world, and eventually reaches toward a narrative finale on finding another human being. The relation between real world and game world was reinforced in game design to provide the players a personal experience of the effects of climate change, and helping them develop logic that connects real world to in-game world. The authors aimed to develop this mode further into 3D first-person game to help players develop empathy for the game's character and environment. In the other game mode: dream mode, the player plays a platform game in which the character is a person who needs to navigate through planets to find clues to go to the next level

in the existence world. This shift in scale was required to demonstrate the complex relationship between the global nature of climate change versus localised and situated weather experiences, so players can relate to interactions between climate and weather. The researchers aimed to build credibility for the game among the players by using data from trusted sources, and they shared this exploratory design approach with a view to establish means of communicating the complexities of climate change to the general public. Although the researchers did not evaluate their design with actual users, their approach in providing understanding for personal and worldwide scale of the climate change problem using the modes of rhetoric of empathy, logic, and credibility opens up new possibilities in game design for climate awareness.

To summarize, existing work show the success of interactive narratives in teaching and increasing literacy on different topics [32] [66], which we believe can be mapped into addressing the climate change problem. Moreover, the interactive narrative designed by Tomas et al. [131] was successful in eliciting intention to make positive attitude changes towards climate friendly behaviors, which we want to further explore in our research. We believe the ability to provide an empathetic experience through interactive narratives [54] [103] [28] can be mapped into the climate problem and build a sense of responsibility towards it. Keeping these findings in mind, we designed our own interactive narrative game for climate change awareness that is described in details in section 3.3.

2.3 Persuasive Strategies

Persuasive strategies are design guidelines aimed towards helping to build persuasive systems. Persuasive systems are digital interventions that are designed to reinforce or alter attitude or behaviors without the use of coercion or deceit [96]. In simpler words, Fogg et al. [51] stated "interactive technology for changing users' attitude or behavior is called persuasive technology". Since our intervention is aimed to raise awareness and promote behavior change to mitigate climate change, it needs to be persuasive to fulfill its goal. To design persuasive intervention, we need to explore strategies that help design and build persuasive systems.

There are several models that have laid out methods and techniques to help build persuasive systems. The art of persuasion has been around since dawn of human

civilisation. For example, in Cialdini's [23] work on the psychology of persuasion, six weapons of persuasion were identified: reciprocity, consistency, social proof, likeability, authority and scarcity that people and companies use to persuade others to perform a target behavior. When it comes to computer-human persuasion or computer-mediated persuasion, computers do not have thoughts of their own so the persuasion has to come from the designer of the system. Fogg [50] addressed the principles behind computer-human persuasion, and referred to the study of computers as persuasive technology as "Captology". Captology investigates how people are motivated or persuaded when interacting with computing products, where the computing product is a participant in the interaction and can be a source of persuasion, in contrast to systems that act as as a mean of communication between a human persuader and target user. Fogg [50] noted certain techniques where computers can act as a persuader such as, playing a social role, being a media for simulation, and being a credible source of information. Although Fogg's work is considered the stepping stone in building persuasive technology, it lacked the explanation how such principles can be utilized as software requirements and implemented as actual software feature. Building on top of Fogg's work and addressing its limitations, Oinas et al. [96] built the Persuasive System Design (PSD) model that comprises of 28 persuasive strategies, divided into four categories which can be directly mapped to system features, and this model is of particular interest in our research.

2.3.1 Persuasive System Design Model

The Persuasive System Design (PSD) model [96] as described earlier categorizes four system design principles: primary task, dialogue, system credibility, and social support. Each category targets a specific aspect of persuasion to help the user reach a target behavior.

The Primary Task Support category assists the users in carrying out main tasks in an application. This category has seven strategies among which *Self-monitoring* has been widely used in applications such as, to promote physical activity [102] [25] and to aid asthma patients in disease management [77]. This strategy allows the users to measure and monitor their performance from within the application, that supports them to reach their target goals. *Tailoring* and *Personalization* are two other popular

strategies that help users easily perform the primary tasks within an application by adapting the content to user's characteristics, which are strong tools in e-commerce applications [2].

Strategies from the Dialogue Support category provide users feedback on their actions for an interactive experience, with a view to helping them reach their target behavior. This category holds many widely implemented strategies such as, *Suggestion*, *Rewards*, *Praise* and four others. *Suggestion* strategy is one of the most common strategies in the PSD model, with its implementation ranging across promoting healthy eating [99], oral health [59] [118], safe sexual behavior [87], vaccination [30] [93], disaster management [47] and online security [90]. This strategy is mostly employed by providing the user relevant information regarding the behavior, e.g., how to identify phishing links or emails as presented in the Phisher Crush application [90]. However, suggestions can crowd the interface of applications which renders them useless as users start to ignore them to prevent hindrance in performing the primary task [2]. *Rewards* is another popular strategy, which is mostly implemented by gifting the user virtual trophies, points and badges [102] [30] [48] [90], or items that help in playing the game such as, powerups [87]. Rewards are given to encourage the user in performing the target behavior so that they stay motivated to continue performing the behavior.

The Social Support category comprises of seven strategies, leveraging the power of social influence in motivating the users to perform a target behavior. *Social Comparison* and *Competition* are commonly used in applications that enable users to compare their performance with other people performing the same behavior, and compete to stay on top that encourages improvement in their performance. These strategies often go hand-in-hand with the *Reward* strategy as users are allowed to compare their collected points or badges with other users. *Reward* strategy has been employed in domains such as, healthy eating [99] [106], physical activity [102], disease management [87] [77] and sustainable transportation [48]. Another powerful tool from this category is *Social Learning*, which helps users to be motivated by observing and learning from others performing the same behavior. This can be achieved by enabling users to view experienced shared by other users such as, showing users' journals in a physical activity application [25]. This is also one of the most commonly used strategy

in e-commerce applications as users share reviews of products that potential buyers can see and get motivated in purchasing the product [2]. Although social support strategies can be great motivating factors, they have their disadvantages too as users can become demotivated by getting overwhelmed by highly performing users, or in case of majority users not performing well, users may not get motivated to improve their performances.

The System Credibility Support strategies increases a system's persuasiveness through enhancing its credibility for the user. *Verifiablility* is a widely used strategy especially in e-commerce applications, where the system allows to verify the product sources by seeing seller or manufacturers' information [2]. This strategy has also been implemented in disease management [88] [89], mental health [7], waste management [92] and physical activity [6] applications by providing links and descriptions to the sources of information provided within the application. The strategies from this category is crucial to applications that aim to address health or social issues as users tend to seek justification of content included in these applications to be able to believe in them, which may be resolved by employing strategies such as, *Verifiablility*, *Authority* and *Expertise* [1].

Although the applications of persuasive strategies span across multiple domains, our focus is on their usage on climate change awareness. In the following section we will share some applications geared towards mitigating climate change in light of the persuasive strategies employed in the system.

2.3.2 Climate Change and PSD Model

There are many applications, websites and services available that try to raise awareness about climate change. Most of these applications explicitly or implicitly apply persuasive strategies in their system design.

Dopplr [49] is an online service for mobile and computer devices that lets its users share future travel plans, based on which it shows the carbon footprint of the users for each trip. By doing so, the application applies *Self-monitoring* and *Social Comparison* strategies as the users can see their own carbon footprint and compare it with others. Users of the application considered it as a tool to measure and reflect upon their own behavior, as it does not coerce the users to reduce their carbon footprint, rather it

makes them self-aware of their behavior towards the climate [139].

Jorge et al. [140] developed a website that allows the users to convert and compare between different units of carbon footprints of everyday products and services, such as number of mobile charges required to emit same amount of CO_2 emitted by five hours of flying in a plane. This is an implementation of *Simulation* strategy, through which the researchers wanted to improve carbon literacy of the users. After six months of hosting the website and tracking user logs, the website saw 2,800 visitors with an average of 40 conversions performed by each user. The authors also gathered feedback on the website from social media, and found that the users enjoyed using the website due to its playful and simulating manner. Users were also surprised after seeing the relation between different conversions, showing the success in understanding CO_2 emission information through the intervention.

PEIR (Personal Environmental Impact Report) [85] is a mobile application developed to explore and share how humans affect the environment and vice versa. By tracking user location data, the application detects walking and driving motion, and calculates carbon emission of the user. It shows the users their movement in a geographical map and details of the carbon impact, along with weekly bar charts of carbon emitted, employing *Self-monitoring* strategy to help users reflect upon their behavior towards the environment. It also allows users to share their data in social media platforms, which is an implementation of *Social Learning* strategy allowing users to learn from each others behavior.

UbiGreen Transportation Display [56] is a mobile application that semi automatically senses and displays information about transportation behavior. The application implements the *Simulation* strategy by showing a tree to the user as it grows for every green transportation activity performed (e.g., walking or carpooling). There is another interface in the application that shows a polar bear in an iceberg which grows with green transportation actions. The application also shows money saved for the actions, which is an implementation of *Self-monitoring* strategy. The researchers behind the application conducted interviews with 14 participants, where majority of the participants wanted to see a variety of visuals in the application such as, different stories and scenery. Some participants complained about not having enough information and that most information was already known to them such as, biking is a good

form of exercise. Participants shared the desire to see negative imagery depending on performance (e.g., polar bear should drown if the user does not perform well). Some participants shared that they had started carpooling to reduce carbon footprint after using the application, while others stated they already followed green transportation habits. Overall, the system offered engaging user experience and increased interest in climate friendly behavior, especially due to its gamification elements.

We Are What We Do [22] is a website for collaboration between users to reach a common goal: reduce carbon emission. In this website, the user is given small actions and information about how to perform them. The primary concept behind the website is to show that small actions by many people can have a bigger impact as a whole i.e., it displays how many people have completed certain actions which accumulates to a large number that can show an impactful change. By doing so, the application implements the *Cooperation* strategy that reinforces user attitude by aiding them to solve a common problem using the benefits of learning from others and the desire to reciprocate their effort.

Ecoisland [125] is a gamified application that allows multiple members of a family to participate in an climate friendly lifestyle. The application is aimed to be installed in a display placed in a common area of a household. The main screen of the application displays an island and the water level of the island depends on the actions taken by the family members, which is an implementation of the *Simulation* strategy. The family can set a common goal of carbon emissions, and individual family members have actions set in their personal devices such as, using the heater less and using the train instead of a car for transportation. If a member emits too much carbon, other members can compensate for them to reach the common goal. This application applies the *Cooperation* strategy to help persuade its users to gain a collective achievement. The system was evaluated with six volunteer Japanese families, consisting a total of 20 participants. Nine participants shared that the sense of saving the virtual island contributed to a change in their consciousness, suggesting that the *Simulation* strategy had influenced the user. However, participants shared they wanted to perform pro-environmental behaviors to save the island rather than for environmental reasons, which shows that the system was not able to encourage intrinsic motivation. Moreover, 17 participants said that they were more conscious

of their attitude towards the environment after using the system, showing the overall success of the intervention.

One Million Acts of Green (OMAOG) [14] was a web-based campaign to persuade users in participating in conversations with one another regarding environmental friendly activities, and encouraging them to complete 'green acts'. The website would show its users a list of daily habits that can positively impact the environment, employing the *Suggestion* strategy to help its users easily adapt to climate friendly behaviors. The website sets a environment friendly act for each day for users to perform, which is highlighted in the user's dashboard. However, the main focus of the website was to show how users across the world are participating in this campaign by displaying the number of green acts performed and carbon emission avoided due to the acts, which is an implementation of *Normative Influence* strategy. The website also displays contributions done by the user, applying the *Self-monitoring* strategy to keep the user motivated. OMAOG reached its target of one million acts in just over one hundred days, showing its success in motivating users to engage in environment friendly behaviors. Although the intervention shows promise, the website relied on self-reported data which can be exaggerated and misleading as there were no full-proof way of knowing the validity of the data inputted by the users.

Overall, the PSD model has seen its fair share of implementation across multiple domains, and persuasive strategies have also been employed effectively in climate research. In light of existing research, we employed strategies from the PSD model in our system design to augment its persuasive nature in raising awareness towards climate change, details of which are provided in section 3.4.

2.4 Summary of Background Research

Although there are numerous studies that have been conducted on climate change related issues, a study on combining data visualizations, interactive narratives and gamification to raise awareness and encourage positive behavior towards mitigating climate change is yet to be investigated. Our research aims to achieve this by designing a system that implements data visualizations and interactive narratives based on the literature reviewed in this chapter, and find its effectiveness in raising awareness and promoting positive behavior change to mitigate climate change.

Moreover, compared to using data visualizations in understanding factors of climate change among researchers, there are fewer user studies that were designed to analyze effectiveness of data visualizations in raising awareness about climate change among the general public. Most of the research on data visualization and climate change explore using data visualization as a tool to understand climate related problems and identify related factors by the researcher [65] [46] [8] [110] [71] [76]. Christian et al. [132] also mentions the lack of utilizing data visualization tools for the non-experts in data visualization. Keeping this in mind, our research would explore its usage among the general public.

In our review of existing literature on interactive narratives for raising climate change awareness, we found a limited number of studies suggesting that interactive narrative is an under-utilized tool in the climate research community. Although it is a popular genre in commercial videogames industry, it can be used to address even complex issues such as, social privilege [13], and as an educational tool such as, for teaching programming [32] and visualization literacy [66]. Additionally, most of the existing research implementing interactive narratives tend to build such tools for a specific user group such as, children [32] [66] and not for the general public. Lastly, there remains a lack of user studies exploring effectiveness of interactive narratives that are conducted on the general public. Our research implements an interactive narrative that is designed for the general public and we aim to analyze its effectiveness on them.

Persuasive strategies are widely used across multiple domains, and we were able to find adequate application of such strategies in climate change related work. However, there is a gap in current research that build data visualizations keeping persuasive strategies as the focus of design. Moreover, we could not find relevant research that utilize the PSD model [96] in interactive narratives. Our research addresses both of these limitations as we apply different persuasive strategies in climate change data visualization and interactive narrative to increase the system's persuasiveness. Moreover, we intend to analyze the effectiveness of the applied strategies by collecting data from running a user study.

Chapter 3

Methodology

Based on a critical review of existing literature, this research aims to raise awareness about and encourage positive behavior change to mitigate climate change by applying visualizations and interactive narratives as an intervention tool. In this chapter, we describe the intervention design in detail and state our research questions.

3.1 Frameworks and Technologies Used

Based on our review of the literature on visualizations and interactive narratives, we decided to design a system that combines both techniques for climate change awareness. As our goal is to raise awareness about the subject matter through an intervention that would comprise of educational material, to strengthen its learning outcome, the whole system was designed supporting the knowledge integration (KI) framework [78]. The KI framework is a cognitive perspective of learning that is consistent with theories of teaching and learning promoted by the learning sciences [29]. The first step of the framework *eliciting ideas*, was initiated by letting the users of our system share their perception on climate change through a pre-intervention questionnaire, encouraging them to reflect upon their level of awareness and behavior towards this phenomenon. Then, the system adopts the second step of the KI framework *introducing new ideas*, by providing evidence and information about climate change to the users to introduce new ideas. The system shows data visualizations of climate change over the years as evidence based on real data collected over the span of last 60 years. Then, to initiate the third step in the KI framework: *developing criteria for sorting ideas*, participants are introduced to the interactive story game where they exercise their beliefs and ideas, where actions in the game are evaluated to help them compare with their initial ideas. Lastly, following the fourth step of the KI framework *sorting and reorganizing their ideas*, the game shows an ending depending on the actions the users took, that engages the users to reflect on new information and

compare with their previous ideas to develop a deeper, integrated understanding of how their actions contribute to climate change.

The system design further supports the three modes of persuasion: *Logos*, *Ethos* and *Pathos*- as defined by Aristotle [97]. These mediums persuade the user through different means: *Logos* utilizes facts and evidence which is presented by the visualization of historic data on climate change. *Ethos* draws upon credibility and reliability for persuasion, which is supported by providing valid sources of the information presented in the system. And *Pathos* appeals to our emotions and feelings, which can be reinforced by the nature of interactive narratives that help users connect to the story with an emotional and empathetic attachment.

While designing the system interfaces, the PSD model [96] was followed to reinforce its persuasive nature. Strategies like *Reduction*, *Cooperation*, *Self-monitoring*, *Social Comparison*, and four others were employed based on their effectiveness across different domains of persuasion and behavior change as discussed in section 2.3.

For our intervention, we designed a web application with the data visualizations and interactive narrative game. A web application is easy to access and requires no additional application to be installed on a device rather than internet browsers, which most people generally already have installed in their devices. The web application was built for bigger screens i.e., desktop or laptop computer, and tablet devices. It was not suitable for mobile screens since there were interactive data visualizations that do not fit mobile screens display appropriately, and become hard to read in smaller screens. Laravel [80], a PHP language-based web application framework, was used to develop the backend of the website that handled the communication to the database server and process all requests made to the web application. The frontend of the website was heavily reliant on JavaScript, with extensive use of Plotly.js [109] and D3.js [18] packages used for building the data visualizations and interactive narrative game respectively. MySql database server [98] was used to store all user data and website interactions. The website was served in a Linux system with Nginx [68] as the web server, following a LEMP stack (Linux, Nginx, MySQL, PHP) which was deployed in a DigitalOcean [79] cloud server located inside Canada. From herein, what we refer to as the "system" is the web application that includes the data visualizations and interactive narrative.

The following sections describe each component of the system in detail.

3.2 Designing the Data Visualizations

The system starts with displaying visualizations of climate change data. We designed three different data visualizations in the system. The primary goal of the data visualizations was to provide evidence to the user about climate change and how humans are playing a role in accelerating the change.

3.2.1 Visualization of Global Temperature Change

First, a choropleth map was displayed (Figure 3.1) to the user which visualized temperature change relative to the 1951–1980 climate normal for the years 1961-2020, for all the countries of the world. A choropleth map is a thematic map, where regions are shaded in different colors to reflect the values associated to the area [84], which is a popular choice for showing spatio-temporal data pertaining to different regions. The data visualized in this page is called the "FAOSTAT Temperature Change" statistics, which provides information on surface air temperature changes, produced in collaboration with the NASA Goddard Institute for Space Studies (NASA–GISS) [44].

The data contains temperature information for 192 countries and 38 territories over the span of years 1961-2020. The users have the option to see the temperature changes over the years using a slider, and play or stop the animation showing the changes over the years. A sequential colorscale was used to demonstrate the numeric values of temperature change. The colorscale was chosen from ColorBrewer which is widely used by visualization researchers to select a color palette for visualizing variables [33]. By hovering over the different countries on the map, the users can see the actual value of temperature change. Users can also zoom in-out and move the map, providing additional interactivity to the visualization. The right side of the page contains a textual description of the data being visualized, a "Highlights" section that points out some key observations from the data, and a "Reference" section that includes citations and links to the sources of the data and information mentioned in the page.

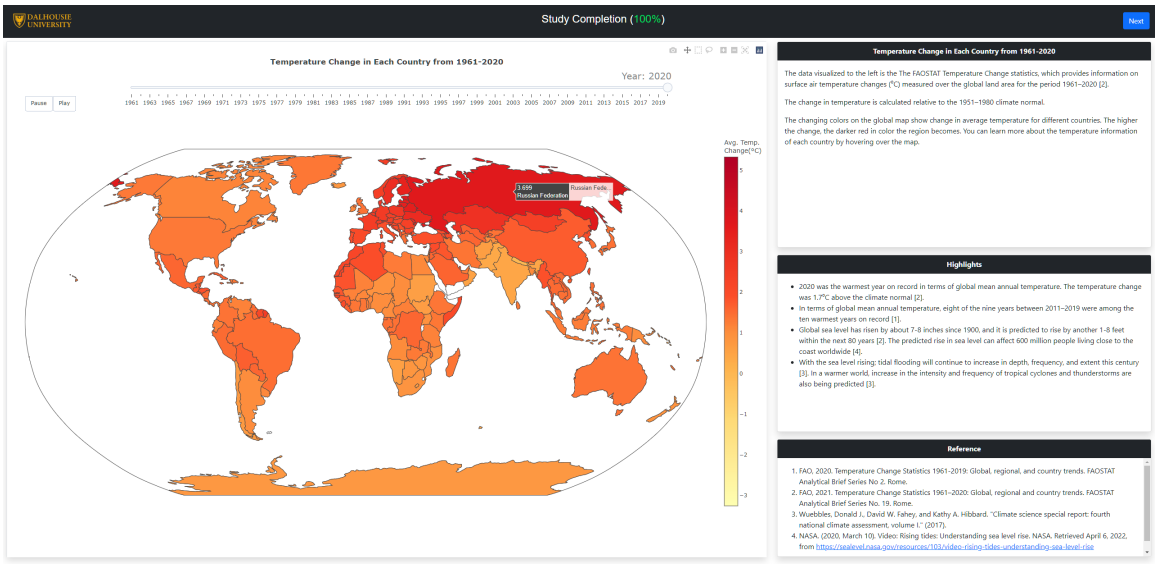

Figure 3.1: Data visualization of world temperature change

3.2.2 Global Temperature Change and Carbon Emission

The next page displayed to the user contained a line chart showing possible correlation between the rising temperature change in global mean temperature, and emission of carbon-based gases, namely, Carbon Dioxide (CO_2) and Methane (CH_4) gases. Increased carbon emission has been considered as a leading cause of warming up the climate, and data showing that carbon emission plays a part in the changing climate has been explored widely in climate research [9] [136] [8] [110] [71]. Moreover, a study on climate related research publications showed that 90%–100% of publishing climate scientists agree that humans play a role in the global warming according to six independent studies [26]. Since our primary goal is to raise awareness about climate change, we need to establish that human activities play a role in this phenomenon, and viewing this in terms of real-world data should work as an evidence for this relation.

The line chart in this page shows three lines depicting the increase of CO_2 and CH_4 gas emissions, and the global mean temperature change over the years 1960-2020, as shown in Figure 3.2. We only showed CH_4 and CH_4 since they are more widely known gases, and to keep complexity of the visualization to minimum. Moreover, reliable data for only those two gases were found that span across for at least 30

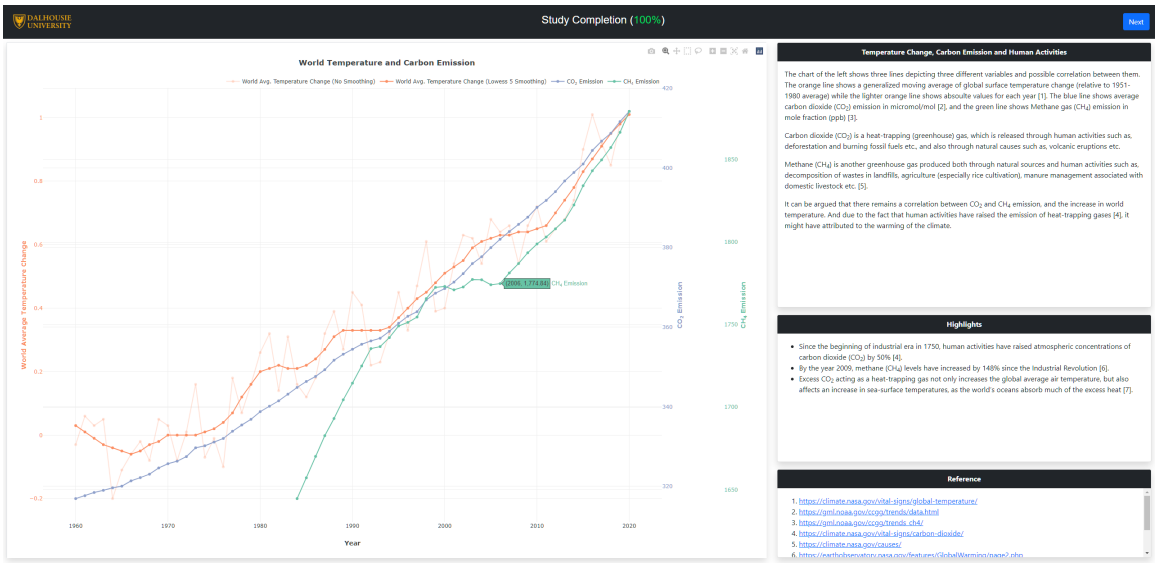

Figure 3.2: Data visualization of temperature change and carbon emission

years. The data used for this visualization was generated by combined effort of National Oceanic and Atmospheric Administration (NOAA) and Scripps Institution of Oceanography [127] [37]. Here, the color for the line charts were selected from a qualitative color scheme from ColorBrewer, since the line charts depict different variables with distinct features. Similar to the previous visualization, description of the data, key points (Highlights section) from the displayed data, and references to the information provided were displayed on the right side of the page. Users had the option to hover over each data point to see the exact values for a given line chart, and could zoom in-out, move, filter lines and select only portions of the data as they seem fit that added interactivity to the visualization.

3.2.3 Social Awareness about Climate Change

The third and last data visualization was focused on raising awareness about climate change based on social influence. As shown in Figure 3.3, this screen illustrated how people across the world have been increasingly getting more active in social media to discuss about climate change related topics. We used the Twitter API [134] to collect the number of posts per year on climate change related topics by searching for posts with hashtags “climatechange”, “globalwarming” and “climatecrisis”. There

are numerous hashtags that have been used to post on climate change, but these hashtags were found to be mostly used and generated satisfactory volume of data. As shown in the stacked bar graph in Figure 3.3, there has been increasing number of posts each year in the Twitter platform, with maximum number of posts in the year 2019, when the "Climate Strike" took place between 20–27 September 2019, leading to an excessive number of posts during that year on climate change.

On the top right side of this page, the description of the data being visualized is provided in textual format. Moreover, one more panel is provided on the lower right corner, where recent posts on Twitter about climate change was displayed that were collected using the Twitter API. We used the hashtag "climatechange" to get most recent posts on the topic, and filtered the posts to keep only original posts and not replies to another post, and discarded all posts that might be sensitive or inappropriate using the filter methods provided by Twitter API. The concept behind this screen was to utilize the *Social Learning* strategy from the PSD model [96], where the system offers means to observe and learn from others who are performing a target behavior. In our implementation, seeing that so many people are partaking in climate related discussion should create a sense of collective awareness towards the climate. The posts on climate change topic mostly involved call to action on dealing with climate issues (e.g., sustainable transportation, industry standards, call for participation in climate awareness related discussions, and shared experiences on climate friendly activities), which would provide the user of our system to learn about ongoing climate discussions from users of Twitter platform. The posts were collected at run-time to show most recent activity on the social media, so each time a user revisits this page they would see updated content making the page's information more dynamic. We also had implemented a backup system to store the most recently fetched posts on our server so that we can display posts to the user regardless of whether the API fails to fetch data from Twitter or not.

Above-mentioned visualizations were aimed to provide data-driven facts, trends and causes of climate change. Following the KI framework, these pages carried out the step of *introducing new ideas*, especially for users who are unaware of the signs of climate change. Moreover, these screens serve the purpose of making the system seem credible by presenting visualized data from trusted sources, since visualizations

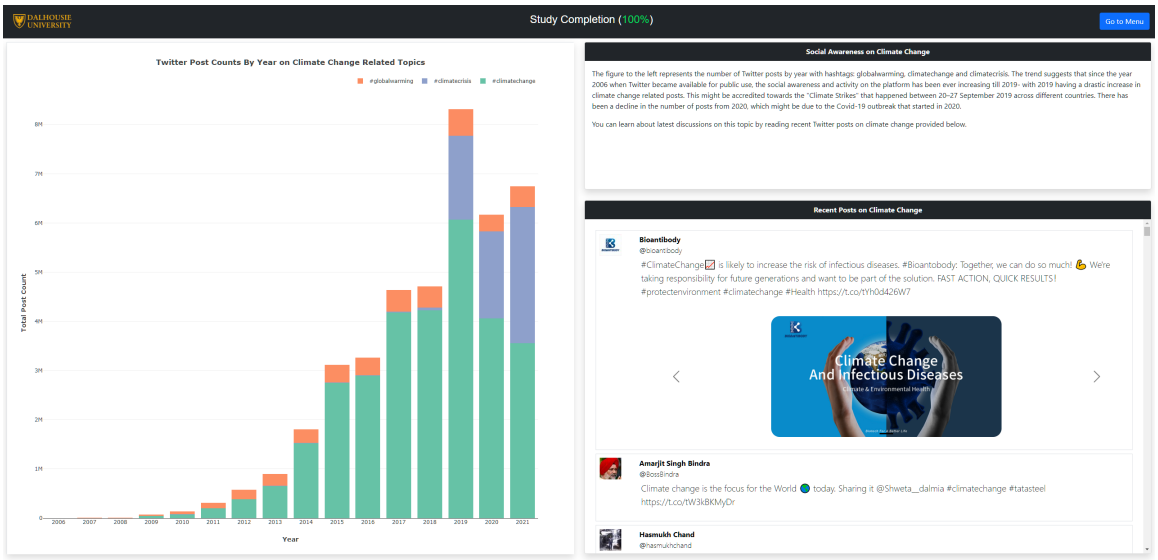

Figure 3.3: Data visualization of Twitter posts, and Twitter data feed on climate change related topics

have been found to increase the credibility of scientific information presentation [126]. Thus, it is reasonable to display the data visualizations as users were introduced to the system.

3.3 Designing the Interactive Narrative

The other primary focus of this research was to utilize interactive narratives in raising awareness about climate change. As discussed in section 2.2, interactive narratives have been successfully employed in teaching, raising awareness and promoting behavior change which led to our implementation of an interactive narrative to encourage climate friendly behavior. Propp [111] identified 31 common structural units in contemporary literature and based on his analysis, an engaging narrative should contain a familiar story-line that progresses in a logical manner, and its characters' behaviors should resemble prototypical behavior. Moreover, in the aspect of learning through narrations, priority of attention tends to lean towards understanding the narrative content over the learning components [112]. Thus, mystical or unrealistic story elements may introduce the risk of distracting players from the educational message

being sent by an interactive narrative, because the player's attention priority may divert to the comprehension of the narrative more than the learning component [112]. Keeping these concerns in mind, and leveraging the fact that we engage in activities that has impact on the environment on a regular basis, the narration of the interactive story game follows a structure that should be familiar to the general public, which involves walking through a regular day in the life of the story's character. Thus. the whole story was designed to be relatable to the general public, and each scenario was designed to reflect the decisions we face in our day-to-day lives that may affect the climate positively, negatively or neutrally. Based on the choices that users make in the narrative, an ending is decided for the story, which shows the fate of the future of the character, and the climate of the in-game world. This establishes the basic characteristic of Role-Playing Games (RPGs) where the story is determined by the player, as seen in popular games starting from traditional Dungeons and Dragons [61] to more recent advanced interactive narrative game like Detroit: Become Human [38]. Elements and scenarios of the interactive narrative is described in detail in the following sections.

3.3.1 Character Creation

The interactive narrative begins by allowing the user to create their own character. This allows the participants to set the protagonist's name, location, profession, workplace and appearance: enabling them to feel more connected to the character and story. The character customization screen is shown in Figure 3.4 and 3.5. The player sets the background of the character such as, name, location and profession which are taken as input in the interactive story as seen in the left portion of Figure 3.4. The participant can also enable voice narration for the story game which would narrate the text displayed in the game using the speech feature embedded within browsers. Moreover, the participant can customize the appearance of their character i.e., choose a gender, skin color and apparel of the main character's avatar as seen in Figure 3.5. The information set in this screen is reflected in the game's scenarios e.g., their name, workplace and profession are mentioned in the story elements, and the designed avatar appears in all of the story scenarios to let participant feel more connected to the story and make it more personalized to each user. This feature of

Figure 3.4: Character Creation Screen– setting character profile

the game follows a common game design element as seen in RPG games which allows players to create their own characters.

After designing the character, the participant is introduced to the story and instructions on how to play the game is displayed. The game involves simple mouse interactions on the web browser, and at the beginning of each scenario the task at hand is explained to the participant. The story of the game is set to walk through a regular day in the life of the protagonist, and facing choices in day-to-day activities that are impactful towards the climate. The participant is instructed to take the decisions on behalf of the protagonist, and based on the decisions taken, the future of the protagonist's life and climate of the in-game world will be determined and shown to the participant. The story can either have a positive or negative ending depending on the decisions made by the participant in the game. After going through the introduction, the participant starts the first scenario in the game.

3.3.2 Kitchen Scenario

The first scenario shows how a regular day begins in the life of the story's protagonist as he/she prepares to leave home to go to work. First, the scene is set by showing a dialogue box that explains what the participant needs to do in this scenario, as

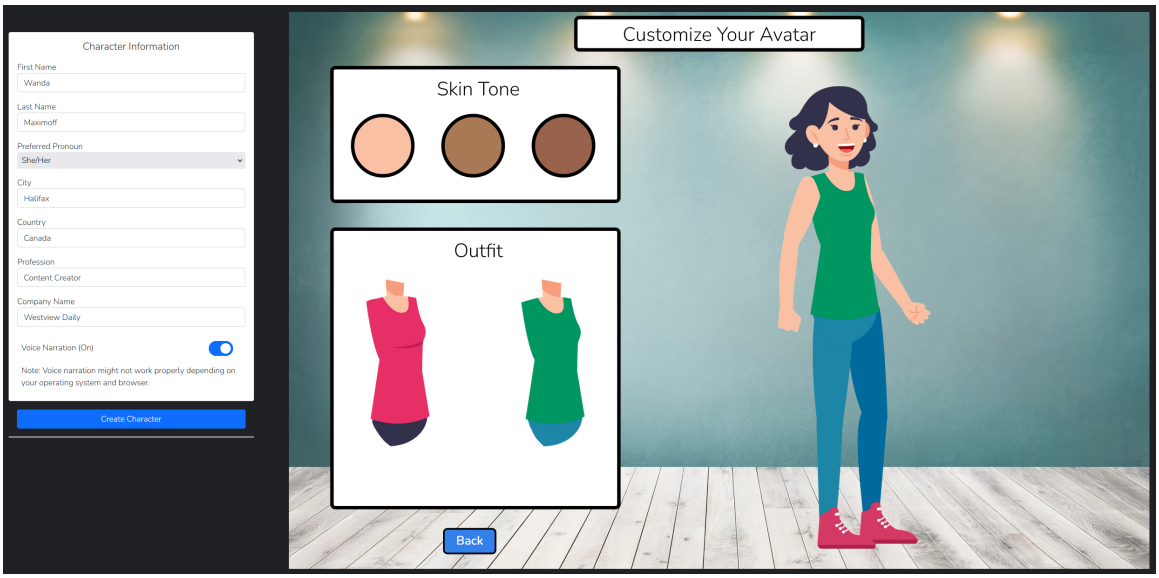

Figure 3.5: Character Creation Screen– customizing selected avatar

shown in Figure 3.6. In this scenario, the participant has to find items that should be turned off before leaving the house, emphasizing the importance of saving energy and resources for the preservation of the climate. There are four items to be turned off: stove, sink tap, coffee machine and the light on the counter, and the participant has to find the items and click on them to turn them off. Items are placed within the screen with subtle indicators such as, steam comes off from the pot above the stove, sink tap leaks water, coffee machine light blinks, and the light above the counter is visible upon inspection of the scene. If the participant finds the items and clicks on them, a point is rewarded which is indicated by popping up a star right beside the item (Figure 3.7). Moreover, a dialogue box pops up from the item's location which is then placed on the top-left corner of the screen. The dialogue box contains information about how turning off an item impacts the climate (e.g., turning off light saves energy and turning off stove not only prevents fire hazards but also saves energy). Here, the participant is given the choice to find all the items or carry on in the story without finding any item. This was allowed to let the participant practice different choices and see how they impact the climate, as the story's ending is determined based on how the participant plays the game. If the participant decides to carry on without finding all items, they are shown a warning with the consequences of their choices.

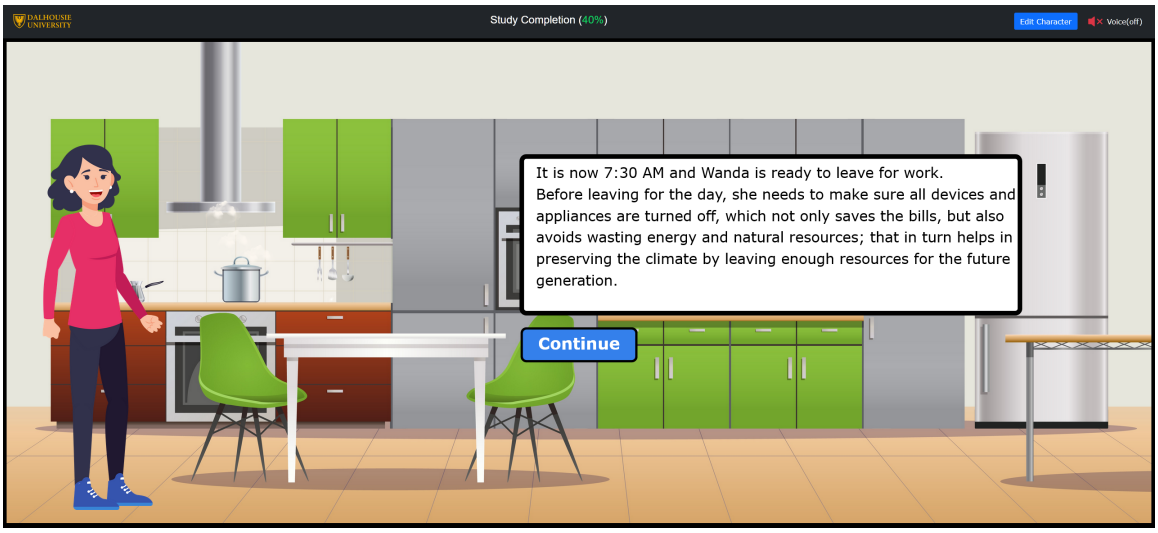

Figure 3.6: The Kitchen Scenario in the interactive story game

The scenario ends if the participant finds all items or decides to carry on regardless of finding any item, and the character then walks towards the end of the screen, which leads to the next scenario.

3.3.3 Garage Scenario

The story's protagonist is now ready to leave for work and arrives in his/her garage. The protagonist is shown to have owned both a car and a bicycle, and also has the option to take the bus to go to work. The participant in this scenario has to decide which transport the character should choose as a daily mode of transportation to go to work, as shown in Figure 3.8. Based on how these different transports can impact the climate, different number of points are awarded to the participant i.e., the most climate friendly option is bike (two points), followed by public transport (one point) and the least climate friendly option is driving the car (no points). As the participant chooses a mode of transportation, points are awarded accordingly, and a justification for the points awarded is shown in a dialogue box (Figure 3.9). The explanation is provided to the participant to share how cars emit carbon-based gases that are believed to be one of the leading causes of climate change, which is why we should avoid driving cars whenever possible. The selected mode of transport is reflected in the story going forward: as animations show the protagonist using the selected vehicle

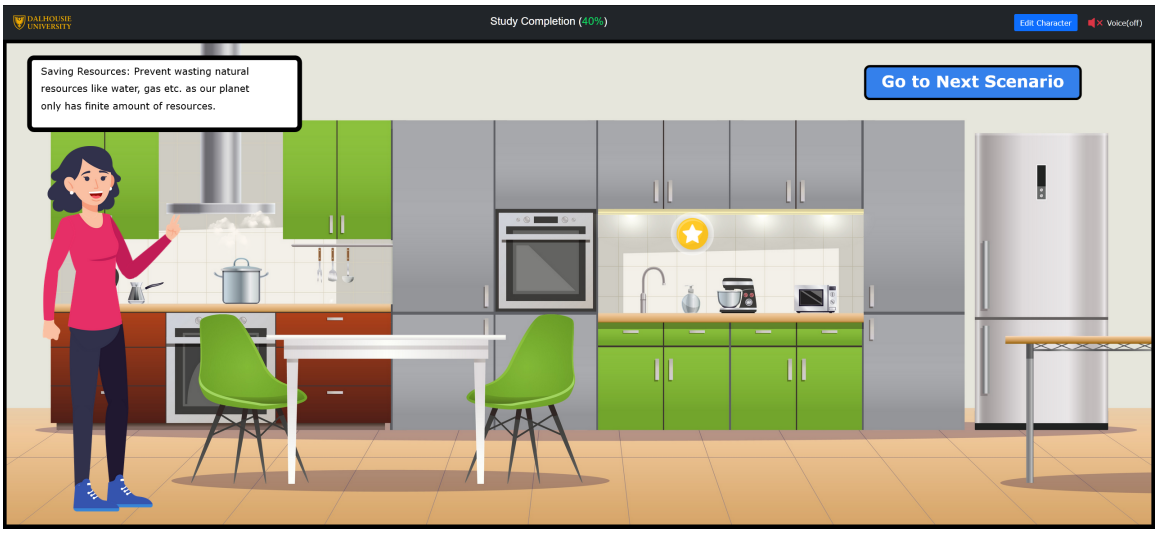

Figure 3.7: Visual cues showing that the participant has earned a point in the interactive story game

to reach work (Figure 3.10). After selecting the mode of transport, the character is shown reaching his/her workplace which starts the next scenario.

3.3.4 Office Scenario

After the protagonist reaches the office, he/she sees a letter from the office administration about implementing a new policy in the workplace as shown in Figure 3.11. The policy addresses the issue of using disposable plastic cups in the workplace and how usage of such cups badly impacts the climate. However, the company does not want to impose a no-plastic-cup policy without the majority's approval, thus, administration is asking all employees to share their opinions on the matter. In this scenario, the participant has to choose one of the three options that reward different amount of points: (1) stop using disposable cups and everyone brings their own reusable flask/cup to the office (two points), (2) stop using plastic cups only if the company provides reusable flasks/cups (one point), or (3) keep using disposable plastic cups regardless of their bad impact on the climate (no point). The participant selects one of the options and confirms their choice, upon which they are rewarded with appropriate number of points and an explanation is provided on how their opinion impacts the climate (e.g., even if companies do not provide reusable cups, it is

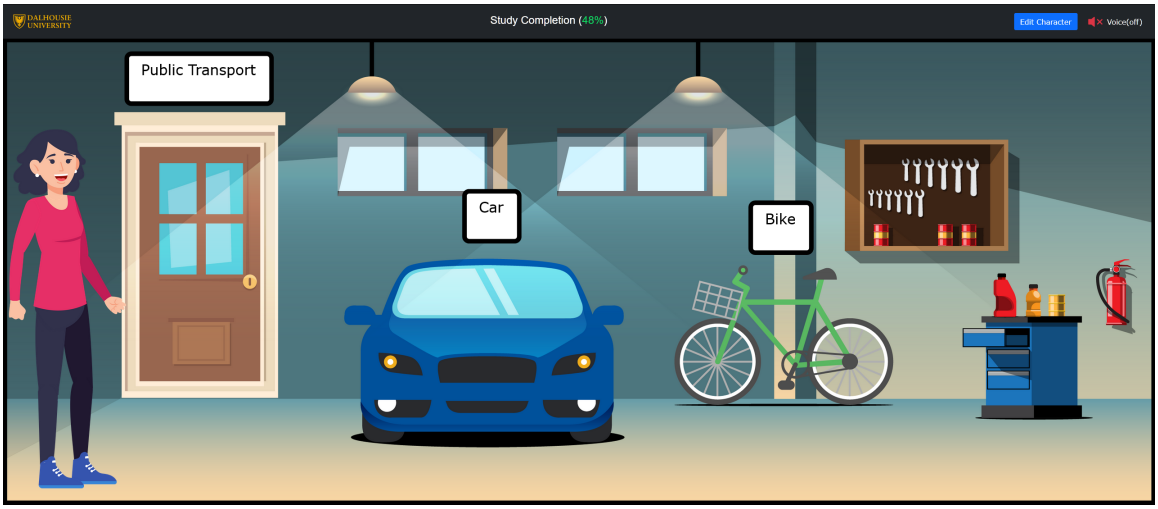

Figure 3.8: The Garage scenario in the interactive story game

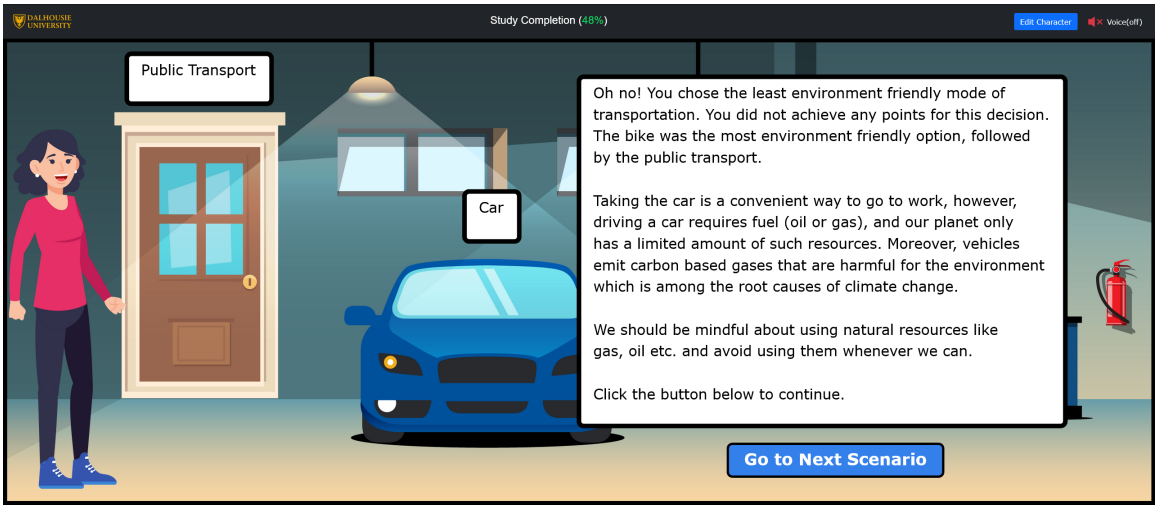

Figure 3.9: Explanations provided for the decisions taken in the interactive story game

Figure 3.10: The interactive story game's character using the mode of transportation chosen by the participant

best practice to use one and bring our own cups to the workplace if needed). After selecting an option, the time in the story fast-forwards to the end of work hours and the protagonist is shown to be leaving the office. The protagonist decides to visit the park after work as the weather is nice outside, which leads to the next scenario.

3.3.5 Park Scenario

After finishing work, the protagonist reaches the park which is a local's favorite and one that the protagonist has been visiting since his/her childhood. While taking a stroll in the park, the protagonist sees a person sitting on a bench and having a smoothie. The person then proceeds to finish the drink and throws it on the ground which upsets the protagonist. We have implemented different facial expressions to show happy, neutral and sad emotions for the protagonist depending on what happens in the scene. As shown in Figure 3.12, the character shows an expression of being upset seeing that the lady dropped the cup on the ground. At this moment, the participant gets to decide what should follow regarding this incident, namely, there are three options to choose from that reward different number of points: (1) ask the person to not litter and explain the bad effects of littering on the climate (two points),

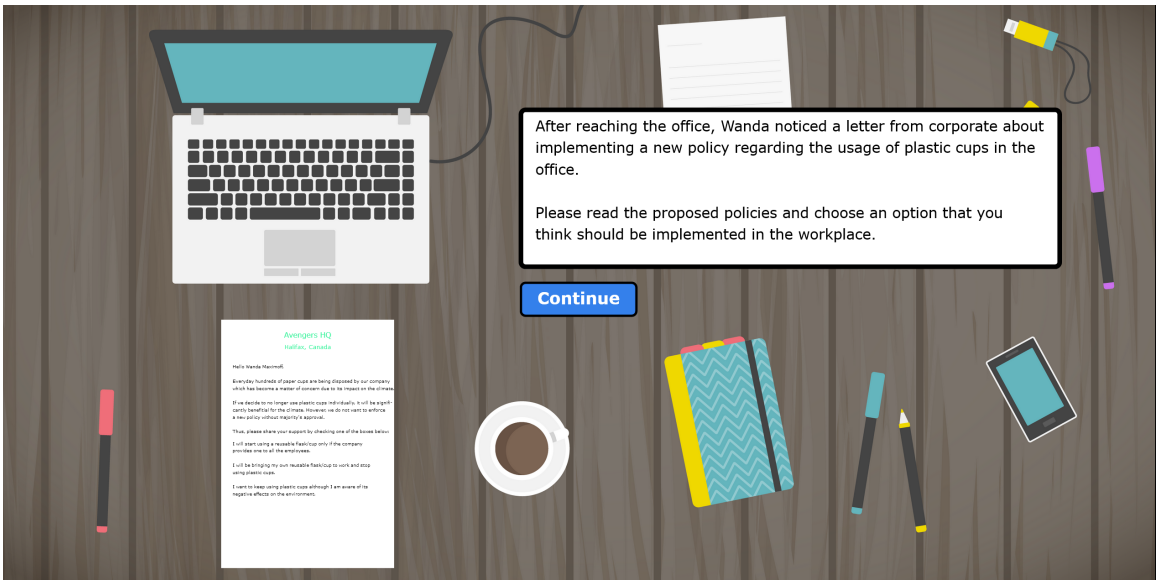

Figure 3.11: The Office scenario in the interactive story game

(2) dispose the item him/herself (one point) and (3) do nothing (no point). Here, we address the importance of following climate friendly behavior with others, and not only follow them ourselves. By choosing the option to share the bad effects of littering to the person in the park, the participant has the option to practice raising awareness about climate change among others. Depending on the option chosen, the protagonist proceeds to perform the action, for example, the protagonist goes to talk to the person which starts a dialogue as shown in Figure 3.13. Then, the story proceeds as the protagonist goes to a grocery store.

3.3.6 Grocery Store Scenario

Before heading back home, the protagonist decides to buy some groceries. This scenario shows that the protagonist has finished shopping and is ready for check-out, that is when the cashier asks how he/she would like to take the items home (Figure 3.14). Here, the participant is given three choices that offer different amount of points: (1) buy a reusable bag for the items (two points), (2) carry the items by hand (one point), and (3) take the items in a disposable plastic bag (no point). Here, buying a reusable bag is the most climate friendly option as even though the protagonist can carry the items by hand now, there will be times when it may not be possible

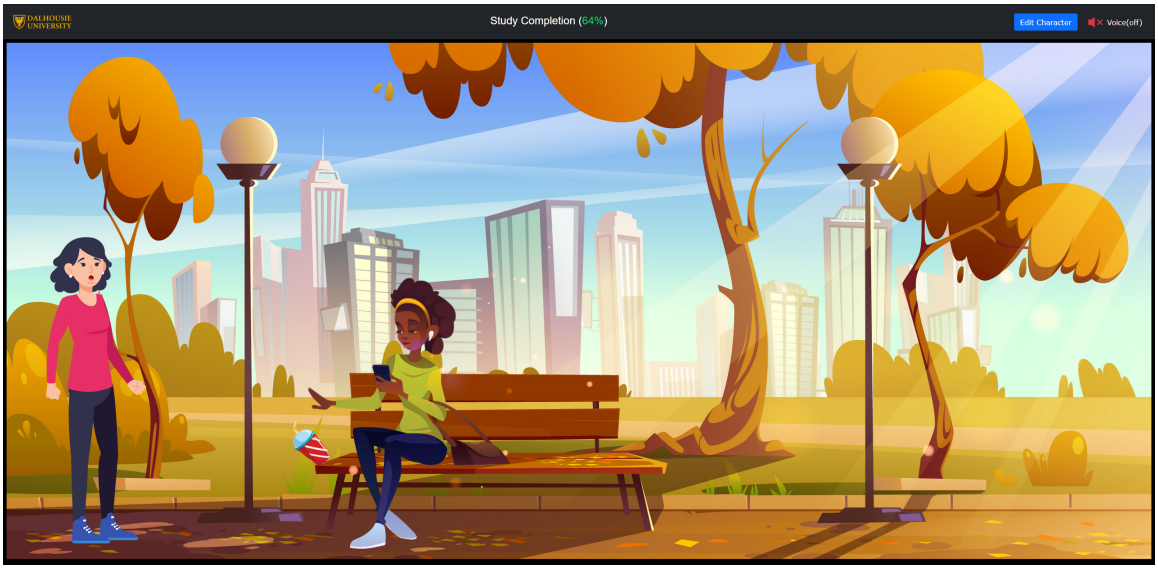

Figure 3.12: The Park scenario in the interactive story game

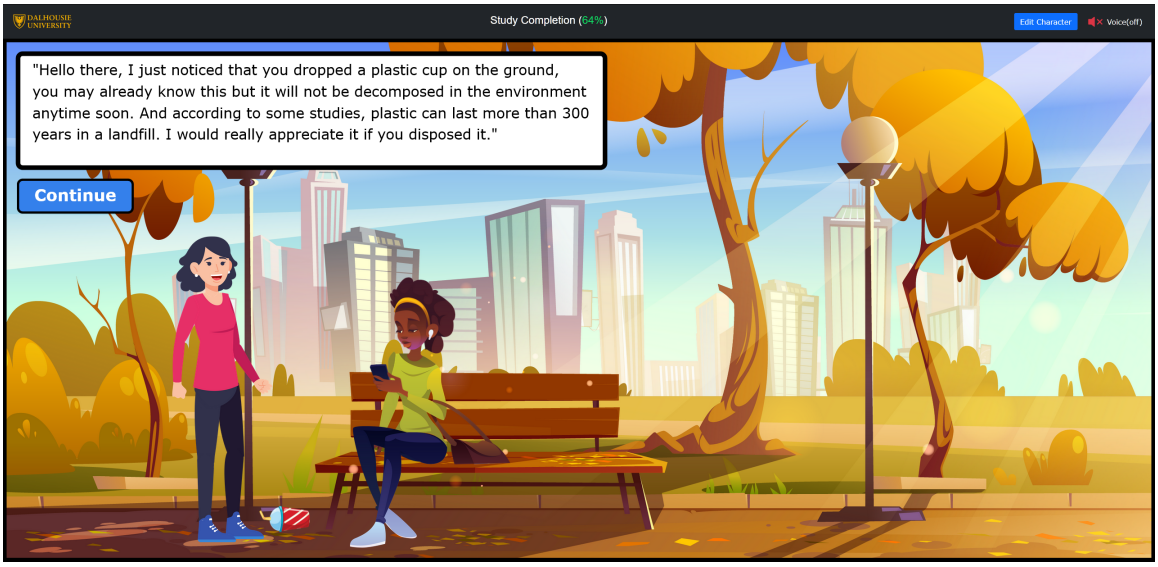

Figure 3.13: Dialogue between characters in the interactive story game

Figure 3.14: The Grocery Store scenario in the interactive story game

to carry all items by hand and using a reusable bag would be preferred. However, to encourage not using plastic bags and taking items by hand if possible, we reward one point for this action. After picking an option, the character proceeds to take the items accordingly and goes back home.

3.3.7 Recycle Scenario

After coming back home, the protagonist decides to do some house cleaning which leads to sorting the garbage items before throwing them out. In this scenario, the participant is given the responsibility of sorting the throw-away items into recycle and garbage bins. This scenario tests the knowledge of recycling of the participants, as they are rewarded for correctly sorting the items. Here, the participant is instructed to drag the items displayed on the screen to either the recycle or garbage bin, that includes different type of common throw away household items such as, milk carton, soda can, coffee cup, cereal box and eight other items as shown in Figure 3.15. After sorting the items, the participant confirms their sorting, and they are shown how many items were correctly sorted. Participants get points for correctly sorted items as shown in Figure 3.16, otherwise they are shown the correct sorting order of the items. This brings to an end of a regular day in the protagonist's life, which also

Figure 3.15: The Recycle scenario in the interactive story game

brings an end to the actions required by the participant in the interactive story game. Based on the actions taken within the game, an ending is now decided for the story.

3.3.8 Story's Ending

Based on the participants' actions throughout the different scenarios and the points earned, an ending is determined for the story. Based on the available points in all of the scenarios, a maximum of 24 points can be collected within the game. A positive ending for the story is determined if the player can earn 80% of the maximum points which leads to 19.2 points, but since fraction of points can not be earned, the threshold to get a positive ending was set to 19 points. If the participant earns more than or equal to 19 points, they get congratulated as seen in Figure 3.17. After the participant is told which ending they have received for the story, the game shows the future of the game's world. Depending on the type of ending earned by the participant, the game's world is shown to have prospered or it gets badly affected by climate, which are generalized reflections of how the participant's actions impacted the in-game environment, considering that the people in general behaved the way the participant played the game. The illustrations shown in the ending involves depictions of the year 2080 and has images that are drawn from the scenarios discussed above,

Figure 3.16: Showing points earned for correctly sorting items in the Recycle scenario of the interactive story game

but are modified to either show a prosperous community in a nice climate or decay in quality of life as it gets badly impacted by the climate.

For the positive ending, the player is shown that the protagonist's community has grown as people in general have been cautious about the climate. To keep consistency and help relate with the game's story better, illustrations for the ending showing a future world were designed to be similar to the illustrations used in the scenarios where the participant interacted with the game. In the positive ending it is shown that the protagonist has raised a family in the same neighborhood he/she was brought up in. The workplace where he/she used to work is shown to have grown and a new generation of employees have joined the workplace while the protagonist has retired from work. Likewise, the grocery store is shown to have prospered as it now serves more customers as the community has prospered. The park shown in the Park scenario (section 3.3.5) is displayed with many people enjoying its still beautiful nature as it remains to be the local's favorite gateway to nature. All the illustrations shown in the positive ending is combined and provided in Figure 3.18, although in the game they are displayed one after another in a slideshow manner, where dialogue boxes with positive messages were included with each illustration.

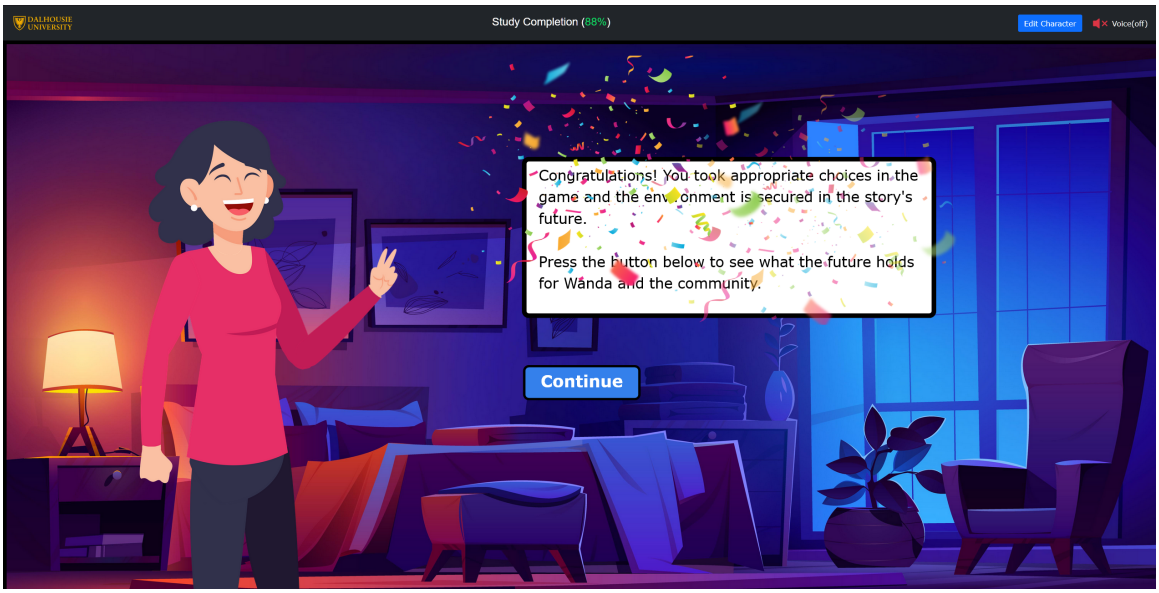

Figure 3.17: Congratulating the participant for achieving the positive ending in the interactive story game

On the contrary, for the negative ending, the illustrations show a future badly impacted by the climate due to people's unfavourable behavior towards the climate. The illustrations show that harsh weather has taken over the protagonist's neighborhood, and due to frequent storms and cyclones it is no longer suitable for living. Thus, the protagonist had to leave his/her hometown and relocate to a different state. The protagonist's workplace is shown to have been abandoned due to it no longer being feasible to conduct their operations in the area. The grocery store is shown to have become dirty and abandoned, as the business shut down since there were not many people left to serve in the neighborhood. Lastly, the protagonist's favorite park is shown to be destroyed by harsh weather, and it is no longer visited by people. The illustrations of the negative ending are shown in Figure 3.19.

After seeing the ending the participant received for the story, the game then also shows the alternate ending, i.e., if the participant receives positive ending, the negative ending is shown as the alternate ending and vice versa. This was done to let the participant learn about how their different choices would have impacted the story. After seeing the alternate ending, the participant gets to the Gameplay Information screen where they see summary of how they played the game which is described in

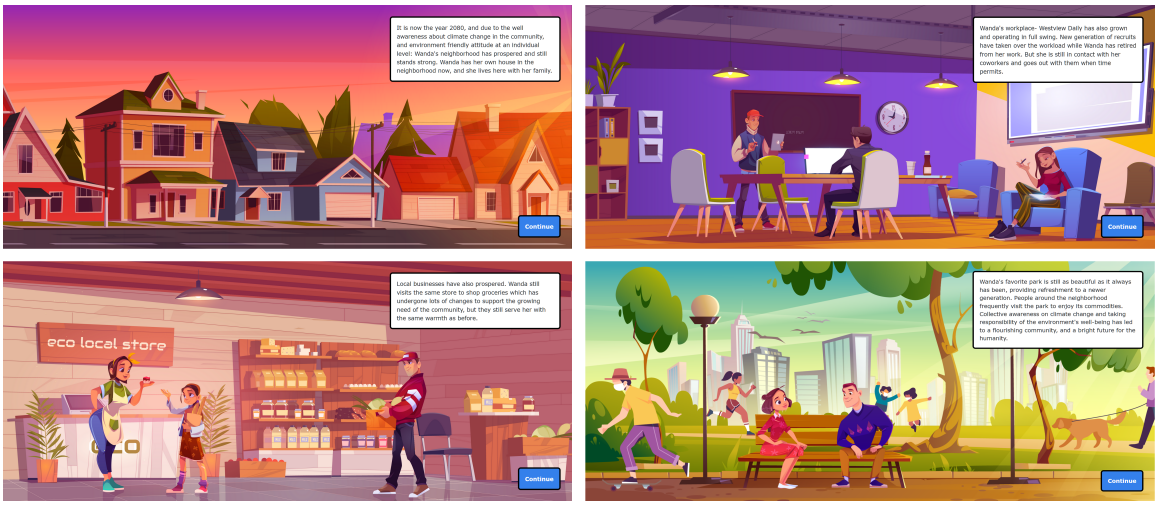

Figure 3.18: Combined screenshots of visuals shown in the positive ending of the interactive story game

the next section.

3.3.9 Gameplay Information

The Gameplay Information screen displays how the participants played the game i.e., the points they have earned or missed in all the scenarios. This is shown to let the participants reflect upon their choices and learn about how they can make better choices. The game allows players to play the story multiple times and encourages them to play the game again by showing them where they missed points. Moreover, the total number of points they earned for each of their playthroughs is shown in this screen, as shown in Figure 3.20. After seeing this screen, the participant sees the Contributors screen.

3.3.10 Contributors

This screen shows the participant how the points they have earned in the game is contributing towards a common goal of raising awareness about the climate. With the title "Let's Make Earth Green", this screen (Figure 3.21) shows the image of planet earth that gets filled in green color based on the points earned by all of the participants from the study. A target of 2,000 points was set for the study, and as participants completed the game, the planet was getting filled in green color.

Figure 3.19: Combined screenshots of visuals shown in the negative ending of the interactive story game

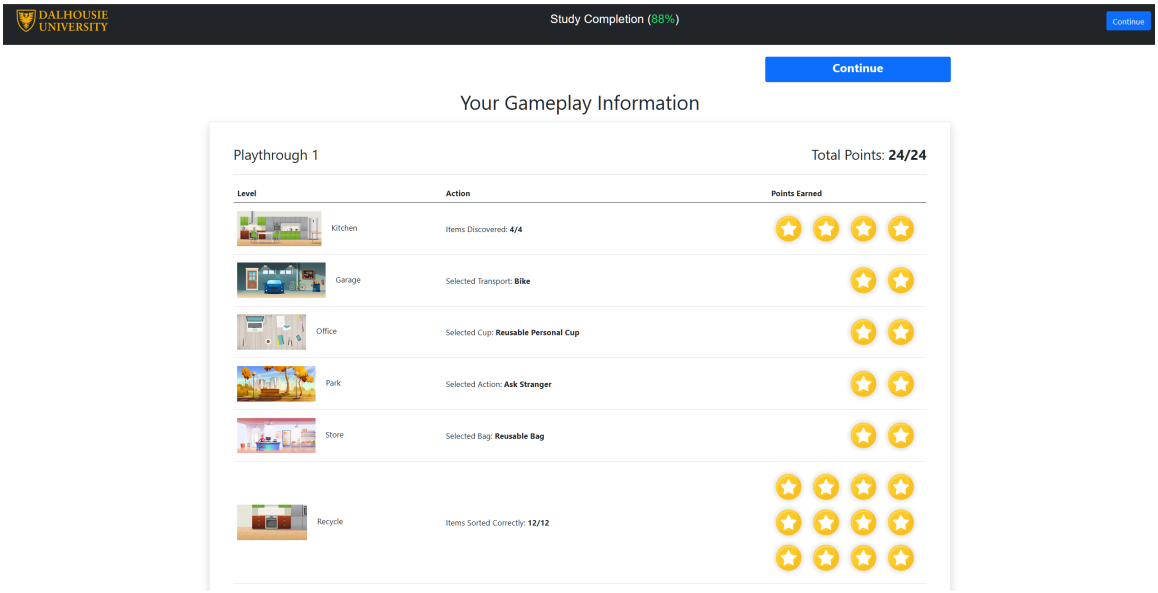

Figure 3.20: Gameplay Information screen

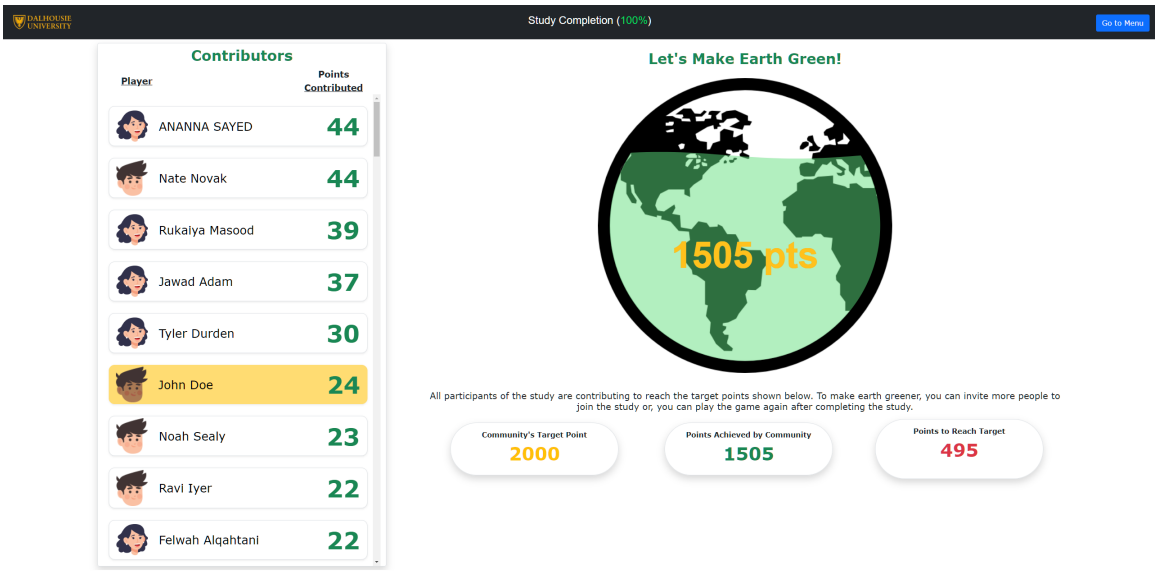

Figure 3.21: Contributors screen

By showing the contributions and progress to reach the common goal, the screen encourages participants to play the game again to contribute more points or invite others in raising awareness about the climate. This screen promotes cooperation, as all the points of the player are contributed towards the common goal of making the earth green. Moreover, a list of the players and their protagonists' names and avatars are shown in the Contributors list, as shown in the left side of Figure 3.21, which helps players to compare their performance with other players. The goal of this screen was to: (1) help players reflect upon their own actions by comparing with others performances, (2) continue contributing and invite more people to join the common goal of raising climate awareness, and (3) to see that saving our climate is a collective effort where everyone has to contribute to save our climate.

This ends all the features of the intervention, and after seeing the Contributors screen the participant fills out the post-intervention questionnaire (Appendix E) and completes the study.

3.4 Implementation of Persuasive Strategies

A total of eight persuasive strategies were implemented to make our system persuasive and promote positive behavior change to mitigate climate change. These strategies

were chosen due to their effectiveness in building persuasive systems as discussed in section 2.3. The strategies and their implementations are mentioned below.

1. **Reduction:** This strategy from the PSD model [96] helps persuade people in reaching a target behavior by reducing the steps and efforts required to reach the target. We used Reduction in the data visualization screens by providing highlights of the visualized data that reduces all the data into a couple of important bullet points and mention them in plain text as shown in Figure 3.1 and 3.2. In addition to providing a way to reduce effort in learning about the information presented in the intervention, this strategy was chosen to help people easily understand the system's content. Since the level of visualization literacy among the general public is low [17], textual descriptions would benefit them who faces difficulty in interpreting the visualizations.

2. **Verifiability:** This strategy from the PSD model [96] enhances the persuasiveness of a system by helping to raise its credibility. It entails providing trusted sources to verify the accuracy and trustworthiness of the system's contents. As our system had visualizations of climate change data, verifiable sources of data and information is crucial in making the visualizations trustworthy. So, we provided references and links to the visualized data and information displayed in the system, as shown in Figure 3.1 and 3.2. Visualizing data from trusted sources is crucial for conveying correct information and building trust among the system's user. Additionally, this strategy was chosen due to its successful implementation in applications addressing public issues such as, disease management [88] [89], mental health [7], waste management [92] and physical activity [6].

3. **Social Learning:** This strategy from the PSD model [96] helps users reach a target behavior by letting them observe and learn from others practicing the same behavior. In our implementation, we wanted to show how people around the globe are practicing and encouraging climate change awareness. We implemented a social feed from Twitter that consists of latest discussions on climate change from people across the world as discussed in section 3.2. Through this feature, we implemented the Social Learning strategy as it allows

participants to learn how others are engaging in climate friendly behaviors. This strategy was chosen due it being one of the primary focuses of other interventions in mitigating climate change problem such as, PEIR (Personal Environmental Impact Report) [85].

4. **Customization:** This is the only persuasive strategy that was implemented outside of the PSD model [96]. The customization strategy identified by Fogg [51] helps users to reach a target behavior by allowing them to relate more to the system by adapting it to suit their preferences. Our implementation of this strategy was shown in Figure 3.4, as it allows the participant to create and customize their own character based on their liking, which is then reflected throughout the story game. In addition to its persuasive effect, this feature is a common practice in RPG games [27] [113] where the player sets the character's background and appearance, thus this strategy was applied in our interactive story game.

5. **Simulation:** The simulation strategy from the PSD model [96] makes a system more persuasive by showing a link between the cause and effect with regards to the target behavior. We simulated the impact of the participant's choices made in the interactive story game on the climate, by demonstrating illustrations of the future of the in-game climate in either a positive or negative manner (section 3.3.8). Simulation has been widely and successfully used in interventions addressing the climate change problem [140] [56] [125], for which we implemented this strategy in our system. Moreover, by simulating the outcome of the actions performed in the game, we intend to let people understand how our day-to-day actions impact the climate.

6. **Social Comparison:** This strategy from the PSD model [96] encourages users to help reach a target behavior by allowing them to compare their own behavior with others who are performing the same behavior. In our system, in the Contributors screen described in section 3.3.10, we show the list of participants and the number of points they have collected by practicing climate friendly behavior within the story game. As shown in Figure 3.21, the list of contributors should encourage the participants in engaging in climate friendly behavior by

observing others contributions. This strategy was implemented to promote positive behavior change by helping the users reflect upon their own behavior by comparing with others, also due to the strategy's successful implementation in applications that promote sustainable transportation behavior [48] [49] which falls under the category of mitigating climate change problems.

7. **Cooperation:** The cooperation strategy from the PSD model [96] makes a system more persuasive by providing means for people to work together in reaching a common goal. The "Let's Make Earth Green" section in the Contributors screen (Figure 3.21) encourages cooperation in reaching a common target goal to collect certain number of points for all participants. This would persuade participants in practicing climate friendly behavior, and also play the game again to contribute more points. This strategy is found in interventions to address climate change such as, "We Are What We Do" [22] "Ecoisland" [125], and since climate change is a collective problem that requires participation of people across the world in mitigating the issue, this strategy was implemented in our system to promote cooperation among the users.

8. **Self-monitoring:** The Self-monitoring strategy from the PSD model [96] suggests providing the users a mean to track their own performance which helps users in performing a target behavior. The Gameplay Information screen as displayed in Figure 3.20 shows the participants the choices they have made in the game and points they have earned or missed, which allows them to learn about their own behavior and encourages improvements by learning from their mistakes. This strategy was implemented due to its wide usage in interventions addressing the climate change problem [49] [85] [56] [14], and to help the users track how their decisions impacted the outcome they received in the interactive story game. By addressing their own gameplay information, participants can both learn about their mistakes which helps them improve their pro-environmental behavior, and helps build positive reinforcement by showing points achieved for making the right decisions for the climate.

With the help of the persuasive strategies implemented, our system aims to achieve its objective in raising climate change awareness and encouraging behavior change to

mitigate climate change. It is important to learn if our system is successful in fulfilling the objectives, also how the system elements played a role in the effectiveness of the intervention. To achieve this we designed a study to evaluate our system which is described in the next chapter.

3.5 Research Questions

For the developed intervention in climate change awareness consisting of data visualizations and interactive narratives, our research goal is to answer the following four research questions:

RQ1: Does the intervention have an effect in raising awareness about climate change?

RQ2: Does the intervention have an effect in promoting positive behavior change to mitigate climate change?

RQ3: What aspects of the intervention design contributed in raising awareness about climate change?

RQ4: What aspects of the intervention design were impactful in promoting positive behavior change to mitigate climate change?

With the above-mentioned questions in mind, an interactive web application was developed and evaluated.

Chapter 4

System Evaluation

To evaluate our developed system, we conducted a quantitative and qualitative study using pre- and post- intervention questionnaires. Conducting this study would help us answer the four research questions mentioned in section 3.5. This chapter describes the design of the study.

4.1 Materials and Procedure

The core element of the study is the web application that includes the data visualizations and interactive story game as described in sections 3.2 and 3.3. We invited participants to use our system and fill-out questionnaires that would help us determine the effectiveness of the system. Before conducting the study, ethics approval was received from the university ethics committee. We created a recruitment notice to invite participants to join our study which included a link that redirected them to our web application. After clicking the link, participants would first see the consent form explaining the system and study process, and only upon agreeing to participate they could start the study. After agreeing to the terms and conditions outlined in the consent form, participants filled out a pre-intervention questionnaire that captured participants' demographics and their climate change awareness, perceived behavior control and willingness to change behavior. Then, the participants went through the data visualizations and played the interactive story game respectively, after which they filled out the post-intervention questionnaire. The study ends with the post-intervention questionnaire and participants are redirected back to the web application where they can continue exploring the system. We asked participants if they would be willing to participate in an optional interview at the end of the study to provide additional feedback on the system. Participants who were willing to participate were contacted to schedule an interview session. The recruitment notice (Appendix B), consent form (Appendix C), pre-intervention questionnaire (Appendix

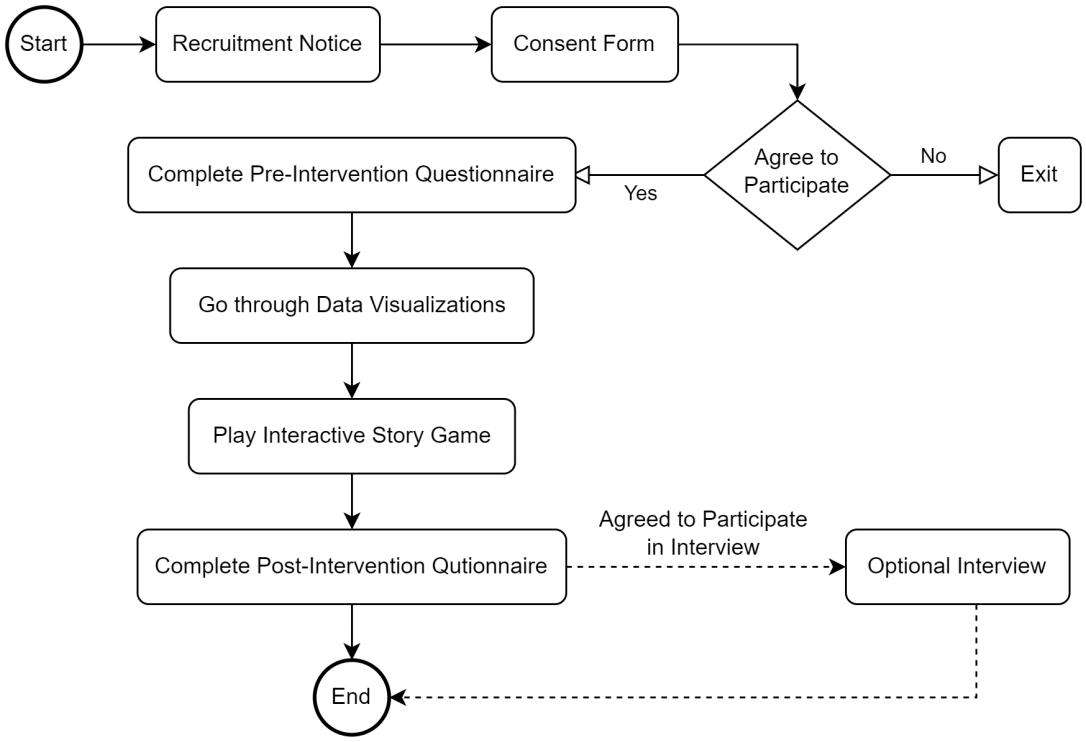

Figure 4.1: Study procedure

D), post-intervention questionnaire (Appendix E), and interview questions (Appendix F) are all included in the appendices section. The steps involved in completing the study is shown in Figure 4.1.

4.2 Measures and Variables

We designed questionnaires consisting of nine scales that would capture feedback from participants about the system and help us answer the research questions mentioned in section 3.5. Among the scales used, the *Climate Change Awareness*, *Perceived Behavior Control* and *Willingness to Change Behavior* were captured in both the pre- and post-intervention questionnaires. These variables would determine the effectiveness of our system in raising awareness and promoting positive behavior change towards mitigating climate change, and help us answer RQ1 and RQ2. Additionally,

we used six scales in our study capturing interactivity, contingency, usability and persuasiveness of our system, participants' defensive response towards the system and their familiarity with data visualizations. These scales would help us analyze the effectiveness of our system design elements and help answer RQ3 and RQ4. For all the measures, participants indicated their level of agreement on a 7-point Likert scale, with 1= "Strongly Disagree" and 7= "Strongly Agree". All the measures used in the study are described below:

1. **Climate Change Awareness:** To measure the participants' level of awareness about climate change, the climate change awareness scale [10] was used that includes four questions. This scale measures how much of a threat participants think climate problems are and whether they believe climate change is a real phenomenon. The questions for this scale were adapted from Arlt et al. [10] (e.g., "Climate change is one of the greatest threats to humankind."). This scale was used both in pre- and post-intervention questionnaire to capture the measure of participants' initial awareness, and any changes to the level of climate awareness due to using the intervention, which would help us answer RQ1.

2. **Perceived Behavior Control:** As a measure of participants' behavior towards climate change, this scale was used before and after going through the intervention to determine the participants' self-efficacy– belief in their ability to perform behaviours that impact the climate. The perceived behavior control scale questions were adapted from Han et al. [62] that consists of three questions capturing individual's perception on how much they believe they have control over a certain behavior, in this case, their control over how their behaviors affect climate change (e.g., "Whether or not I try to mitigate climate change is completely up to me."). In addition to the *Willingness to Change Behavior* scale, this scale would help us answer RQ2.

3. **Willingness to Change Behavior:** This scale aims to capture how willing the participants (i.e., participant's behavior intentions) are to change their current behavior that impact the climate such as, driving, recycling, saving energy, using reusable items and not using disposable items. These five questions map directly to the scenarios presented in the interactive story game (e.g., "I plan to

save household energy to mitigate climate change."), which were adapted from Brody et al. [19] and Jagers et al. [69]. In addition to capturing participants' perceived behavior control, capturing the participants willingness to change behavior before and after going through the intervention helps us measure the participants' behavior change to mitigate climate change, which helps us answer RQ2.

4. **Perceived Interactivity:** The perceived interactivity scale captures how interactive participants found the data visualizations. As increased interactivity helps engage more in the system, a couple of interactive controls for the data visualizations were provided to the participants as discussed in section 3.2. This scale consists of three questions that were adapted from Oh et al. [95] which captures the level of perceived interactivity (e.g., "The climate change data visualizations were interactive."), and help capture the effectiveness of the intervention's design and answer RQ3 and RQ4.

5. **Perceived Contingency:** Perceived Contingency scale measures the level of engagement with the interactive story game. This scale measures the perception of back-and-forth dialogue and feedback of the interactions with the system (e.g., "I felt like I was engaged in an active dialogue with the story game."). This is necessary for heightened user engagement that may lead to desired cognitive, attitudinal, and behavioral outcomes [123]. Since the interactive story game is designed to reflect participants' choices and allowing them to control the story in an interactive manner, this scale would capture if it was effective in imbuing the feeling of connectivity and engagement in active dialogue with the system. Through the five questions in this scale adapted from Sundar et al. [123], this scale would help in answering questions RQ3 and RQ4 by providing insight on the effectiveness of the interactive story game.

6. **Defensive Responses:** The defensive response scale captures how the participants perceive the message conveyed through the intervention and whether they responded defensively to the system (e.g., "I thought the system tried to manipulate my beliefs on climate change."). Participants may have a negative response to the message sent by the intervention, which may be due to their

prior beliefs or, if the message feels exaggerated or forced, all of which can influence how they responded to the contents of the system. This scale has four questions that were adapted from Shen et al. [116] which would aid in answering RQ3 and RQ4.

7. **Familiarity with Data Visualization:** This scale measures the participants' familiarity with data visualizations as it can impact the effectiveness of the visualizations. Participants not experienced in gaining insights from data visualizations may not find them useful and feel overwhelmed by the intervention. This scale asks how familiar participants are with data visualizations (e.g., "I feel confident using visual data to understand information.") which allows us to understand how a participant perceived our data visualizations. The three questions for this scale adapted from Sundar et al. [124] would help us answer RQ3 and RQ4.

8. **System Usability:** The system usability scale was used to determine the intervention's usability aspects such as, ease of use, complexity, learnability, integrity and consistency. This scale consists of 10 questions adapted from Barnum et al. [12] (e.g., "I thought the system was easy to use.") that lead to a usability score for a system. Through this scale we would be able to measure the usability aspects of our system design that would help us answer RQ3 and RQ4.

9. **Perceived Persuasiveness:** The perceived persuasiveness scale measures the effectiveness of the persuasive strategies in persuading the participant towards positive behavior change. The scale has three questions that were adapted from Drozd et al. [39] (e.g., "This feature influences me to be aware of climate change."). This scale which will help us analyze the effectiveness of the eight persuasive strategies that were implemented in the intervention, and help answer RQ3 and RQ4. This scale was used for each of the persuasive strategies implemented in the system that were mentioned in section 3.4. In addition, the participants were also asked to rate the persuasiveness of the whole system using this scale.

All the scales mentioned above are included in Appendix D and E. Apart from the

questionnaires, we also conducted optional interviews to collect additional feedback on the system. The questions in the interview were designed to get unrestricted comments on various aspects of the system, and gain insight on the effectiveness of the system. The interview questions are provided in Appendix F.

4.3 Participants and Recruitment

The study recruitment involved posting a recruitment notice with a link to join the study. The recruitment notice was distributed in university email lists and social media platforms. Additionally, we performed snowball sampling techniques that allowed participants to recruit more people. A total of 100 participants completed the study among which we contacted 20 participants to participate in the interview. To conduct the interviews, interested participants were selected randomly, giving preference to participants who responded to setting a schedule for the interview. Participants were contacted via email to set a schedule for an online meeting. Each interview took between 15-45 minutes to complete, and participant responses were noted down during the interview.

4.4 Data Analysis

The study included collection of both quantitative and qualitative data, and they were analyzed separately using different methods. The quantitative data (collected from questionnaires) were analyzed to draw statistical conclusions, and involved generating graphs and charts for better understanding of patterns and trends. All the analysis and generation of visualizations for the quantitative data was performed using SPSS software [67] and Python programming language [52]. SPSS is a is a powerful tool for analyzing data and performing statistical analysis, for which we used it to perform inferential statistics such as, t-tests and pairwise comparisons. Python programming language has useful packages such as, Plotly [108] for easily creating data visualizations. Thus, we used Python to generate visualizations that complements the statistical findings.

The analysis of qualitative data involved performing thematic analysis [24] on the interview responses. This involved going through all the notes taken during the

interviews, and arranging the responses to themes iteratively. Initially, the themes were generated without much generalization, and after first round of themes, we went through them and combined common themes together to avoid duplication and overlapping of themes. The analysis and the process of combining themes were repeated iteratively until no more themes were overlapping each other and the themes were exhausted (i.e., no more new themes could be generated to report new findings).

In the next section, we describe the results from the analysis of our study data.

Chapter 5

Results

In this section we present the results of the analysis performed on the collected data from the conducted study.

5.1 Demographics

The demographics of our study population is shown in Table 5.1, also an overview of the demographics is illustrated in Figure 5.1. Most of the participants were aged between 23-30 years (42%), while holding a bachelor's degree was the most common minimum level of education (36%) among the participants. The genders of the participants were almost equally split (54% males and 46% females). Majority of the participants' marital status was single (62%). Since our intervention was aimed for the general public, participants of different age groups and genders in the study would help us better analyze the effectiveness of our intervention. We were able to have participants of all intended age groups in our study, although most (83%) of the participants were aged below 40. For the genders of participants, almost equal distribution of male (54%) and females (46%) helps us analyze the effectiveness of our intervention in both of these genders almost equally, but we do not have participants from other genders which would have been helpful in better representation of the general public.

5.2 Quantitative Analysis

To answer all our research questions stated in section 3.5, we conducted different statistical analysis on the quantitative data collected from the study. An alpha level of 0.05 was set for all statistical tests. The results from our quantitative data analysis are provided in the following sections.

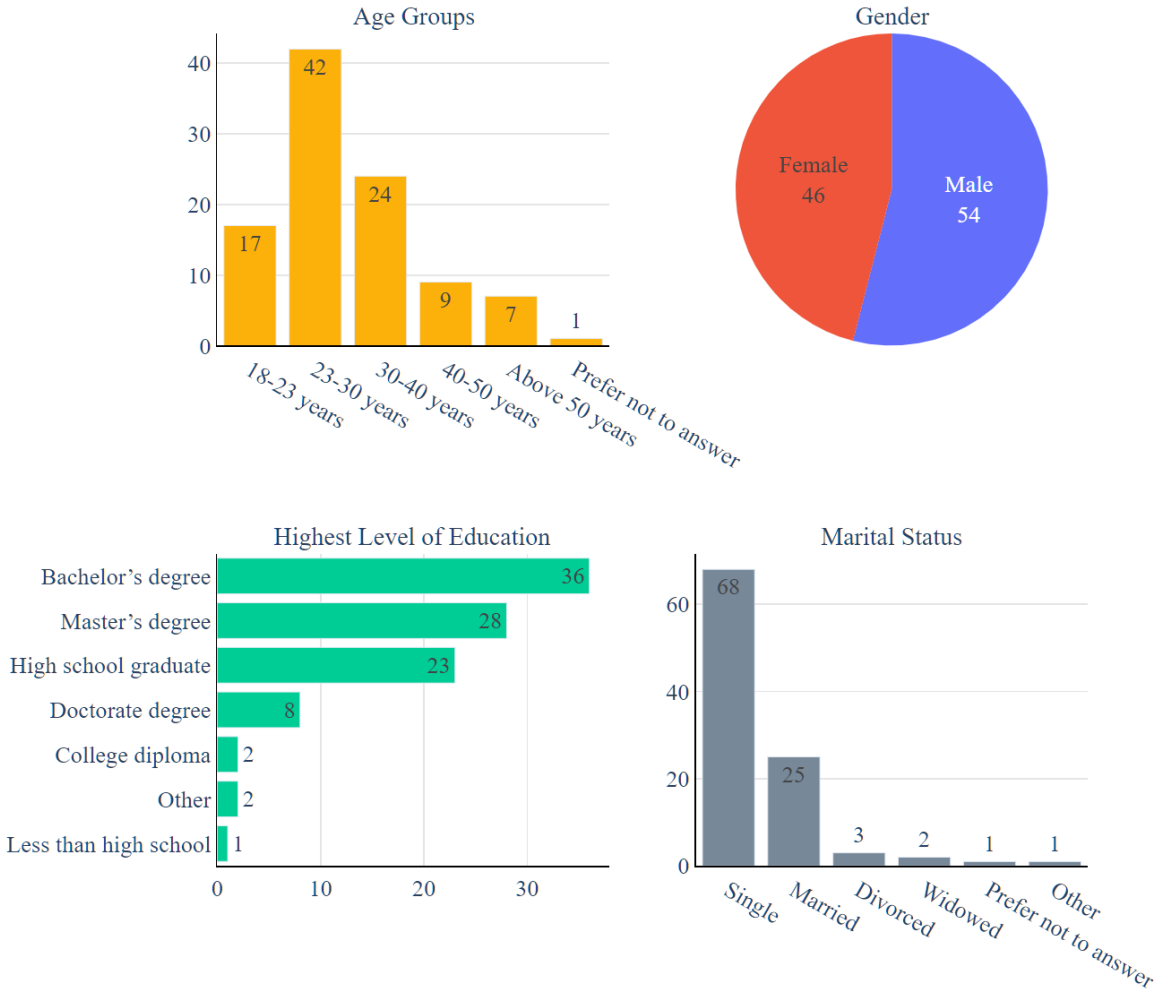

Figure 5.1: Overview of the demographics of study population

Demographic Factor		n (%)
Gender	Male	54 (54%)
	Female	46 (46%)
	Prefer not to answer	0 (0%)
	Other	0 (0%)
Age Groups	18-23	17 (17%)
	23-30	42 (42%)
	30-40	24 (24%)
	40-50	9 (9%)
	Above 50 Years	7 (7%)
	Prefer not to Answer	1 (1%)
Highest Level of Education	Bachelor's Degree	36 (36%)
	Master's Degree	28 (28%)
	High School Graduate	23 (23%)
	Doctorate Degree	8 (8%)
	College Diploma	2 (2%)
	Other	2 (2%)
	Less than High School	1 (1%)
Marital Status	Single	68 (68%)
	Married	25 (25%)
	Divorced	3 (3%)
	Widowed	2 (2%)
	Prefer not to Answer	1 (1%)
	Other	1 (1%)

Table 5.1: Frequency and percentage of the demographics of study population

Scale	Condition	Mean	Median	Std. Dev.	Skewness	Shapiro-Wilk (p)
Climate Change Awareness	Pre	5.98	6.25	1.08	-1.32	0.00
	Post	5.98	6.50	1.19	-1.23	0.00
Perceived Behavior Control	Pre	4.53	4.67	1.54	-0.38	0.01
	Post	5.16	5.67	1.49	-0.86	0.00
Willingness to Change Behavior	Pre	5.43	5.80	1.25	-1.10	0.00
	Post	5.93	6.20	1.22	-1.70	0.00

Table 5.2: Descriptive statistics of climate change awareness, perceived behavior control and willingness to change behavior variables

5.2.1 Analysis of Climate Change Awareness, Perceived Behavior Control and Willingness to Change Behavior

The *Climate Change Awareness* scale was used to measure the level of climate change awareness, while *Perceived Behavior Control* and *Willingness to Change Behavior* scales were used as measures of behavior change towards mitigating climate change of the participants. Responses to this scale was captured before and after using the system. These scales together help us analyze the effectiveness of the intervention, and answer RQ1 and RQ2. All these variables were measured in 7-point Likert scale, where the neutral value is four. To analyze these scales, first we computed their descriptive statistics, results of which is presented in Table 5.2. Second, we performed one-sample t-test to measure statistical significance of the responses to these scales (Table 5.3). Third, we performed paired-sample t-test to measure the significance of the changes to the responses of these scales from pre- to post-intervention conditions (Table 5.4).

Observing Table 5.2, we can see that all the scales reported higher than neutral mean value in both pre- and post-intervention condition. The mean value for the *Perceived Behavior Control* and *Willingness to Change Behavior* scales increased from pre- to post-intervention condition, however, the mean value did not change for *Climate Change Awareness* scale. Figure 5.2 illustrates boxplot of the scales, where we see increase in median value across all the scales, along with increase in first and third quartiles from the pre- to post intervention condition. The *Willingness to Change Behavior* scale shows the maximum increase in its quartiles, showing that participants rated the responses more positively in post-intervention for this scale.

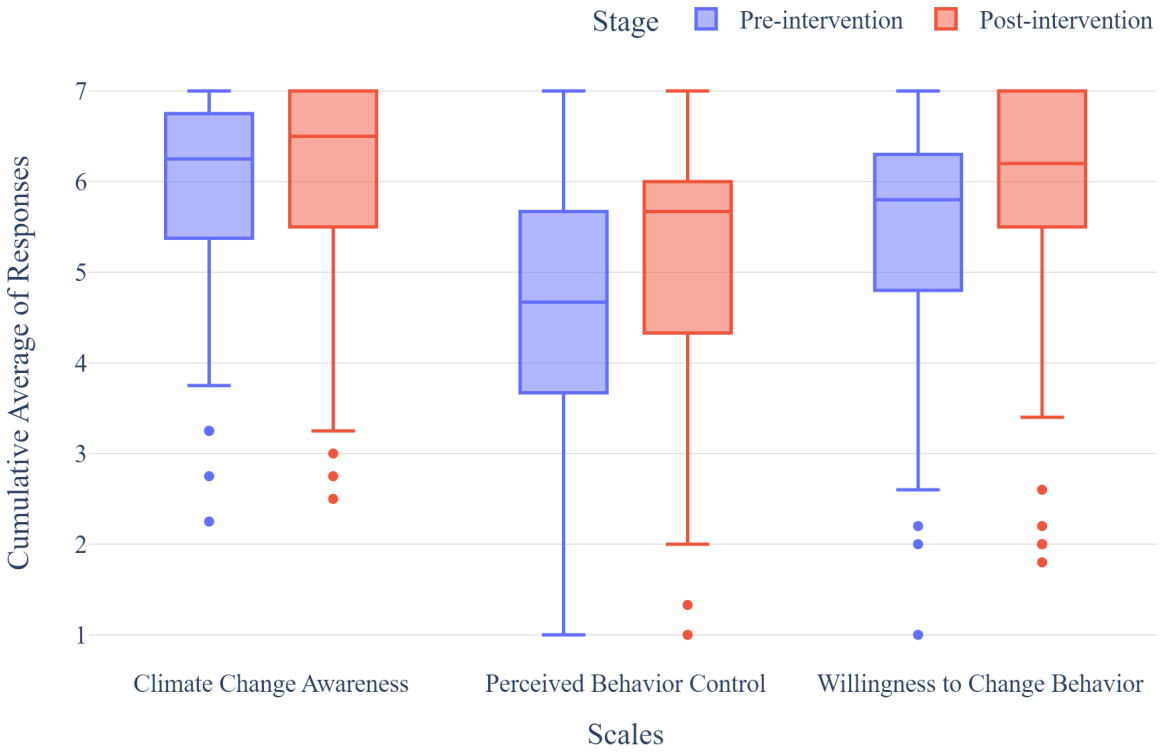

Figure 5.2: Boxplot of climate change awareness, perceived behavior control and willingness to change behavior scales

However, we see the most increase in median value for *Perceived Behavior Control* scale. Analyzing the boxplot affirms the observations of the descriptive statistics, as we do not see much change in responses for *Climate Change Awareness* scale from pre- to post-intervention condition, but increase in positive responses is observed for *Perceived Behavior Control* and *Willingness to Change Behavior* scales.

The descriptive statistics do not provide us with statistical significance of the higher than neutral mean value for the scale. To find out if their is statistical significance in the difference from the neutral values, we performed one-sample t-test for the scales in pre- and post-intervention conditions. Results from one-sample t-test showed that the higher than neutral mean value for all these scales were statistically significant, with $p\text{-}value<0.05$ (Table 5.3).

In addition to observing the statistical significance from one-sample t-test, we want to find the statistical significance of the differences in the mean values for the scales between pre- to post-intervention conditions. Statistically significant difference

Scale	Condition	t	p	df
Climate Change Awareness	Pre	18.24	0.00	99
	Post	16.5	0.00	99
Perceived Behavior Control	Pre	3.42	0.00	99
	Post	7.77	0.00	99
Willingness to Change Behavior	Pre	11.51	0.00	99
	Post	15.88	0.00	99

Table 5.3: One sample t-test of the climate change awareness, perceived behavior control and willingness to change behavior variables

Scales	Z	p
Climate Change Awareness	-1.099	0.27
Perceived Behavior Control	-5.204	0.00
Willingness to Change Behavior	-5.691	0.00

Table 5.4: Wilcoxon signed-rank test results

from pre- to post-intervention condition would help us determine if the system was able to bring significant positive changes to the participants in terms of climate change awareness and positive behavior change to mitigate climate change. To achieve this, we performed paired sample t-tests. Although the responses were captured in Likert scale consisting of ordinal data, we performed parametric tests for the mean values because such tests have been found effective in analyzing Likert scales [122]. The results from paired-sample t-tests showed that the increase in mean value for the *Perceived Behavior Control* and *Willingness to Change Behavior* scales from pre- to post-intervention condition was statistically significant, with $p\text{-}value<0.05$ (Table 5.4). This shows that the intervention was effective in promoting positive behavior change to mitigate climate change among the participants. However, the lack of significance for the *Climate Change Awareness* scale in paired-sample t-test ($p\text{-}value=0.27$) shows that the intervention did not raise awareness on climate change with significance.

Together, the results from these scales enabled us to determine the effectiveness of our intervention, we describe findings from the analysis of these scales in more detail below.

5.2.1.1 Climate Change Awareness

The *Climate Change Awareness* scale captured the level of awareness about climate change. First, by looking at the descriptive statistics in Table 5.2, we can see that *Climate Change Awareness* mean value did not change from pre- to post-condition. The higher than neutral mean value (M = 5.98) for the pre-intervention condition shows that most participants were already aware of climate change. The highly negative skewness value of the *Climate Change Awareness* scale indicates that the distribution of the responses is not normal, and that the responses are more distributed towards the positive end of the scale from the mean value.

Table 5.3 illustrates the result of the one-sample t-test for the scale, where we the *p-values* being less than 0.05 shows that the above neutral average values for the scale in pre- and post-conditions are statistically significant. Considering in the post-intervention condition we saw high average value (M = 5.98) for *Climate Change Awareness* scale, the statistical significance from one-sample t-test is a positive outcome for our intervention, showing that the overall awareness about climate change among participants after using the intervention was significantly high.

Before performing the paired-sample t-test to determine statistical significance of the changes in mean value between the conditions, we need to determine if the distribution is normal for the responses to the scale. The high negative skewness as seen in Table 5.2 shows that the distribution is not normal for the scale, however, to confirm the fact we performed the Shapiro–Wilk normality test on the scales which resulted in a *p-value* of less than 0.05 for the scale (Table 5.2). This rejects the hypothesis that the distribution of responses for this scale is normal. Thus, since the distribution of scales is not normal, we performed a non-parametric paired sample t-test i.e., Wilcoxon signed-rank test, results of which are provided in Table 5.4. Results show that *Climate Change Awareness* scale did not have any statistical difference from pre- to post-intervention condition ($p = 0.27$), which was also indicated from the descriptive statistics. This helps us answer RQ1: the intervention did not increase overall climate change awareness among the participants.

The statistical analysis on the *Climate Change Awareness* scale helped us understand the overall responses to this measures, and the effect of our system on

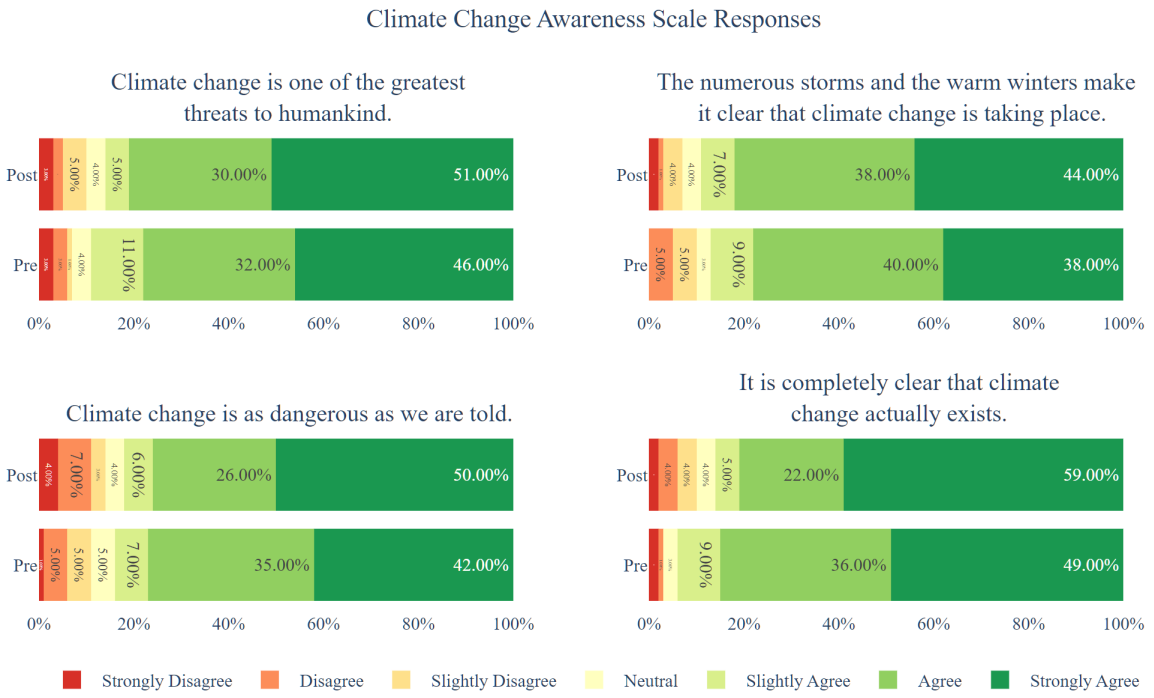

Figure 5.3: Frequency distribution of responses to climate change awareness scale

participants' climate change awareness. Additionally, we want to further explore responses to each of the questions of this scales to get a better understanding of the participants' responses. To achieve this, we analyzed the frequency distribution of the responses to each of the questions for this scale individually by creating stacked bar plot.

Figure 5.3 illustrates how all participants responded to each of the questions of the *Climate Change Awareness* scale during the pre- and post-intervention conditions. The figure illustrates that across all questions, there is an increases between 5-10% in the *Strongly Agree* responses from pre- to post-intervention condition. The question "It is completely clear that climate change actually exists" saw a 10% increase for the *Strongly Agree* responses, but it also saw increased numbers in negative responses in the post-intervention responses. Increase in *Strongly Agree* responses indicates that the system increased strong positive agreement on climate change awareness. But there are increases in negative responses in some of the post-intervention responses, which may indicate that some participants had responded defensively towards the intervention. Moreover, although all the questions of this scale saw an increase in

Strongly Agree responses in the post-intervention condition, none of the questions showed overall increase in positive responses which aligns with the finding from the paired sample t-test analysis that there was no significant difference from pre- to post-intervention condition. However, this helps us answer RQ1: the intervention increased strong positive agreement towards climate change awareness among the participants.

5.2.1.2 Perceived Behavior Control

The *Perceived Behavior Control* scale was used as a measure of self-efficacy to perform climate friendly actions among the participants. Table 5.2 shows the descriptive statistics of responses to the *Perceived Behavior Control* scale. By looking at Table 5.2, we can see that the mean value increased from pre- (M = 4.53) to post-intervention condition (M = 5.16) for this scale. In the pre-intervention condition, the mean value was near to the neutral value four, which increased towards the positive end of the scale in post-intervention condition. Moreover, in the pre-intervention condition of the scale is not highly skewed (-0.38), but in the post-intervention it got highly skewed (-0.86) which shows that the responses got more distributed towards the positive end of the scale from the mean value in post-intervention condition.

Table 5.3 illustrates the result of the one-sample t-test for the scale, where $p<0.05$ for both pre- and post-conditions show that the higher than neutral mean values in both conditions is statistically significant. This is a positive outcome for our intervention, showing that the overall perceived behavior control to perform climate friendly actions was significantly positive among participants after using the intervention.

The Shapiro–Wilk normality test on the *Perceived Behavior Control* scale resulted in a *p-value* of less than 0.05 (Table 5.2), rejecting the hypothesis that the distribution of responses for the scale is normal. So, we performed the Wilcoxon signed-rank test, results of which are provided in Table 5.4. Results show that there is a statistical difference for the increased mean value from pre- to post-intervention condition for the *Perceived Behavior Control* scale. This helps us answer RQ2: the intervention is significantly effective in promoting self-efficacy of participants in performing pro-environmental behavior.

Now, we further explored the responses to the *Perceived Behavior Control* scale by

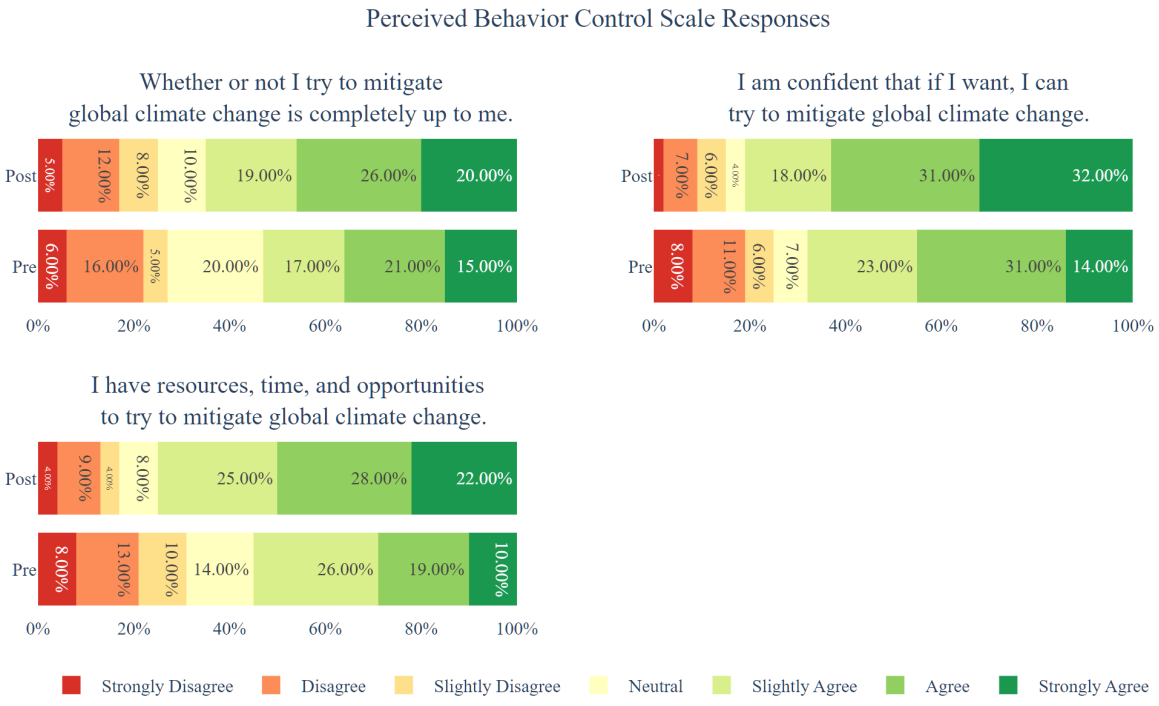

Figure 5.4: Frequency distribution of responses to perceived behavior control scale

looking at the frequency distribution of the responses to all the questions for this scale. Looking at Figure 5.4, we see that in contrary to responses to the *Climate Change Awareness* scale, there is increase in positive responses (12-20%) across all questions in the post-intervention condition, especially in the question "I have resources, time, and opportunities to try to mitigate global climate change" which has 20% more positive responses than in the pre-intervention condition. Also, for *Perceived Behavior Control* scale there are higher number of negative responses both in pre- and post-intervention conditions than *Climate Change Awareness* scale questions. This shows that participants from our study had considerably less perceived behavior control to mitigate climate change than their level of awareness about the phenomenon. Increase in overall positive responses to the *Perceived Behavior Control* scale show that participants' perceived more control over their behavior that can impact climate change after using the system, which is a desired effect of our system. Moreover, increased perception on their behavior control will help them bring change to their behavior to be more positive towards climate change. The findings align with the paired sample t-test where we saw significant differences from pre- to post-intervention

condition, and confirms that the system had a more positive effect on participants' perceived behavior control.

5.2.1.3 Willingness to Change Behavior

The *Willingness to Change Behavior* scale was used to measure participants' behaviour intention towards performing pro-environmental behavior. Table 5.2 shows the descriptive statistics of responses to the *Willingness to Change Behavior* scale, looking at which we can see that the mean value increased from pre- (M = 5.43) to post-intervention condition (M = 5.93) for this scale. In the pre-intervention condition, the mean value relatively high (M = 5.43), which shows that most of our participants had positive behavior intention towards mitigating climate change. Also, in both pre- and post-intervention condition the skewness is highly negative, showing that most responses are distributed towards the positive side of the scales from the mean value.

The results of one-sample t-test for the scale reported $p<0.05$ for both pre- and post-conditions (Table 5.3), showing that the higher than neutral mean values in both conditions is statistically significant. This is a positive outcome for our intervention, showing that the overall willingness to change behavior for a positive impact on the climate among the participants was significantly high among participants after using the intervention.

The Shapiro–Wilk normality test on the *Willingness to Change Behavior* scale resulted in $p<0.05$ (Table 5.2), rejecting the hypothesis that the distribution of responses for the scale is normal. Thus, after performing Wilcoxon signed-rank test, the results show that there is a statistical difference for the increased mean value from pre- to post-intervention condition for this scale. This helps us answer RQ2: the intervention is significantly effective in promoting behavior intention of participants in performing pro-environmental behavior.

Observing the frequency distribution of responses to the *Willingness to Change Behavior* scale we see similar findings as the *Perceived Behavior Control* scale, where there is an increase in positive responses (7-16%) from pre- to post-intervention condition across all questions. Moreover, similar to *Climate Change Awareness* scale responses, there is not many negative responses in the pre-intervention questions for

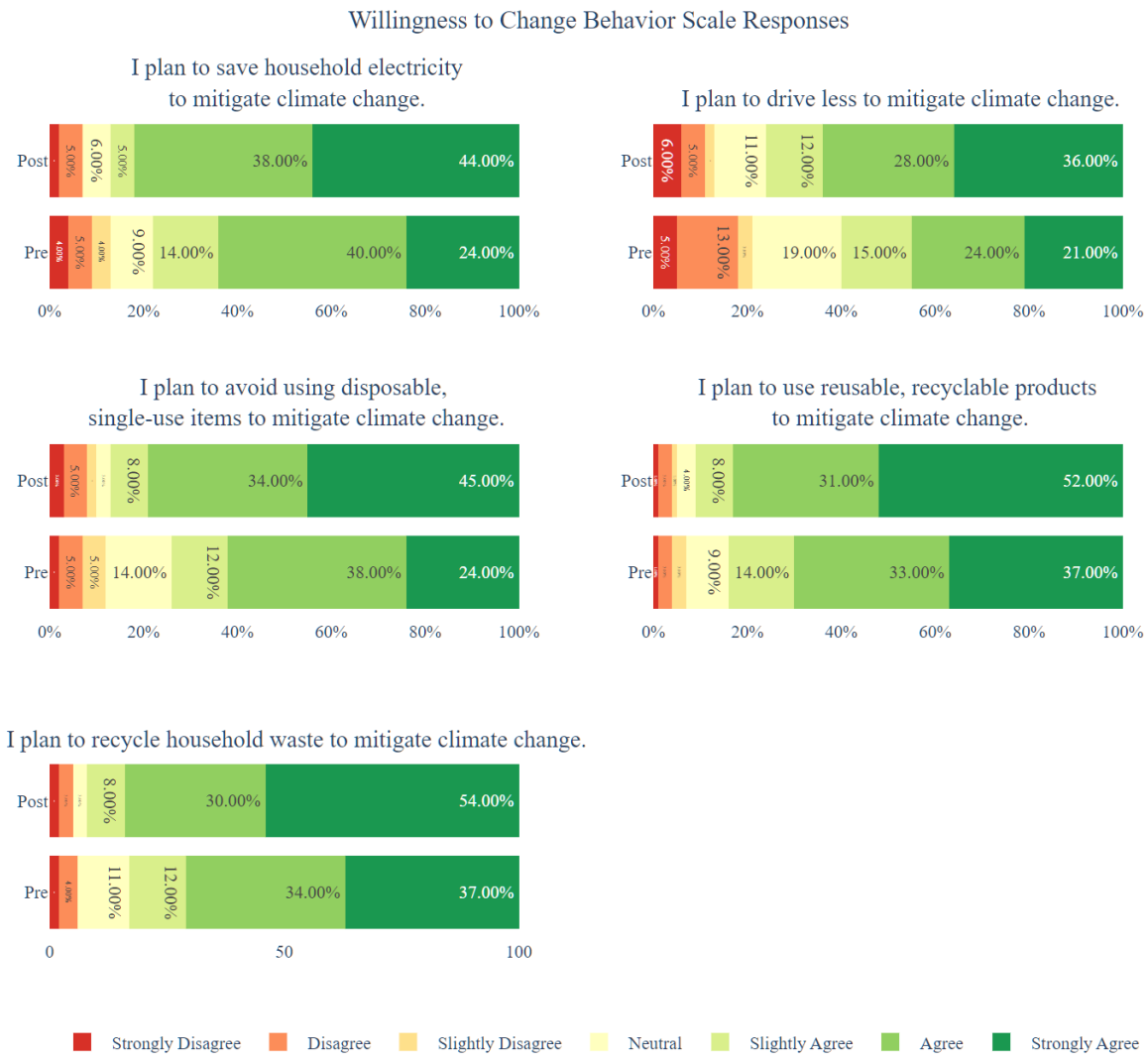

Figure 5.5: Frequency distribution of responses to willingness to change behavior scale

the *Willingness to Change Behavior* scale, which shows that most participants from our study were already practicing or were willing to perform climate friendly actions. Although in the pre-intervention condition there were mostly positive responses, we still see increase in positive responses in the post-intervention condition, especially for the question "I plan to drive less to mitigate climate change", participants rated 16% more positive responses in the post-intervention condition. Increase in overall positive responses for this scale helps us answer RQ2, and shows that the system was able to motivate the users in willing to change their current behaviors to mitigate climate change, which is a desired outcome of our intervention. Moreover, in spite of having high volume of positive responses during the pre-intervention condition, increase in positive responses shows that the system was able to motivate participants who were already practicing such behaviors to be more active in following climate friendly actions.

Overall, the system did not significantly raise awareness about climate change, but it was able to increase *Strongly Agree* responses to the *Climate Change Awareness* scale, which reflects the system's positive effect on increasing strong positive opinion on climate change awareness. This answers our RQ1, and shows that the system has potential in raising strong positive agreement on climate change awareness, but we need to bring new improvements to help reduce negative responses on climate change awareness. Additionally, the results show that our system was effective in significantly increasing participants' perceived behavior control and willingness to change behavior to mitigate climate change, which answers our RQ2 and supports that the intervention has a significant effect in promoting positive behavior change towards mitigating climate change.

In the next section, we analyze the rest of the measures captured in our study. This enables us to identify the design aspects of the systems that were effective in raising awareness and promoting positive behavior change towards mitigating climate change, and help us answer RQ3 and RQ4.

5.2.2 Analysis of Familiarity with Data Visualization, Defensive Responses, Perceived Interactivity and Contingency, and System Usability

As described in section 4.2, we captured participants' familiarity with data visualizations, defensive responses towards the intervention, perceived interactivity, contingency and usability of the system. These scales would help us analyze the effectiveness of different design aspects of our system. All of these variables were also captured in 7-point Likert scales, and similar to the process followed in section 5.2.1, we first want to investigate the data using descriptive statistics.

Table 5.5 shows descriptive statistics for the *Perceived Interactivity*, *Perceived Contingency*, *Defensive Responses*, *Familiarity with Data Visualization*, and *System Usability* scales. The mean and median values for all those scales are higher than their neutral value (four), except from *Defensive Responses* scale where it is lower than neutral value, which is the desired outcome since we want participants to have low defensive response towards our system. The mean and median values for the *Familiarity with Data Visualization* scale is almost near to maximum value of seven, showing that most of the study's participants were familiar with data visualizations. The standard deviation for all the scales is considerably high except from *Familiarity with Data Visualization* and *System Usability* scales. A standard deviation of near to or more than one can be considered high since the distance between each of the responses in a 7-point Likert scale is one, thus, value of standard deviation $\geq \pm 1$ needs to be inspected carefully.

Here, for *Perceived Interactivity* and *Perceived Contingency* scales which have high standard deviations, also have high negative skewness, meaning that the relatively high standard deviation show that the distribution is more spread towards the positive responses. On the other hand, the *Defensive Responses* scale has a high standard deviation with a relatively high positive skewness, meaning that the responses are more distributed towards the negative end of the scale from its mean value, which is a desired outcome for our system. Moreover, the highly negative skewness, and low standard deviation values for the *Familiarity with Data Visualization* and *System Usability* scales show that the responses are more distributed towards positive end of the scale with less variations from the mean. Overall, the descriptive statistics of

Scales	Mean	Median	SD	Skewness
Perceived Interactivity	5.90	6.00	1.18	-1.77
Perceived Contingency	5.96	6.00	0.91	-1.37
Defensive Responses	2.63	2.12	1.44	0.97
Familiarity with Data Visualization	6.34	6.50	0.66	-1.12
System Usability	5.99	6.00	0.68	-0.95

Table 5.5: Descriptive statistics of the variables capturing effectiveness of system design

the *Perceived Interactivity*, *Perceived Contingency* and *System Usability* scales show that our system was generally considered as highly interactive, participants felt like they were in an active dialogue with the system, and that they found the system usable. The high mean and median values for *Familiarity with Data Visualization* scale indicate most participants were familiar with data visualizations, which may have contributed towards the perceived usability and interactivity of the system as users with more experience with data visualizations should have found the contents of the system easier to interpret and interact with. Lastly, the results of the descriptive statistics for *Defensive Responses* scale show that most participants did not have a defensive response towards the contents of system, however, since this scale has considerably high standard deviation (1.44), it might have outliers that should be explored further.

Now, we explore if the mean values for these five variables are significantly higher than their neutral values. Thus, we performed a one-sample t-test on the scales, results of which are provided in Table 5.6. While performing the *t-test*, the neutral value was considered four for all the scales except for the *System Usability* scale. For the *System Usability*, a value higher than 68% is considered above average for rating the usability of a system [135], thus the neutral value for this scale was considered 4.76 (68% of a 7-point Likert scale). All the scales reported a highly positive *t-values* except for *Defensive Responses* scale, for which a negative value is the desired outcome since we want the responses to this scale to be less than the neutral value. Moreover, all scales show a *p-value* of less than 0.05, which suggests that the differences of the means for the scales from their corresponding neutral values are significant. Thus, we can say that the findings from the descriptive statistics analysis stated above are

Scales	t	p	df
Perceived Interactivity	16.12	0.00	99
Perceived Contingency	21.45	0.00	99
Defensive Responses	-9.51	0.00	99
Familiarity with Data Visualization	35.45	0.00	99
System Usability	18.02	0.00	99

Table 5.6: One sample t-test of the variables capturing effectiveness of system design

also supported by statistical significance.

5.2.2.1 Correlation Analysis with Climate Change Awareness and Behavior Change Scales

Finally, we explore how these five variables had an impact on the responses to the *Climate Change Awareness*, *Willingness to Change Behavior*, and *Perceived Behavior Control* scales which would help us better understand the findings from section 5.2.1. To achieve this, we performed a Pearson's correlation analysis between the responses to these scales in the post-intervention condition. We generated a heat-map of the results of correlation analysis, depicting the correlation coefficients (r) in each cell which is displayed in Figure 5.6. Based on Figure 5.6, we can easily identify that *Defensive Responses* scale has a high correlation with *Climate Change Awareness* and *Willingness to Change Behavior* scales with a coefficient value of -0.63 and -0.49 respectively. The *Defensive Responses* scale had the highest standard deviation in Table 5.5, and it was expected that it will help explain outliers within the responses. Moreover, there is slightly high correlation between *Perceived Contingency*, and *Climate Change Awareness* and *Willingness to Change Behavior* scales with values 0.35 and 0.37 respectively. The *Perceived Contingency* scale is related to the participants' measure of perceiving a back-and-forth conversation with the interactive story game, and *Willingness to Change Behavior* scale questions are directly associated with different scenarios within the game. Thus, it was expected that the *Perceived Contingency* scale would impact *Willingness to Change Behavior* scale responses. We also see a relatively high correlation ($r = 0.38$) between *Climate Change Awareness* and *System Usability* scale, showing that participants who found the system more usable also rated highly in their climate change awareness responses. Figure 5.6 also

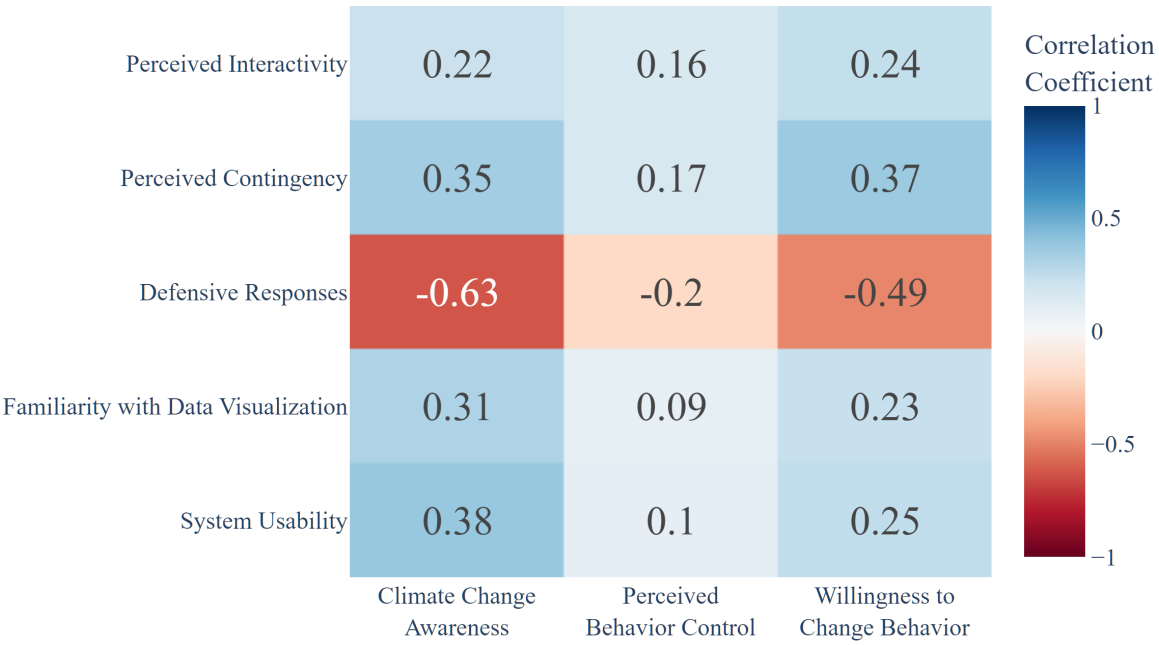

Figure 5.6: Results of Pearson's correlation analysis of the variables capturing effectiveness of system design

depicts that none of the scales to measure effectiveness of the system design had any considerable correlation with the *Perceived Behavior Control*, which makes it difficult to understand what could impact the perceived control on climate change behavior among the participants. Moreover, none of the variables have any negative correlation with *Climate Change Awareness*, *Willingness to Change Behavior*, and *Perceived Behavior Control* scales, except from the *Defensive Responses* scale where negative correlation is expected, which shows that these variables did not have any negative impact towards the effectiveness of our system.

Now, we further investigate the high correlation between *Defensive Responses* scale, and *Climate Change Awareness* and *Willingness to Change Behavior* scales that we observed in Figure 5.6. By plotting all the responses to these scales, we will be able to analyze any existing trends between them. *Defensive Responses* scale captured how the participants perceive the message conveyed through the intervention and whether they responded defensively to the system. Figure 5.7 shows a line chart, plotting the mean of responses from individual participants to the *Defensive Responses*, *Climate Change Awareness* and *Willingness to Change Behavior* scales.

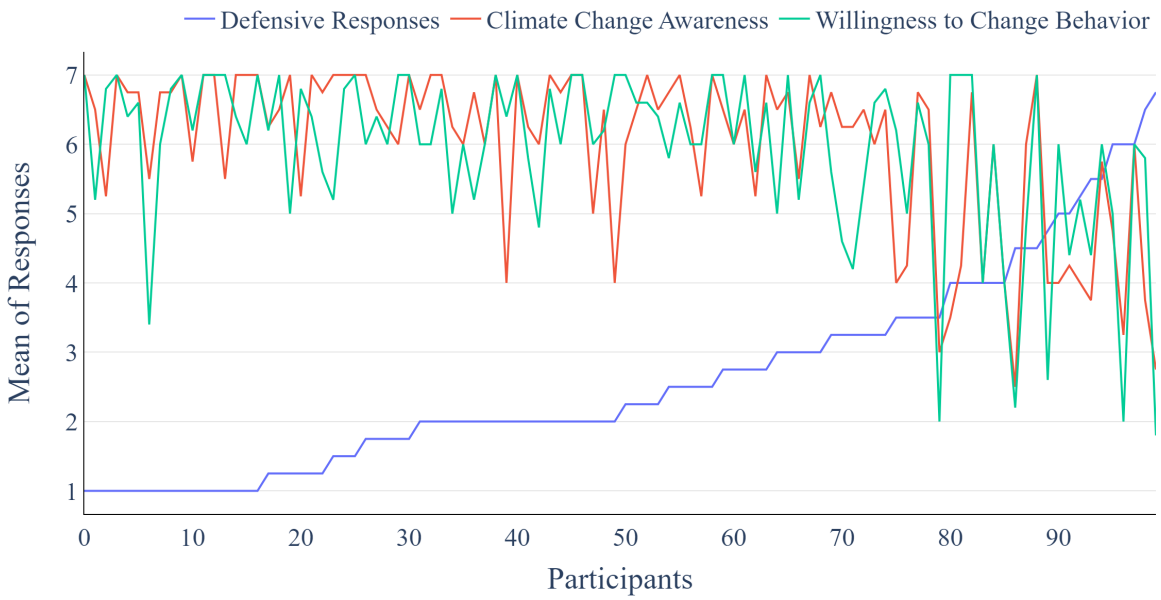

Figure 5.7: Mean of responses to the *Defensive Responses*, *Climate Change Awareness* and *Willingness to Change Behavior* scales

We have sorted the data on the line chart based on responses to the *Defensive Responses* scale in an ascending order, for better understanding of the relationships. Here, the x-axis does not represent participant ID, but merely a sorted observation number for this plot. Although there is no clear negative correlation that can be observed from the plot, we can identify that most lowly rated response to the *Climate Change Awareness* and *Willingness to Change Behavior* scales also are accompanied by highly rated *Defensive Responses* scale values. Only 25% of the response to the *Defensive Responses* scale are rated on or above 3.5, and among those 25% responses we find the most negatively rated responses to the *Climate Change Awareness* and *Willingness to Change Behavior* scales. Moreover, all the extreme low values to the *Climate Change Awareness* and *Willingness to Change Behavior* scales fall under this 25% of responses with highly rated *Defensive Responses*. The observations make it clear that most participants who had a high defensive response to the system also reported low level of climate change awareness and willingness to change behavior to mitigate climate change.

Persuasive Strategies	Mean	Median	SD	Skewness
Reduction	5.48	5.67	1.16	-1.59
Verifiability	4.76	5	1.72	-0.71
Social Learning	4.80	5.16	1.66	-0.83
Customization	4.52	4.33	1.81	-0.26
Simulation	5.56	6	1.4	-1.25
Social Comparison	5.09	5.33	1.75	-0.86
Cooperation	5.17	5.33	1.66	-0.97
Self-monitoring	5.33	5.67	1.42	-1.06
Overall System	5.53	6	1.31	-1.43

Table 5.7: Descriptive statistics of the perceived persuasiveness of the persuasive strategies

5.2.3 Analysis of Perceived Persuasiveness

Now, we want to explore the effectiveness of the eight persuasive strategies that were applied in the system. In addition to capturing the perceived persuasiveness of the eight persuasive strategies, we also captured the perceived persuasiveness of the overall system, which led to a total of nine set of questions for the *Perceived Persuasiveness* scale (described in section 4.2). Similar to the process followed earlier, first, we performed descriptive statistical analysis on the collected responses: results of which is provided in Table 5.7. The perceived persuasiveness of the strategies and overall system was evaluated using a 7-point Likert scale, with neutral value being four for this scale. Seeing the mean and median values, we found that all strategies reported higher than neutral mean values. However, *Customization* strategy had the lowest mean (4.52) which is close to the neutral value, meaning that the participants did not find the strategy highly persuasive. The highest mean (5.56) is observed for the *Simulation* strategy, which is an indication of the effectiveness of showing simulations of the future in-game world as part of the ending in the interactive story game. The *Reduction* and *Self-monitoring* strategies also received high mean values (5.48 and 5.33 respectively), showing the effectiveness of providing highlights in textual format in the data visualization screens, and allowing users to see how they performed in the interactive story game. Moreover, we see high standard deviation values for all the strategies, meaning that the perceived persuasiveness of the strategies varied considerably between participants. The highest standard deviation was observed in

the *Customization* strategy which has the lowest mean value, indicating that participants had most mixed perception of the persuasiveness of this strategy. All scales also reported considerably high negative skewness, indicating that the responses are more distributed towards the positive end of the scale. However, the *Customization* strategy has a low skewness value, and adding to the fact that it has high standard deviation and near to neutral mean, it is expected that the persuasiveness of this strategy had the least impact on participants. The persuasiveness of the overall system has the second highest mean value (5.53), suggesting that the system was overall persuasive.

Next, we want to verify that the above neutral mean values for the persuasive strategies is statistically significant. Similar to before, we performed a one-sample t-test on the responses to the *Perceived Persuasiveness* scale, results of which are provided in Table 5.8. All the persuasive strategies reported a *p-value* of less than 0.05, which shows that the difference of the mean values for the strategies is significantly different from the neutral value four. All the strategies also show a high *t-value*, except from the *Customization* strategy, which was expected considering its mean value being near to the neutral value. The highest t-value is observed for the *Reduction* strategy, followed by *Simulation* strategy and persuasiveness of the *Overall System*, which were also found to be most persuasive in the descriptive statistics analysis. Overall, there are significant differences of the means from their corresponding neutral values for all the persuasive strategies, showing that all the persuasive strategies were significantly persuasive.

5.2.3.1 Correlation Analysis with Climate Change Awareness and Behavior Change Scales

Now, we explore the effect of the perceived persuasiveness of the persuasive strategies on the *Climate Change Awareness*, *Willingness to Change Behavior* and *Perceived Behavior Control* scales. As done previously, we performed Pearson's correlation analysis between the responses to these variables during the post-intervention condition. Figure 5.8 shows the correlation coefficients between the variables in a heatmap. Based on Figure 5.8, we uncovered many interesting findings, especially that most

Persuasive Strategies	t	p	df
Reduction	12.80	0.00	99
Verifiability	4.43	0.00	99
Social Learning	4.81	0.00	99
Customization	2.88	0.00	99
Simulation	11.08	0.00	99
Social Comparison	6.23	0.00	99
Cooperation	7.08	0.00	99
Self-monitoring	9.36	0.00	99
Overall System	11.65	0.00	99

Table 5.8: One sample t-test of the perceived persuasiveness of the persuasive strategies

persuasive strategies had a positive correlation with the *Willingness to Change Behavior* scale, with the *Reduction* strategy having the highest correlation coefficient of 0.64 in the analysis. It is interesting to note that all the strategies applied from the Social Support category of the PSD model [96] (*Social Learning*, *Social Comparison* and *Cooperation*) had considerably high positive correlation ($r \geq 0.50$) with the *Willingness to Change Behavior* scale, along with *Simulation* strategy and persuasiveness of the *Overall System* that showed similar pattern. No significant correlation is found for the *Climate Change Awareness* and *Perceived Behavior Control* scales and the persuasive strategies. Another finding that stands out is that, although all the persuasive strategies had a positive correlation with the *Climate Change Awareness* scale to some extent, the *Customization* strategy had almost no correlation whatsoever with this scale ($r = 0.08$). This strategy also had the least correlation with *Willingness to Change Behavior* scale where all other strategies had slightly high correlation with this scale. This along with the findings from descriptive statistics indicate the overall least persuasiveness effect of the *Customization* strategy.

To further understand the high correlation between the *Reduction* persuasive strategy and the *Willingness to Change Behavior* scale, we plotted all the responses to these scales to identify any existing trends. *Reduction* persuasive strategy helps persuade users in reaching a target behavior by reducing the required effort [96], which was applied in the data visualization pages by summarizing the visualized data into few highlights (Figure 3.1). Figure 5.9 shows the line chart of individual responses

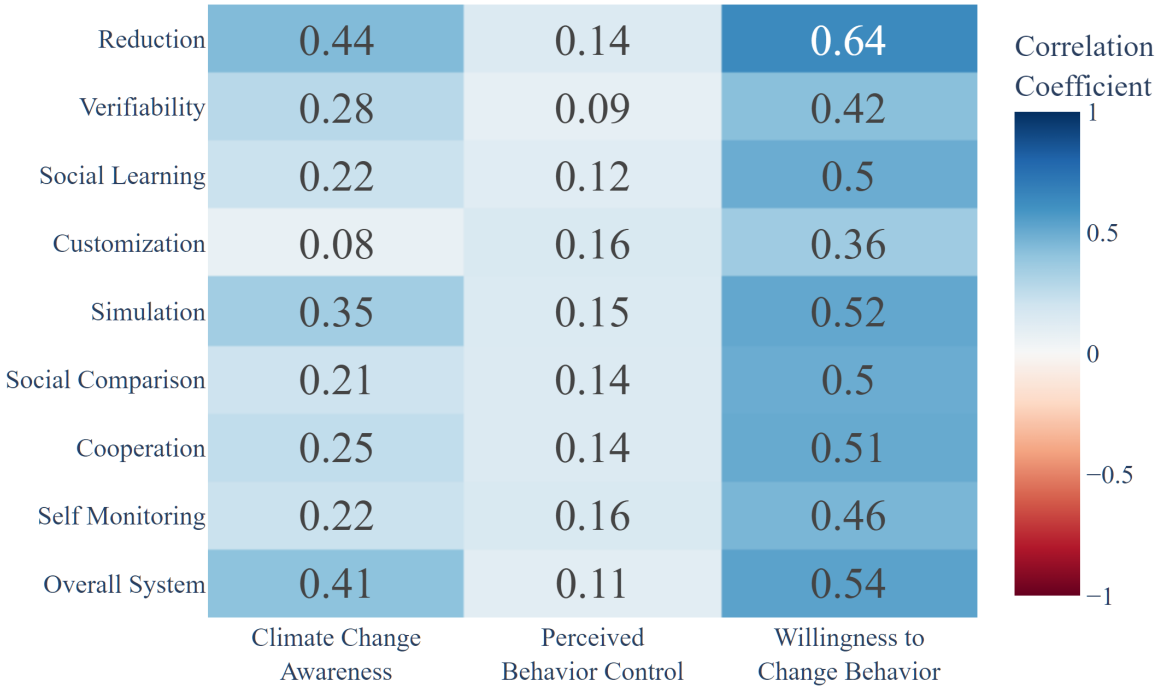

Figure 5.8: Results of Pearson's correlation analysis of the perceived persuasiveness scale

from all participants to the perceived persuasiveness of *Reduction* strategy and corresponding response to the *Willingness to Change Behavior* scale. Here, we have sorted the chart based on increasing order of response to the perceived persuasiveness of *Reduction* strategy, where the x-axis is the number of observation and y-axis depicts the mean of responses for the scales. Based on Figure 5.9, it is difficult to find any definite pattern between the two variables, however, we observed that all the responses with mean value equal to or lower than neutral value for the *Willingness to Change Behavior* scale has a perceived persuasiveness value of five or lower for the *Reduction* strategy. Thus, we can say that, all participants who were either neutral or did not express willingness to change their behavior in mitigating climate change, also did not agree strongly to finding the *Reduction* strategy persuasive. Only 30% of participants rated the persuasiveness of the *Reduction* strategy five or below, and among those participants are the few participants who also did not show any willingness to change their behavior. The *Reduction* strategy was applied in the data visualization screens, where we showed quick facts about climate change, thus it indicates that participants

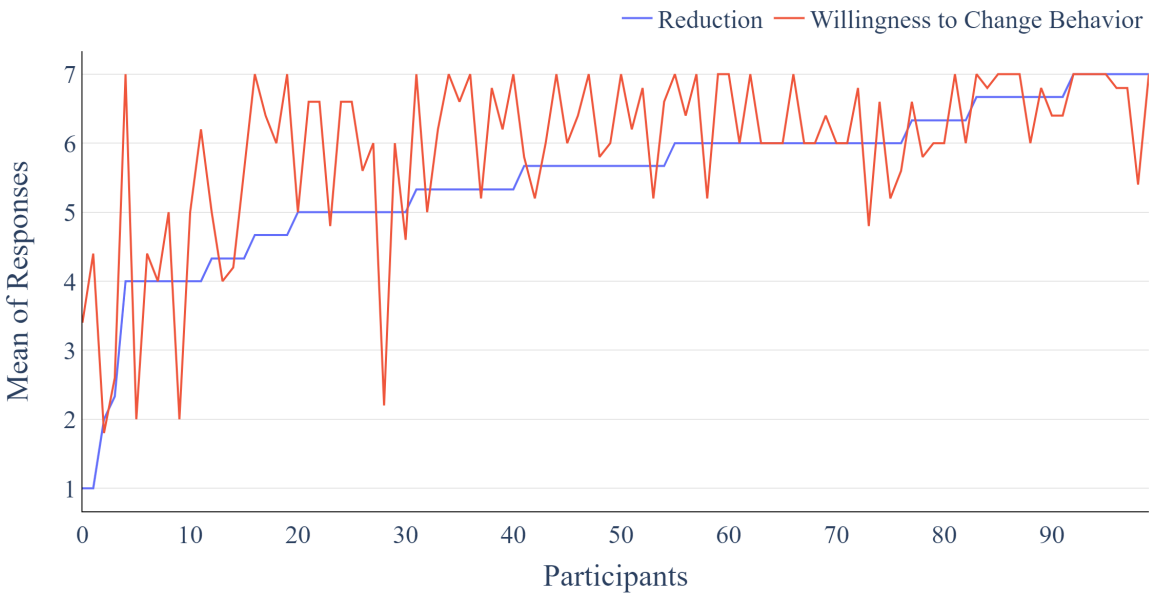

Figure 5.9: Responses to the perceived persuasiveness of *Reduction* strategy and *Willingness to Change Behavior* Scales

not willing to change their behavior either did not read those information or were not interested in reading information about climate change at all.

5.2.3.2 Differences in the Effectiveness of Persuasive Strategies

Finally, we examined if the persuasiveness of the different persuasive strategies differed between each other among the participants. It is desirable to know that different persuasive strategies have differences in their persuasiveness, since otherwise we can not tell if all the strategies were generalized in their persuasiveness, rendering the application of different strategies ineffective. Each persuasive strategy is applied with different expected outcome as they differ in their implementation, so it is desirable to know that the effect of the strategies are different from each other. Moreover, this might surface some strategies not having differences in their persuasiveness, which may surface strategies having similar persuasive effect. To achieve this, we performed repeated measure ANOVA analysis for all the captured *Perceived Persuasiveness* scale responses. The tests of within-subjects effect resulted in a factor value $F = 16.008$, with $p < .001$ showing that the mean scores for persuasiveness of the strategies were statistically significantly different.

Now, considering that the mean effect is significantly different for the persuasive strategies, we analyzed the pairwise comparison of the strategies using Bonferroni post hoc test, and plotted the resultant p values in a heatmap that is shown in Figure 5.10. Observing Figure 5.10, there are significant differences ($p < 0.05$) between most of the pairs of persuasive strategies, especially the *Customization* strategy had the most significant differences with other persuasive strategies. *Customization* was perceived as least persuasive among all strategies as can be seen in Table 5.7, and it has statistical difference in perceived persuasiveness with all the strategies except from *Verifiability* and *Social Learning* strategies. The *Verifiability* and *Social Learning* strategies also have second and third most lowest perceived persuasiveness mean value as can be seen in Table 5.7. This along with the findings from the pairwise comparison test shows that *Customization*, *Verifiability* and *Social Learning* strategies were the least persuasive strategies with no significant difference in their perceived persuasiveness. Also, the strategies with high mean values in perceived persuasiveness i.e., *Reduction*, *Simulation* and *Self-monitoring* strategies do not have statistical difference in their perceived persuasiveness (Figure 5.10), showing that the highly perceived persuasive strategies do not have statistical difference in their persuasiveness. From Figure 5.10 we can also see that the *Cooperation* strategy had the least statistical difference with other strategies, and considering that this strategy also had considerably high mean value among the strategies (M = 5.17), it indicates that the persuasiveness of this strategy was most common among the participants. Overall, the strategy implementations were found to be significantly different, and the pairwise comparisons between the strategies show that the least perceived persuasive strategies can be grouped together since they do not have statistical difference in their persuasiveness, while the same applies for strategies which were found to be highly persuasive.

Overall, we found desired outcomes from the analysis of all the variables that captured effectiveness of our system design. First, we found that our system was perceived as interactive. Participants felt like having a back-and-forth conversation with the system, and the system was also considered usable. Since most participants were already familiar with data visualizations, this might have attributed towards finding the system usable and being able to properly interact with the system. Participants who had a defensive response towards the contents of the system reported

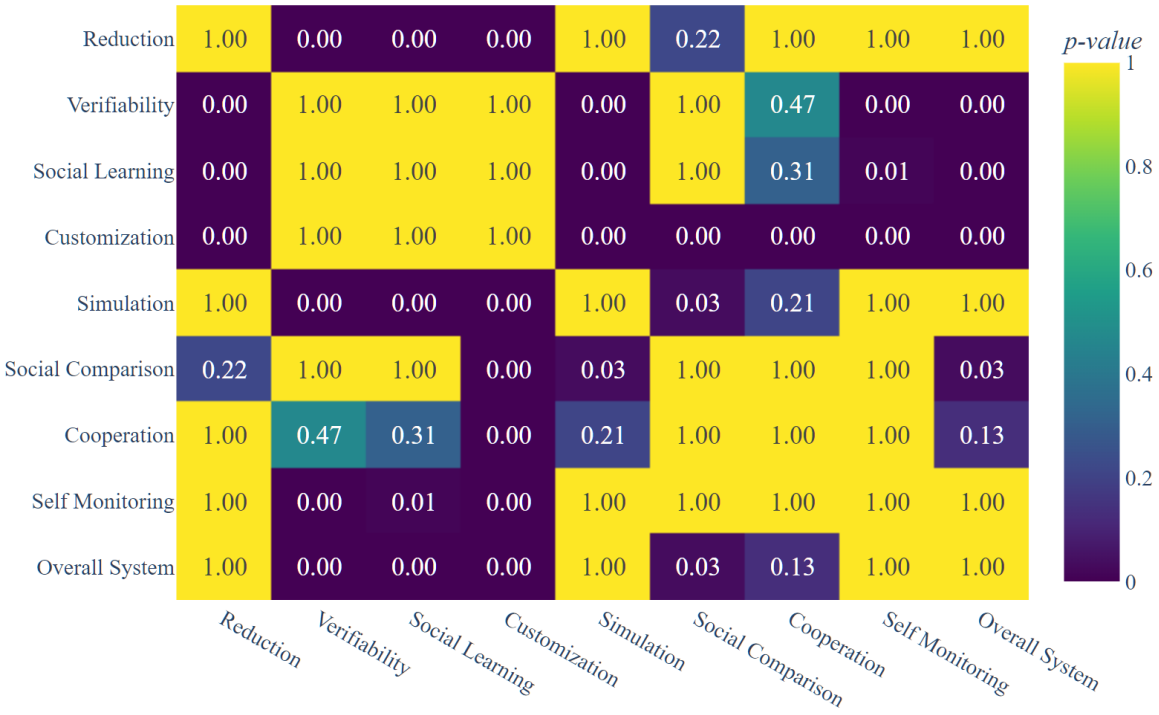

Figure 5.10: Results of pairwise comparison between persuasive strategies

low awareness about climate change, and showed less willingness to change their behaviors to build a more positive behavior towards mitigating climate change. This helps us answer RQ3 and RQ4, and we can say that participants' defensive response toward the system has a major role in raising awareness about climate change and their behavior towards it. Moreover, our overall system was perceived as persuasive, especially for persuasive strategies: *Reduction*, *Simulation* and *Self-monitoring* the perceived persuasiveness was highest. The persuasiveness of the system had highly influenced the willingness to change behavior for mitigating climate change among the participants, especially the *Reduction* persuasive strategy where all participants who did not express their will to change behavior also found the *Reduction* strategy not highly persuasive. All social support strategies applied in the system influenced the willingness to change behavior among participants, showing the effectiveness of social constructs in bringing behavior change. This aids in answering our RQ4, the persuasiveness of the system positively impacts willingness to change behavior but we could not find any conclusive finding that impacts participants' perceived behavior

control. The mean effect of the persuasiveness of the strategies was statistically different, with *Customization* strategy having most distinction among the strategies, while *Cooperation* strategy had the most common effect in its persuasiveness with other strategies. Strategies with least perceived persuasiveness (*Customization*, *Verifiability* and *Social Learning*) can be grouped together due to there being no statistical significance in their persuasiveness, which also applies for strategies that were found to be most persuasive (*Reduction*, *Simulation* and *Self-monitoring*).

5.3 Qualitative Analysis

We conducted interviews to collect general feedback from 20 participants. Participants interested to join in an interview shared their email addresses at the end of the study, and interested participants were contacted to schedule an interview. No criteria was followed in selecting interested participants for the interviews. As we conducted the interviews, the feedback were getting analyzed to get an understanding of the overall reception of the system, and to generalize the comments. After conducting 20 interviews, we observed that enough themes could be generated from the feedback, thus, we decided to conclude the interview process and proceeded to perform analysis on all the collected feedback.

A thematic analysis [24] was performed on the interview responses. The lead researcher conducted the thematic analysis by going through all of the interview responses iteratively and grouping similar quotes which resulted in 18 groups of quotes. In the first round of grouping, the quotes that were semantically related or having similar keywords for example color, animation, interactive, aware and such were grouped together. By reading through the grouped quotes, the quotes were further merged based on overall thoughts and concepts shared within each quote, and that resulted in 10 themes. Finally, going through the 10 themes again resulted in combining two themes as one, which resulted in nine themes, and further merging was not necessary after going through these nine themes. These resultant nine themes surfaced many aspects of the system that allows better understanding of the effectiveness of our intervention. The extracted themes and example quotes relating to them are provided below.

5.3.1 Interactivity of Data Visualizations

The interactive aspects of the data visualizations were mentioned numerous times by the participants. The most recurring comment on the three data visualization screens was about the interactive world map, especially how it was animated to display temperature change over the years. Some quotes from the participants regarding this aspect is provided below:

P3: *"One thing I really loved was when the years got changed and the picture changed. There, the reddest part showed highest temperature change so I could see which country is suffering the most."*

P17: *"I really liked the animation as it played along. The colors were getting redder which was a nice experience."*

P83: *"It was really interesting because I stopped and paused it, re-watched it again and again to see the countries which are affected the most."*

P88: *"I think I like the map view, it shows how urgent the climate action is."*

The comments above show that participants enjoyed the animations and use of colors in a geographic map to depict temperature change over the years as it provided a visual representation of climate change all around the world at a glance. This type of geographic data visualization is also easy to understand since most people are already familiar with the world map, and using colors to show temperature (e.g., red color representing hot regions) allows understanding the underlying data without inspecting the actual values for viewers who are not much interested in the details.

Moreover, different interaction options provided in the data visualization screens were mentioned to be helpful in understanding the visualizations. As some participants stated:

P3: *"It is very self-explanatory, when I was hovering over the graph I could see more info."*

P31: *"There was a scroller and (I could) see amount of average temperature, that was cool."*

P96: *"I clicked or zoomed in and out that was good, when I hover over the data points it gave readings that I liked."*

The above comments show that participants explored the visualizations by interacting with it to gain additional insights from them. To avoid complications, it is sometimes

desirable to hide the details of different data points to provide an overall understanding of the data. Interaction options such as, filtering, zooming, hovering and clicking on the visualizations allow interested viewers to dive deeper into the visualized data, and the above comments state that they were effective in better understanding of the visualizations.

Overall, the data visualizations received positive feedback, and many participants stated that they were easy to understand. We also had textual explanations to support the data visualizations which helped in avoiding complexity to users who are not familiar with interacting and extracting information from data visualizations.

Again, participants were able to grasp the severity of climate change and possible correlation between human activities and climate change from the visualizations, which were some of the main goals of the screens. Textual descriptions helped participants who may not be comfortable using the data visualizations to extract information. The following comments show that the data visualization screens were effective in delivering their intended messages:

P19: *"The climate crisis is real (which) was the main part for me to learn, and I got that from the graphs."*

P46: *"The correlation graph made a strong case."*

P86: *"For any person who does not have enough knowledge on how to look at charts, it was easy for me. If someone does not understand the data visualization they can read from the text."*

However, few participants complained about the amount of data presented, and that they were not able to understand the visualizations. Most of the difficulties mentioned are related to the second data visualization screen where we displayed possible correlation between human activities and climate change using line charts (Figure 3.2). This is probably due to multiple variables (i.e., CH_4 emission, CO_2 emission and temperature change) being displayed in one screen, along with the complexities related to understanding correlation between variables. Line and bar graphs are also hard to relate to real-world aspects compared to geographic maps, since they are more abstract and can not be naturally mapped into real-world objects. Moreover, hindrances in understanding the data visualizations can be attributed to lack of proper screen space (i.e., smaller screens) that prevent seeing the visualizations properly as

elements get overlapped and are shrunken in size to fit the screen– making elements become difficult to identify. The following comments highlight some difficulties faced by the participants for the data visualization screens:

P8: *"The second graph was hard to skim through, the legend was obscuring the graph."*

P18: *"I did not go through these pages that well, too much visualized data I did not like."*

P88: *"The line chart is difficult to interpret, I see it more as a statistic than something that is impacting the world I live in."*

Overall, the interactivity of the data visualizations was appreciated by most people while we were also able to identify some limitations of our visual representation of climate change data.

5.3.2 Impact of Mapping the Story Game to Real-life Scenarios

The real-life aspects of the story game received numerous mentions by the participants, suggesting that it is a successful design choice for the interactive narrative. Structuring the story game based on real-life scenarios was intended towards helping participants understand how our actions can impact the climate, and the following comments from the participants show that the game was successful in achieving it.

P3: *"It showed real life scenarios and how our actions are very much related to climate change. I could make decisions and see their effects which caught my attention, I could interact with the game, and it was interesting to me."*

P10: *"I learned that it would affect climate change even if an individual does something it can have an impact."*

P88: *"The story game was so compelling, because when I was playing it, I felt the need and got emotional that my actions can actually destroy my community. I had attachment, emotions and feelings about the environment."*

P89: *"The storyline was more of a practical way to learn how I can help the environment."*

Participants also liked how the story reflected their customized character profile, as it allowed them to relate more to the story. As some participants stated:

P7: *"I liked that profession, city (and) everything was linked."*

P8: *"At your workplace you could see what was happening, the personalization was well done and made me enjoy the game."*

P19: *"The (character) name, company name I can remember them, so it is really helpful for relating and feels good."*

Participants were also able to get a better understanding of how individual actions can impact the climate, and that our day-to-day actions play a role in climate change. The following comments support this notion:

P3: *"Previously I did not think that much, that even my small decisions can impact the climate. But now, I know every single decision affects the climate."*

P13: *"You do not know on a regular basis what small choices you are making (and) how it is affecting in a bigger scale. The game showed how little actions can affect the whole climate."*

P88: *"Before, I thought saving energy was just for conserving energy but now I know it is a climate action."*

Overall, designing the game based on actions we face in our daily lives allowed the participants to reflect upon their own behavior and see their impact on the climate. The experience was made more immersive by incorporating customized elements (such as, character's background information and appearance) set by the participants as it made them feel more connected to the interactive story game.

5.3.3 Willingness to Do More for the Climate

Most participants shared their willingness to be more climate friendly in performing their day to day tasks after using the system. Some of those comments were directly associated with the scenarios presented in the interactive story game as shown below:

P3: *"Everywhere I go to grocery I will try to use reusable bags (to) avoid plastic. In my work I will try to use my own jar, a lot of other things in my life will now be shaped by that game."*

P17: *"I am going to get the reusable bags from now on and carry my own bag."*

P46: *"I should probably look around the house for appliances that are wasting power, so it did raise my awareness."*

Some participants shared they would like to bring changes to their daily lives in the long run to be more friendly towards the climate, as it may not be possible

to bring drastic changes to their current lifestyle. This shows that the intervention was successful in introducing willingness to change behavior among the participants. Some example comments are as follows:

P10: *"I am trying to figure out how I can lead my life to do things (climate friendly actions), that did occur to me and I am thinking about that after using the system."*

P17: *"Further down the road I might change a little cause I was reminded of everything."*

P18: *"It might have changed a little bit of my mindset. It did not yet bring change to my actions yet, I want to now change after this."*

Some participants shared their concerns regarding how saving the environment is a collective effort, and without acting on it we may suffer altogether. This reflects on the social features of the system where we emphasized participating in climate friendly behavior collectively as our actions also impact others, and by doing so we can save the environment. Some example comments are followed:

P3: *"I am thinking of what I can do to improve the environment like I can plant a tree everyday, and if not our children, (and) grand children will suffer."*

P13: *"It did change my level of awareness, everyone knows about it but people are not acting on it."*

P18: *"It is a little difficult but if all of us should take initiative to do those things, it is not hard. It will take time but it is possible."*

Overall, the system brought about participants willingness to change their behavior for the betterment of the climate among the participants, which was one of the primary goals of our intervention.

5.3.4 Visuals of the Story Game

There were numerous mentions about the aesthetics of the interactive story game in the interviews. Most participants had something to comment regarding the visuals of the game, which shows that the design had a long-lasting impression on participants. The avatar design, animations, colors and overall graphics of the game was appreciated by most people, some example comments are provided below:

P8: *"I really liked the characters, and whole setup was very aesthetic."*

P17: *"I really liked the graphics, animation, visual, cartoon, the little bubbles of*

texts, and voice narration."

P89: *"The visualization and colors were very fantastic, (also) the color combination and the storyline."*

Some specific details of the visuals were also mentioned which show that comprehensive visual design can be appealing to the participants. For example, one participant mentioned their liking for the emotion that was demonstrated by the avatar: this was a very subtle detail in the game where the avatar changed its face depending on the participants' decision in a scenario. The following comments highlight specific visual elements that were liked by some participants:

P8: *"Seeing the character show emotions was really something (that) I liked."*

P17: *"I really liked the customization of the character."*

P89: *"I liked where you select body and liked that it supported diversity and inclusion."*

In contrast, inconsistencies within the design were also easily caught by the participants. The animations implemented within the game were very simplistic and we did not focus on many advanced movements just as seen in modern game industry. Some participants requested more advanced animations such as, smoother movement, proper blending of the avatar with the environment and more natural voice narration tool. Moreover, the game was designed in two dimensions without a dynamic environment, which served the purpose of demonstrating the desired effects within the scenarios, but this might not be enough to reach the expectations of some participants regarding the game's visual design as can be seen in the following comments:

P16: *"The animation could be smoother, the movement is not very smooth, it is a bit struggling."*

P18: *"I think it was a little slow, it was unlike other PC games we play."*

P31: *"The avatar was not blending in with the background."*

P86: *"When I tried to recycle, it would be better to see the items go inside the bin."*

In summary, although the visuals of the game were praised by most participants, there is enough room for improvement which would increase the engagement of the game and help in reaching the expectations of the players. Repeated mentions of the visual design bring out the importance of pleasing visuals for any system as it leaves

an impact within the participants regarding their liking towards a system. Hence, designers should pay attention to this.

5.3.5 Affirmation of Existing Beliefs

Most participants reported that the system affirmed their existing beliefs regarding climate change, adding that their understanding of the phenomenon was reinforced after using the system. From the quantitative data analysis we also saw that in the pre-intervention phase, most participants were aware of climate change. Being able to reinforce their awareness would indicate a positive impact of the intervention, the following comments show that participants already aware of climate change still got benefited by the system:

P16: *"I am conscious (about climate change), but after using this (system) I am more conscious now."*

P46: *"If not introducing anything new (on climate change) it refreshed it at least."*

P84: *"The system made me more aware, the information were vital."*

P88: *"I did not learn anything new, but I got a better definition and it (the system) brought it alive, it made me appreciate information better."*

In addition to reinforcing existing beliefs, the system was able to help reflect upon the participants existing behavior and get a better understanding of their own actions that can impact the climate. By achieving so, the system allowed participants to improve on their behavior and act better for the climate. The following comments show that the participants reflected upon their own behavior after using the system:

P8: *"I got the bad ending, that is when I realized in real life, I let things (household electronic items) turned on. I was very confident about myself, but it made me think more. Also, I had this attitude, "why should I care about recycling?" But after playing it, now I started thinking about reconsidering my choices."*

P10: *"When the system shows the amount of harm you can do (by) maybe using your car or using more electricity, that made me think how we live our life right now."*

P88: *"Most things in the system like recycle, use trash can, do not throw things, use vehicle, I never took seriously before playing this game how little actions can have an impact."*

P96: *"I guess I am not that good at recycling as I thought I was."*

These comments on the system indicate that by affirming the participants' existing awareness about climate change, and letting them reflect upon their behavior, the system was able to help bring positive behavior change towards climate change among the participants.

5.3.6 Appreciation for the Social Elements

The social elements of the system were built around the Social Support strategies from the PSD model [96], and although not being the core feature of the system, they were cordially received by the participants. The social aspects of the data visualization screen where we visualized how climate change is becoming more popular in social media, and the Twitter feed as described in section 3.2 were liked by many participants and helped them become more aware of climate change:

P10: *"The Twitter part where I could see posts, that made me more aware about climate change."*

P19: *"The Twitter feed was interesting and after clicking it, I was gone into the rabbit hole. I went to read the comments of Tweets from there and it was interesting."*

P72: *"The Twitter data was showing more people are focusing on global warming."*

Another important social element of the system was the Contributors screen (described in section 3.3.10). Many participants mentions that it was the highlight of the intervention. The goal of this screen was to reach the common goal of restoring the climate together, and encourage them in achieving the goal by showing how others are contributing to fulfill this common target. Although being the last screen of the system, the following comments show that the screen was successful in delivering the intended message and capturing their interest:

P7: *"Scoreboard where the earth was healing, (it) was a hopeful thing seeing the earth filling in green. It basically said not all is lost (and) we can help it, and gave me hope."*

P8: *"Also, at the end, the goal was filling in (referring to the Contributors screen's earth image shown in Figure 3.21), it had the togetherness in it which I really liked."*

P45: *"There is another key feature in the system, the scoreboard, that is my favorite part of the system... I would want to see more encouraging words like "Let's Make the Earth Green" in this screen."*

P87: *"Also, the scoreboard at the end, maybe you can find you are below average and need to better."*

P88: *When I saw my score I felt I would have done better.*

The comments above show that the social elements of the system were successful in helping users to be more active in climate friendly behavior. By showing how all participants' contributions are helping the climate, the Contributors screen was able to make participants feel connected to this global phenomenon, while the list of contributors and their collected points helped participants realize how much they can improve their behavior to contribute more to the climate. Overall, the social aspects, although not being the focus of the system, turned out to be one of the most liked features of the intervention.

5.3.7 Impact of Simulating the Outcome

The outcome of participants' actions was simulated in the story game by showing visuals of the future, with an intention to provide an image of extreme climate change consequences. It is difficult to properly visualize predicted outcomes of climate change, but our implementation focused on keeping the visuals consistent with the scenarios presented in the game. Many participants commented on the impact of seeing the simulated future of the game's environment:

P8: *"I was pretty happy with the outcome and (it) made me feel really good."*

P86: *"When I saw the end, I really felt bad."*

P87: *"It sticks with you like you see the burning park and (you would) think "oh no!"."*

P83: *"I really liked how you have added the alternate situation, how it would happen if I did not take care of my day-to-day life."*

P96: *"I liked to see the contrast where you see the alternate ending, that was the thing I liked the most."*

From the comments above, we observe that the both the positive and negative endings were able to elicit positive and negative emotions respectively, which emphasizes the effectiveness of simulating the outcome of the participants' actions. Moreover, showing both positive and negative endings to the participant helped them better realize the consequences of our actions and shows that the design choice in depicting

both outcomes was useful.

5.3.8 A New Way of Learning

Many participants shared how much they liked the concept of the system in conveying information regarding climate change, and reported that it was a new learning experience for them:

P16: *"I never thought climate change related stuff can be visualized this way."*

P17: *"Interesting learning experience, I never thought reading a story could be a learning experience this way."*

P83: *"Really liked the concept, it was very unique. I have joined many studies but I really enjoyed doing this study."*

Many participants shared that it can be a useful tool to teach about climate change, especially for children:

P87: *"It is a good way to teach people, it gamifies learning which is a powerful tool...it can go into schools as it is a great tool for learning."*

P19: *"Would be good for corporate training and in schools."*

P46: *"I saw potential there to get kids learn more interactively playing games like this."*

Many participants reported different findings they were able to get from the system, showing that the system was able to teach about climate change:

P3: *"I never knew that Russia was suffering from climate change for a long time, I thought third world countries like Bangladesh would be most vulnerable."*

P18: *"I would like to learn more about recycling and how we can do it. I was able to learn from that (the system) and would like to learn more."*

P45: *"The posts on the social media (where) the actual number is like 8 million in 2019. I think it is a very popular topic on climate change, none of my friends have posted this, even I do not post concerns on climate on my social media but maybe I should post more that is (what) I learned new from the system."*

P87: *"Climate crisis has never been on Twitter much until three years ago, it gained popularity then it was very interesting, it showed like we are in crisis mode now."*

P88: *"Normally, I see climate action I think that is something in hundred of years*

to come, but within just few number of years it can happen that I learned from the game."

Based on the comments, we gathered that participants appreciated the concept of raising awareness about climate change using data visualization and interactive narrative tools, and they were able to extract useful information from the system, especially from the data visualizations. The main objective of the data visualizations was to show the users how climate has been changing and educate them regarding its trends and causes. Our results show that the system has been effective in letting the participants learn some facts about climate change. And most of the reported findings are from the graphs and charts that were visualized, not the summarized text, which means participants interacted with the visualizations and extracted the information from them. Moreover, the appreciation for the system and its concept shows that the intervention can be a useful tool for the general public, and can also be targeted for children to teach them about climate change.

5.3.9 Room for Improvement

Through the interviews we were able to get numerous recommendations for improving the system, along with identifying limitations of the current system. Although the reception of the interactive story game was overly positive, some participants complained about the lack of complexity and low number of scenarios within the game:

P8: *"Number of scenarios was not too much or too less. Maybe some options could be made more complex, but that could be a double-edged sword."*

P10: *"Maybe it could have more scenarios in other countries and places."*

P13: *"It was quite easy to right answer, it could have been done in a trickier game."*

P45: *"The ending (of the story game) was rushed maybe you could show the progression."*

Thus, as an improvement, we can add more scenarios to the story game and have more complex game elements as the story progresses. Some participants have already thought of some suggestions for designing new scenarios which are very useful for our future considerations:

P3: *"The story could have more story elements like a hero, heroin or a super-hero...You could add these things like people are getting sick and there is more diseases due to climate change."*

P13: *"I would say to make the data visualization to be made a game, (and) if we could see the information through the game."*

P88: *"Tell more stories about other aspects of life like, if social media is affecting climate, shopping and other related stories that can relate to climate action. In a soccer game thousands of people (are) packing in a stadium, does that impact the climate? Stories like that would be nice."*

P96: *"Maybe it would be cool to see graphs as part of the story, like put them within each other."*

Some participants also complained that we did not cover some aspects of climate change that should have been included, as shown in the comments below:

P3: *"You could have researched more biologically, and how industrialization is harmful for our climate."*

P84: *"We know carbon emission is high, and major reasons why we should avoid is industries need to avoid it too, those information should be added."*

Moreover, participants also requested some additions for the data visualizations:

P3: *"Perhaps you could add other type of graphs like time, bar, pie charts."*

P7: *"It will be nice if we could see the actual average temperature of the whole world."*

P96: *"Seeing the world map of 2080 would be good too."*

Overall, the suggestions above indicate building a more comprehensive system that covers all aspects of climate change that range from impact of individuals' actions to governments and industries who play a major role in affecting the world's climate. In addition to enriching the story of the interactive game by adding more scenarios and adding more complexity within the scenarios, we can have more comprehensive data visualizations that include different type of graphs and aggregated data which would be useful for participants who seek more detailed information regarding the topic. Above all, the suggestions also show that the system stirs participants interest, and they were highly engaged with the system. They also felt some connection with the system that motivated various suggestions on how the system could be improved or

extended. The recommendations above give us enough material to extend our system to be more feature rich and comprehensive.

Chapter 6

Discussion

After analyzing the collected data, we were able extract findings to determine the effectiveness of our system. In this chapter we will address how our system performed in answering the research questions we had in section 3.5.

6.1 Effects on Raising Awareness about Climate Change

From our analysis on the system's effect on raising awareness on climate change, we gathered some interesting findings that needs further discussion as stated below.

6.1.1 Lack of Significance in Raising Awareness

Determining whether the system has an impact on raising awareness about climate change was set as RQ1, and the results discussed in section 5.2.1 show that the system was able to increase strong positive opinion on climate change awareness, although there was no significant increase in overall climate change awareness. Dorothee et al. [10] were inconclusive in finding relation between media usage (TV and printed) and awareness about climate change. Their findings show that people who keep themselves informed through public news programmes had higher level of awareness contrary to people who watch only commercial programmes or read printed media. Our system is similar to printed media in the way that it was not dictated by any presenter, and required self-exploration. Other studies also found that reporting on climate change through printed media did not lead to conviction that human-influenced climate change exists [58] [107]. The results from these studies are in line with our findings as our system also presents information on climate change to its users, but it had no significant effect in raising awareness about climate change. However, as discussed in section 5.3.8, participants were able to extract useful information from the system and shared that they were able to learn new information about climate

change, which shows that the intervention was successful in delivering information regarding climate change. But since the quantitative responses do not report significant increase in overall increase in climate awareness, this draws attention to investigating which aspects impact the level of awareness among people about climate change.

6.1.2 Reinforcing Awareness

Our study participants reported high awareness of climate change during both the pre- and post-intervention conditions. Reporting high percentage of climate change awareness was also found in a survey conducted by Dorothee et al. [10], where 68% of the participants showed strong awareness about climate change, while in a survey study conducted by Jan et al. [115] the percentage was 81%. This indicates that people consider themselves well aware of climate change in general, which leaves less room for reporting improvements in awareness after exposure to an intervention. However, examining the individual questions from the *Climate Change Awareness* scale, it became obvious that compared to pre-intervention, all the participants generally reported higher number of *Strongly Agree* responses in the post-intervention condition (Figure 5.3). Although the total number of positive responses did not change much, it suggests that our system was able to increase strong positive opinion about climate change. Responses from the interviews also support this finding as described in section 5.3.5, where we found that the system reinforced existing beliefs on climate change among the participants. Many participants reported how they are more conscious about the climate after using the system, while many reported how they want to be more active in climate friendly actions (sections 5.3.3). These findings show the effect of our system in raising awareness level about climate change among participants who already show some level of awareness.

6.1.3 Awareness is Impacted by Defensive Response

The effect of the system on climate change awareness was also highly affected by defensive responses from the participants. In the post-intervention condition, only a few participants reported below neutral level of climate change awareness, and all of them also reported high defensive response to the system. As discussed in section 5.2.2,

only 25% of the participants belong to this category, thus, it is clear that higher defensive response towards the system was associated with low awareness about climate change. In a study on perception of severity of obesity related health risks, Jeeyun et al. [94] found that defensive responses to their system was influenced by perceived interactivity, which in turn influenced the perception of severity of obesity negatively. Also, since most of our participants showed high level of awareness about climate change, it indicates a strong opinion on the matter due to which participants with lower awareness may have reacted defensively towards the system's message on raising awareness. This helps us answer RQ3, as defensive response towards the system negatively impacts raising awareness about climate change, and minimizing defensive responses must be kept in consideration while designing interventions. Jeeyun et al. [94] found that interactivity of the system was negatively associated with defensive responses, although our results report high perceived interactivity (Table 5.5), it can not be concluded that high interactivity would be a possible solution. However, our results showed that perceived contingency of the system was considerably correlated with climate change awareness. Thus, building a more engaging interactive narrative could positively impact climate change awareness, and possibly lead to less defensive responses. Introducing more scenarios, advanced animations and complex interactions are some of the improvements mentioned in section 5.3.9 that can be introduced to aid in this matter.

6.1.4 Positive Effect of Aesthetics and Interactions

In terms of positive effect of the system on raising awareness about climate change, many aspects could be identified especially from the interviews which helps us further answer RQ3. Participants mentioned about discovering new findings on climate change that helped them become more aware of the phenomenon which were accompanied by appreciation for the visuals of the data visualization as mentioned in section 5.3.1. The aesthetics of the system was appreciated by most participants, which is consistent with the findings by Jie et al. [76] where the aesthetics and visual design was their system's most highly preferred aspect. Interactivity of the data visualizations offered better engagement and understanding of the data as was mentioned in section 5.3.1. Participants shared that they explored and learned about the

trends and causes of climate change through different interaction options provided by the system, which is similar to the findings of related research that emphasize data exploration through interactive data visualizations [71] [46] [136] [65].

In addition to offering multiple interaction options, our system offered fast performance which may have benefited the user experience. We developed our system and hosted the web application focusing on keeping its performance fast and consistent, and used servers with adequate resources (processing power and memory) to deploy our web application. It led to a pleasant experience for its users, as Jie et al. [76] found that their system scored low in perceived interactivity due to the system being slow. Moreover, our overall reception of the chosen methods of data visualizations that included 2D representation of world map, line chart and bar chart was overwhelmingly positive, which is consistent with the findings by Christian et al. [132] where participants preferred simple 2D visualizations over complex higher dimensional techniques. Christian et al. [132] also emphasized under utilization of novel visualization techniques, as was also noted by some of our participants who wanted to see more types of visualizations, and integration of data visualizations within the interactive story game, a combination of which has not been well explored in the research community. However, variety of data visualizations and the complexity that comes along with them needs to be handled with caution as some of our participants also complained about the difficulties in comprehending the information presented in the data visualizations.

6.1.5 Success of Mapping Real-life Actions

Mapping the interactive story game's scenarios to real-life was a successful design choice as participants mentioned better understanding of climate actions and how we need to be more aware of our day-to-day activities through these scenarios (section 5.3.2). Participants became more aware about the climate actions by seeing and practicing them through the decisions taken in the scenarios, considering that some participants reported that they did not believe such activities could impact the climate. Many climate friendly actions are often performed due to economic or social reasons (e.g., saving electricity and gas bills) [10] [115], introducing climate awareness to such actions is desirable considering people's economic and social statuses can

change that may lead to behavioral changes. Moreover, depicting the future of the climate through different endings of the story game was impactful in raising awareness as many participants mentioned how they could comprehend the effect of climate change through the visuals presented (section 5.3.7). Federica et al. [103] found that exercising different choices and seeing their impacts in interactive narrative games encourage learning and boosts emotional engagement, which is consistent with our finding as participants reported becoming more aware of climate change by seeing how our daily life actions impact the climate, and reported that the story endings had an emotional effect.

Overall, our system helped raise awareness about climate change, especially in increasing strong agreeableness towards climate awareness. This answers our RQ1, and leaves room for exploration in finding factors that can significantly increase climate change awareness. To answer RQ3, defensive response is a key indicator in the system's effectiveness in raising awareness about climate changes, as people with low awareness about climate change reacted defensively towards our system. We encourage having high interactivity within the system and ensure back-and-forth communication between the system and its users to limit defensive responses. Our system's multiple interaction options, compelling visual design and options for exploring different outcomes aided participants in learning about climate through an engaging experience, that in turn helped raise awareness, which aids in answering our RQ3 about the system's effect on climate change awareness.

6.2 Effects on Behavior Change towards Climate Change

There is a significant effect of attitude on someone's environmental behavior [128] [133], where positive attitude towards environmental behavior leads to consistently positive behavior for the environment [5]. Stern [120] found four influences on environmentally significant behavior: (1) attitudes, values and beliefs, (2) contextual forces (social, economic, institutional and political), (3) personal capabilities (knowledge, skills, and resources) and (4) habit. Among these influences, we did not explore contextual forces in our study as exploring economic or political effects on climate change was outside of scope for this study. Additionally, determining changes in actual behavior was not possible during our cross-sectional study, however, our qualitative

study indicates that our system led to actual change in behavior. From our study, the *Willingness to Change Behavior* scale was a measure of behavior intention while the *Perceived Behavior Control* scale measured any changes to perception of ones personal capabilities in mitigating climate change, that is self-efficacy. Together, the use of these scales surfaced many interesting findings that promote behavior change to mitigate climate change which are described below.

6.2.1 Success in Promoting Behavior Change

We found statistical significance in a positive change from pre- to post-intervention condition for both *Willingness to Change Behavior* and *Perceived Behavior Control* (section 5.2.1), suggesting that our system was effective in motivating behavior change towards mitigating climate change. In a survey study conducted by Mei-Fang [21] on climate change, the mean responses to *Perceived Behavior Control* scale was reported as near to neutral value (M = 4.5), similarly in our pre-intervention condition the value was 4.53 which increased towards the positive side of the scale in the post-intervention condition (M = 5.16). This indicates that people generally have neutral perception of their behavior control to mitigate climate change, which might be due to other aspects that make climate change a global phenomenon such as, the policies made by industries and political parties play a major role in the environment on which individuals have no control over. The effect of climate change actions have non-existent immediate visible outcome on the climate, and it introduces a severe collective-action problem, which might also be an explanation for the low perceived behavior control to mitigate climate change [21]. Considering our intervention targeted positive behavior change towards climate change on an individual level, increasing their level of perceived behavior control suggests the effectiveness of our system. This helps us answer our RQ2, as the findings suggest a positive change in perceived behavior control to mitigate climate change after using the system.

For *Willingness to Change Behavior* participants already had higher than neutral responses in the pre-intervention condition but they became more positive after using the system in post-intervention condition. Brody et al. [19] in their study also found that most participants (66%) agreed to change their behavior to mitigate climate change. Reports of high agreeableness to change behavior to mitigate climate change

indicate that people generally tend to perform climate friendly behavior, although it can not be concluded that all climate friendly behavior are intended for the benefit of the climate as some are performed out of economic, health or social intents. Sverker et al. [69] found multiple intents that lead to pro-environmental behaviors, where behaviors related to transport and energy saving were dominated by economic and health related intents rather than environmental reasons. In our study, we captured participants' willingness to change their behavior through questions related to energy saving, travel, recycling, using reusable products and avoiding single-use products. All these aspects were included in the interactive story game, and the impact of the participants decisions on the climate was discussed in the game. Considering we observed increase in positive responses in willingness to change behavior, the results show that our system motivated the participants for environmental reasons even if they performed pro-environmental behaviors due to other factors. The significant effect of the system in increasing willingness to change behavior to mitigate climate change, together with the finding of significant positive effect on perceived behavior control shows that the intervention was successful in motivating positive behavior change towards climate change, which answers our RQ2.

6.2.2 Lack of Effect on Perceived Behavior Control by System Elements

As for the system design aspects that impacted the perceived behavior control of the participants, we could not find any correlation between any variable and the *Perceived Behavior Control* scale. This makes it difficult to answer our RQ4, however this finding is interesting as the system increased the participants' perceived behavior control to mitigate climate change. The most notable effect on this scale was from *Defensive Responses* scale where we noticed a slight negative correlation (p = -2), indicating that participants who responded defensively towards the system's content showed lower perception of their ability to control their behaviors towards mitigating climate change. When individuals perceive a threat to their freedom, it leads to psychological reactance, and they try to re-establish their freedom [53]. This may result in rejection of the message conveyed by a system– manifested by defensive avoidance, denial or reluctance [94], which explains why participants may have a decreased perception of their control over a behavior (i.e., mitigate climate change). Moreover, since the

climate change phenomenon creates perception of severe collective-action problem and hinders the perception of behavior control to mitigate climate change [21], the social elements of the interactive story game may have impacted positively towards this factor which is supported by interview responses in section 5.3.6. Participants shared that seeing the collective participation in mitigating climate change made them hopeful about being able to avoid the negative outcomes of this phenomenon, which suggests a positive effect on their perceived behavior control. Additionally, many of the recommended behaviors related to mitigating climate change require relatively high individual efforts (e.g., changing transportation habits, recycling regularly and ensuring conservation of natural resources) which negatively impacts perceived behavior control [21]. Our system allowed practicing pro-environmental behavior in the interactive story game, and participants reported that they very much liked seeing the effects of their actions on the climate (section 5.3.2) which indicates a positive effect on perception of behavior control.

6.2.3 Behavior Intention is Impacted by Defensive Response

We found multiple interesting findings of the system design aspects' effect on the *Willingness to Change Behavior* scale, i.e., participants' behavior intention to mitigate climate change. First, the *Defensive Responses* scale was moderately negatively correlated (p = -0.49) with the *Willingness to Change Behavior* scale, showing that participants who responded defensively to the system showed low willingness to change behavior to mitigate climate change. Jeeyun et al. [94] found that lower defensive responses were indirectly related to higher agreement in policy changes to prevent obesity with significance, which is inline with our findings although instead of agreement to policy changes we measured agreement or willingness to alter behavior to mitigate climate change. Other studies have found how smokers reinforce their smoking habit as a way of restoring threatened freedom [36] [42], which is caused by reacting defensively towards anti-smoking messages. Thus, it is expected that participants having higher defensive responses to our intervention show less willingness to change their behavior to mitigate climate change. More specifically, the 25% of the participants from our study population who showed lower than or equal to neutral defensive response towards the system (Figure 5.6), also disagreed to show willingness

to change their behavior (with the exception of one participant). Thus, it is crucial to keep in mind while designing interventions to ensure that it elicits least amount of defensive responses. A considerable amount of correlation ($p = 0.37$) between *Perceived Contingency* and *Willingness to Change Behavior* scale suggest reinforcing the design elements that help establish dialogue between the system and its user, which may help lowering the defensive responses towards the system.

6.3 Effectiveness of Persuasive Strategies

Persuasive strategies from the PSD model [96] played a major role in the design of our intervention. We discuss the effect of these strategies from our study results below.

6.3.1 Significant Persuasive Effect of the Strategies

Our results show that the persuasiveness of all the persuasive strategies implemented in our system were significantly effective as seen in Table 5.8, with all the strategies having higher than neutral mean values in their perceived persuasiveness (Table 5.7. The highest rated strategy was *Simulation* (M = 5.56), which was implemented through showing illustrations of a simulated future of the in-game world affected by the decisions taken by the participant while playing the story game. As discussed in section 5.3.7, showing both positive and negative ending for the story elicited positive and negative emotions within the participants respectively. Ostrin et al. [101] stated that one of the main advantages of interactive narratives is their ability to enable the player empathize with the story elements. Considering that simulating the climate of the game's world enabled our participants to feel connected and emotional towards the story shows that *Simulation* strategy was effective in making our interactive narrative empathetic for the players. In our qualitative analysis, many participants shared their liking towards the Contributors screen (Figure 3.21) where we implemented *Cooperation* and *Social Comparison* strategies, which were highly rated in their perceived persuasiveness with mean values M = 5.17 and M = 5.09 respectively. These findings show the effectiveness of the implementation of strategies from Social Support category of the PSD model [96]. Moreover, considering that the pairwise comparison between the persuasive strategies showed significant difference in

the persuasive effect of the strategies (section 5.2.3), we can say that the implementation of the strategies in our system were significantly effective and helped make the system more persuasive towards raising awareness and motivating behavior change towards mitigating climate change.

6.3.2 Significant Positive Effect on Promoting Behavior Change

Additionally, all the persuasive strategies present in the system showed considerable positive correlation with the *Willingness to Change Behavior* scale, which indicates great success in the strategy implementations. The *Reduction* strategy showed the highest positive correlation with the *Willingness to Change Behavior* scale ($p = 0.64$), which indicates that participants found the summary of the data visualizations in textual format useful. However, usefulness of this implementation was only mentioned in one interview, which is surprising considering it had the highest correlation among all the variables in our study. More precisely, from our study population, only 30% of the participants showed low to no agreement in finding the *Reduction* strategy persuasive, among which belonged all the participants who did not agree to show willingness to change their behavior to mitigate climate change (Figure 5.9), indicating that those participants may have been ignorant in reading facts about climate change due to their unwillingness to change their behavior. The success of the *Reduction* strategy is an interesting find, considering this strategy's effectiveness could not be found in many studies. However, a study performed on 30 e-commerce applications [2] found that *Reduction* is the second most commonly used strategy in e-commerce applications and has been found to be a key factor in successful e-commerce systems.

The *Simulation* strategy also had considerably high correlation with the *Willingness to Change Behavior* scale, which was also found to be effective in other applications that implemented persuasive strategies for climate change awareness [140] [125]. We addressed some limitations of this strategy's implementation from the UbiGreen Transportation Display [56] application where participants wanted more variety in story visuals and wanted to see both positive and negative imagery based on game's performance. We addressed these limitations by having compelling visuals and variety in the environments in our interactive story game's scenarios, and we also added both positive and negative ending that were mentioned multiple times and have been

highly appreciated by our participants (section 5.3.7). Orji et al. [100] also reported the effectiveness of *Simulation* strategy in their study on encouraging healthy eating, as they found significant effectiveness of this strategy in motivating behavior change, emphasizing the fact that healthy lifestyle does not have immediate visible effect and simulating the outcome can have significant motivational impact. This was also noticed in our interviews as participants reported having emotional reaction to seeing the simulated future of the in-game world and how it was affected by their actions, which shows the effectiveness of simulating the outcomes of climate change.

6.3.3 Shortcomings of Customization Strategy

The *Customization* strategy had the lowest mean in perceived persuasiveness (Table 5.7), and it had no significant correlation with climate change awareness, perceived behavior control or willingness to change behavior to mitigate climate change. These findings show that the *Customization* strategy was the least effective among the implemented strategies. However, we found repeated mentions of the implementation of this strategy during our interviews as discussed in section 5.3.4. Participants liked seeing their customized character in the story game, and it offered sense of diversity and inclusion which made the system more relatable. Nilsen et al. [91] designed a game for earthquake preparedness where players were allowed to choose different avatars, and they also found no significant effect of avatar choice in increasing earthquake preparedness. The authors shared that avatar choice may have diverted the player's attention to the survival of the avatar and away from the surrounding environment of the game due to increased identification and similarity of the avatar. Comments from our participants also show increased relatedness and similarity with the avatar due to customization. This helps explain finding no significant correlation between *Customization* strategy and climate change awareness or behavior change towards mitigating climate change, as the customized avatar enabled them to feel more related to the avatar itself, but not the environment of the game, for which participants could not relate this strategy to climate change awareness. However, our results do not indicate any negative correlation with any of the variables and the *Customization* strategy. Hence, considering that the customization strategy increased likeness and relatedness towards the system, these are desirable outcomes of the

implementation of this strategy for which it is considered beneficial for the system.

6.3.4 Effectiveness of Social Support

Another important finding from our study was the success of social elements in our system design. From showing social media posts of people across the world to illustrating how the study participants were contributing towards mitigating climate change, these social elements were repeatedly mentioned in our interviews (section 5.3.6). Moreover, all the three persuasive strategies: *Social Learning*, *Cooperation* and *Social Comparison* from Social Support category of the PSD model [96] had slightly high correlations with the *Willingness to Change Behavior* scale (Figure 5.8). The fact that climate problem demands participation of people all around the world to be conscious about it, and that people are social beings who rely on each other to improve their quality of life by solving problems together [11], the success of social elements in our system that addresses a global phenomenon is self-explanatory. Moreover, strategies from the Social Support category are commonly found in interventions that address the climate change issue [49] [85] [22] [125] [14], which emphasizes the recommendation in implementing such strategies to raise awareness about climate change. Also, Ajzen [4] defined subjective norm as a determinant of behavioral intention, where subjective norm is "the perceived social pressure to perform or not to perform the behavior". Through implementing the *Cooperation* and *Social Comparison* in the Contributors screen (section 3.3), we emphasized subjective norm that was also mentioned by participants, where they felt togetherness by seeing others contributing to raising awareness about climate change. This motivated participants to perform better, while for some others, comparing their performance with others performances was the motivating factor (section 5.3.6).

6.3.5 Exploring Different Implementations of Strategies

Implementation of the persuasive strategies in our system were effective as all the strategies were found as significantly persuasive (Table 5.8). However, other ways of implementations can be explored as improvements. Especially, considering the success of the *Social Comparison* and *Cooperation* strategies, implementing those strategies earlier in the intervention is desirable as some participants claimed that

the Contributors screen was their favorite part of the system (section 5.3.6). Introducing the common goal of "Let's Make the Earth Green" as shown in Figure 3.21 at the beginning of the interactive narrative game can have a positive impact as it was found to elicit hopefulness and togetherness among the participants (section 5.3.6). *Reduction* strategy was among the most successful strategies in our system, and we received feedback from participants to find ways to further reduce their effort in learning about climate change such as, providing the climate change data visualizations within the interactive narrative. Considering the success of this strategy, having videos in the system explaining climate change information can also be explored that would reduce effort in learning. Moreover, *Simulation* strategy was rated the highest in perceived persuasiveness scale (Table 5.7), and in addition to our implementation of this strategy in the interactive narrative, we can show simulation of predicted data in the data visualization screens, such as showing expected world temperatures in future years which was suggested by a participant (section 5.3.9). Predicting climate change data is an aspect of climate research [110], which can be used to simulate outcome of climate change in data visualizations. Exploring the effectiveness of such different implementations of persuasive strategies is desirable for our research, since they have the potential of improving the persuasiveness of our system and may increase the level of awareness and promote positive behavior change to mitigate climate change.

Overall, the system's significant effect in increasing participants' perceived behavior control and willingness to change behavior to mitigate climate change shows the effectiveness of our system in bringing positive behavior change to mitigate climate change, which answers our RQ2. To answer RQ4: first, we found defensive responses to be a determining factor in the system's effect in encouraging positive behavior change to mitigate climate change, and we recommend reinforcing the system's perceived contingency by allowing back-and-forth conversation between the user and the system to minimize the defensive responses. Lastly, reducing the effort in learning about climate change, simulating the outcome of the phenomenon with compelling visuals, providing ways to observe others behaviors and creating social presence for the users within the system are design considerations that have been found to be effective in encouraging behavior change to mitigate climate change.

6.4 Design Recommendations

Based on the discussions above, we offer a set of guidelines for designing systems to raise awareness and encourage positive behavior change to mitigate climate change below:

1. **Incorporate Pleasing Aesthetics**:

   Designers need to make aesthetically pleasing visualizations that offer proper use of colors, animations and graphics that attract the user to the information displayed in the system. Our system's visual design had a long-lasting impression on participants as mentioned in the interview comments in section 5.3.4. Colors play an important role in data visualizations, as they are not only for aesthetics but also can be used to convey information. Our participants mentioned being able to identify regions suffering the most using the colors on the global map, and that it also helped understand the urgency of the climate change problem (section 5.3.1). Even simple details in the design elements such as, showing different facial expression depending on the scenario taking place in the game were noticed by participants, which emphasizes attention to detail in creating interesting graphics for a system. However, animations and character design needs to be handled carefully to not introduce eerie visuals as users seem to notice unnatural animations very easily (section 5.3.4). Moreover, having various options in character design helps support diversity and inclusion that was appreciated by participants. These details help build visuals that draws attention of the users and offers an engaging experience that should be considered in designing comprehensive systems.

2. **Minimize Complexity**:

   Showing simple visualizations such as, 2D choropleth map, line and bar charts are preferred over complex ones by non-visualization-experts [132], and they seem to have also been effective in providing an attractive and engaging experience to the participants of our study. Advances in technology lead to high expectation from users which sometimes are unnecessary. This has also become challenging and an enormous burden on the designers. As discussed in section

5.3.8, our participants liked the use of world map, line and bar charts, and were able to extract necessary information from them. Participants especially liked seeing the global map as it is more recognizable, and using animations and color to show the temperature changes limits the complexity of observing temperature change over the years. This shows that data regarding a complex issue such as climate change can be visualized in a simple manner which is useful for the general public. Moreover, designers should consider using textual descriptions as a complimentary to data visualizations since they help in reducing complexity of visualized data, as was discussed in section 5.3.1.

3. **Increase Interactivity and Feedback**:

   Designers need to increase interactivity, provide proper feedback, and address user interactions to help them establish a dialogue with the system. The interaction options provided in our data visualizations such as, sliders, playing/pausing animations, hovering and zooming were liked by our participants and allowed them to extract information about climate change (section 5.3.1). Moreover, increased interactivity and feedback can help minimize defensive response [94] which is important considering that defensive response was a key factor in raising awareness and promoting behavior change towards mitigating climate change (section 5.2.2). Some recommendations from our participants such as, showing overall world temperature and predicted temperatures of the future world can be incorporated to increase interactivity. Participants have also mentioned covering all aspects of climate change such as, industrialization and political influences, which could aid in increasing the system's credibility and reduce defensive responses. Moreover, improved animations in the story game would offer a more engaging dialogue between the system and the users, since some participants complained about the game's animation not being as convincing as seen in commercial videogames (section 5.3.4). Considering these improvements, the system designers need to offer multiple methods of interaction to ensure that the user's actions are addressed with proper feedback that would help minimize defensive responses.

4. **Enable Exercising Choices**:

System designers should simulate daily life climate actions to show how individual's day-to-day life can affect the climate, and encourage practicing different behaviors to demonstrate their consequences. As discussed in section 5.3.2, participants liked how the story game reflected their daily life decisions and allowed exploring different decisions. This enabled participants understand the consequences of even the simple tasks we perform in our daily life. Also, exercising different choices help better understand the reasons behind performing a climate actions, as participants shared that some actions that they had thought were for economical reason (e.g., saving electricity), can also impact the climate. Moreover, exercising choices in a story game helps users drive the story instead of a linear storyline, which is a crucial part that discerns interactive narratives from traditional storytelling. Thus, designers need to ensure providing multiple choices while designing interactive narratives.

5. **Simulate Outcomes**:

   By illustrating both positive and negative simulation of the future world that can result from how humans deal with the climate change problem, system designers can enable users better understand the consequences of their actions. In addition to letting users exercise different choices, the experience remains incomplete without proper visuals simulating how the future world can be impacted by climate change. Showing both positive and negative outcome have their benefits, as each elicited positive and negative emotion respectively within the participants as discussed in section 5.3.7. The simulations also had a long-term effect on the participants due to its emotional impact. Moreover, participants also wished to see predicted data of future world's temperature (section 5.3.9). This further supports the need of simulations as people like seeing actual impact of climate change. This may be due to the difficulty in comprehending the outcome of climate change since the effects are not immediate, as one participant stated that they felt the change would not take effect in hundreds of years, but seeing the simulations helped better grasp the consequences of climate change (section 5.3.8). Hence, it is recommended to simulate how our climate can change depending on how we deal with the climate change problem.

6. **Reduce Effort in Learning**:

   Reduce effort in learning about climate change and its related factors through providing facts and explanations in simple textual format and highlighting the key factors. The *Reduction* persuasive strategy was among the highest rated in perceived persuasiveness scale (Table 5.7), also was highly correlated with willingness to change behavior to mitigate climate change. Making the learning experience easier for users is important, especially for complex issues such as the climate change. In addition to providing summary of information displayed in a screen, user effort can also be reduced through animations as many of our participants shared that they enjoyed seeing the world temperature changing in an animated matter (section 5.3.1). This indicates that having videos and narrations may also aid in reducing efforts for users. Such features help convey information without the need of user interaction, in addition to helping users who are not familiar with using data visualizations. Hence, system designers should provide means for reducing efforts for users to understand the issues related to climate change through simple explanations, animations, videos and narrations.

7. **Create Social Presence**:

   Encourage participation in practicing climate friendly behaviors by demonstrating how others are also contributing to tackle this problem which requires collective effort. In our system, we set a common goal to make the earth green for the participants (Figure 3.21. As discussed in section 5.3.6, this created a sense of togetherness and provided hope in tackling the climate change problem together. Considering that climate change is a collective problem, it is especially crucial to encourage cooperation in mitigating climate change, which can be achieved by creating such social presence in the system. By showing how others are contributing to the common goal, we also enabled participants to compare their contributions with others, which motivated to perform better for low performing participants (section 5.3.6). Moreover, the Twitter feed showing latest posts regarding climate change from users around the world (Figure 3.3) helped make our participants more aware about climate change (section 5.3.6),

and encouraged them to participate more in discussions on the topic (section 5.3.8). Thus, we encourage designers to incorporate social elements to motivate users to participate in mitigating climate change.

6.5 Limitations and Future Work

Our findings show that our system was successful in meeting the goals of this research, however, there are some shortcomings that can lead to future research directions. First, the lack of significant results in raising awareness among the participants can be attributed to insufficient variation in our sample. Since most of our participants were already highly aware about climate change, increasing the sample size and having more variation in the level of awareness among the participants may possibly bring new findings and make the results significant. This might also help address the issue where we could not find sufficient effect on the participants' perceived behavior control to mitigate climate change.

Moreover, we noticed that our age distribution was unbalanced. There were a greater percentage of younger compared to older participants (over 40 years old). Looking at the distribution of the age groups in our demographics (Table 5.1), we can see that most of our participants (83%) are below 40 years of age. Since our intervention was designed for the general public, balancing the number of participants in different age groups would provide a better representation of the target audience. It is also in our interest to introduce this intervention to the younger generation (aged below 18 years), especially, school students since many participants mentioned this would be beneficial for children due to its learning components and gamified features. This can be offered as a classroom exercise similar to the work by Varma et al. [136] where they helped middle school students understand the science behind the greenhouse effect through interactive visualizations. Since our study was designed during the Covid-19 pandemic, we excluded school students from joining the study as it was difficult at that time to arrange sessions including the students with their parents considering the ethical issues involved. However, conducting this study and finding its effectiveness on the adult population has paved the way to cater the intervention for the younger generation and conducting a future study with younger participants.

The distribution of genders of our participants were almost equally split between male (54%) and female (46%), and we did not have any participants of other genders. Again, as a better representation of the general public, it is desirable to include participants of other genders. Additionally, we did not analyze any differences between the responses from different genders and age groups. It would be interesting to perform separate analysis on the data collected from different genders and age groups in future work, since these factors have been found to affect the perception of climate change among individuals [3]. Moreover, capturing participants' nationality and identifying differences in responses from different countries can be considered in a future study, as perception of climate change related problems have been found to vary between people of different nationalities [70]. Moreover, background of the participants also impacts their perception of the interactive narrative as was found by Frey et al. [54]. Thus, in our future work we may explore the intervention's effect on different demographics.

Many of the limitations of our intervention design can be found from the proposed improvements suggested by participants in section 5.3.9. Shortcomings of the interactive story game mostly revolved around limited scenarios, lack of complexity in the game, and animations not being on par with industry standard commercial videogames. These limitations can all be addressed in future iterations of the design and research through including dedicated designers and animators for the game design. Also, the intervention was designed to run on web browsers without requiring to install any additional software, which allowed smooth delivery of the intervention that only required the basics– a computer with access to the web. But this also had its technical limitations as advanced graphics and interactions found in commercial computer games could not be integrated with browser support. Building a dedicated computer game using advanced game engines such as Unity [130] or Unreal Engine [41] would offer the flexibility in building a more compelling videogame. However, this was out of scope for our research considering we wanted to build something easily accessible to the wider audience. But to address the improvements suggested by participants, a future study can consider building an advanced computer game with much more compelling graphics and complex interactions. This can be further enhanced by supporting mobile platform for the intervention, which can be achieved either

through responsive web design or a dedicated mobile application. Our system was responsive enough to support different computer screens and large handheld displays such as, tablet computers, however, displaying comprehensive data visualizations will be a challenge in small screens such as mobile devices. Instead of a standalone mobile application, it may work as a complimentary to the computer application where users can see simpler visuals. Nevertheless, other researchers can take this intervention to the next level by supporting mobile devices and expand on the features.

Chapter 7

Conclusion

The goal of our research was to build an intervention that raises awareness and encourages positive behavior change to mitigate climate change for the general public. The findings of our research suggest that our intervention was successful in achieving the set targets. To the best of our knowledge, combination of data visualizations and interactive narratives is a novel way to address the climate change problem. By introducing this combined approach, we offer benefit to the research community by providing a new way to communicate about this global phenomenon to the general public.

Moreover, the findings of this research contributes to the field of data visualizations, interactive narratives and climate change research, and offers multiple design recommendations that can benefit future researchers to build interventions in mitigating climate change related problems. Such interventions have to ensure that they minimize the defensive responses by offering a highly interactive experience for its users, since defensive responses were found as one of the primary factors that influenced awareness and behavior towards climate change. Considering the success of providing ways to reduce the efforts for the participants to learn about the visualized data through providing summaries: textual descriptions that provides insight into the visualized data should be an integral part for data visualizations. Participants were motivated by seeing the simulations of the future of the climate that depicted both positive and negative outcomes, thus, demonstrating how our actions can impact the future needs to be included in such interventions to provide a better understanding of climate change. Reinforcing social presence within the intervention through providing ways to learn from observing others behaviors impacted the participants' behavior towards climate change. Considering that climate change related problems require collective effort, integrating social elements within such interventions are highly encouraged as they have been found to be effective in our findings.

In conclusion, this research paves a way to build new interventions combining data visualizations and interactive narratives to raise awareness about climate change and bring positive behavior change in mitigating climate change. We believe that our findings will benefit future researchers and through mass adaptation of such interventions, we can battle the negative consequences of climate change that threatens our world and secure a better future for humankind.

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Appendices

Appendix A

Research Ethics Board Approval Letter

Social Sciences & Humanities Research Ethics Board Letter of Approval

October 29, 2021
Ashfaq A Zamil Adib
Computer Science\Computer Science

Dear Ashfaq A,

REB #: 2021-5767
Project Title: Persuasive Visual Interface: Using Data Visualization and Interactive Visual Narratives for Climate Change Awareness

Effective Date: October 29, 2021
Expiry Date: October 29, 2022

The Social Sciences & Humanities Research Ethics Board has reviewed your application for research involving humans and found the proposed research to be in accordance with the Tri-Council Policy Statement on Ethical Conduct for Research Involving Humans. This approval will be in effect for 12 months as indicated above. This approval is subject to the conditions listed below which constitute your on-going responsibilities with respect to the ethical conduct of this research.

Effective March 16, 2020: Notwithstanding this approval, any research conducted during the COVID-19 public health emergency must comply with federal and provincial public health advice as well as directives from Dalhousie University (and/or other facilities or jurisdictions where the research will occur) regarding preventing the spread of COVID-19.

Sincerely,
Dr. Karen Foster, Chair

Appendix B

Recruitment Notice

Hello,
We are inviting you to a study from the Persuasive Computing lab at Dalhousie University on climate change awareness. In this study, you will go through data visualizations, play an interactive story game, and fill-out surveys to share your opinion on the system. Your participation will take around 15-30 minutes.

To participate: you must be at least 18 years old, and you will need to use a laptop/desktop/tablet computer.

If you are interested, please click this link to get started:
https://research.ashfaqadib.me/

Thank you.

Lead Researcher
Ashfaq A Zamil Adib (ashfaq.adib@dal.ca)
Master of Computer Science
Faculty of Computer Science, Dalhousie University

Academic supervisor
Dr. Rita Orji (rita.orji@dal.ca)
Faculty of Computer Science
Dalhousie University
Research ethics board approval reference: 2021-5767

Appendix C

Consent Form

Thank you for your interest in this study. Information regarding your participation is provided below.

What You Will be Asked to do

In this study, first, you will fill-out an initial survey that contains some demographic and climate change awareness questions. Then, you will use a website that contains data visualization of climate change (e.g., world temperature, carbon emission etc.) and play an interactive story game where your decisions will determine the outcome of the game's story. After playing the game, you will fill-out a survey to provide feedback on the website. Your participation should take approximately 15-30 minutes.

Data Protection and Privacy

Collected data will not be used to personally identify any individual, all data will be anonymized using unique identifiers (e.g., P1). You may wish to participate in an optional interview after completing this study: in that case, your quotes may be used in research publications using an anonymized identifier. All the data will be stored in secured servers located in Canada, and password-protected personal computers of the lead researcher and research supervisor.

Usage of Collected Data

Data collected in this study will only be used for research purposes. The lead researcher will describe and share general findings of this research in his master's thesis and possibly through publications in conferences and journals. All collected data will be destroyed 5 years after completing/reporting the results.

Benefits for Your Participation

There will be no direct benefit to you for participating in this research. However, you may learn about climate change and develop a positive attitude towards how

your actions may impact the climate. Moreover, your participation might contribute to new findings in using visualizations for persuasion of positive attitude change towards climate change. If you would like to see the findings of the study when they are available, please visit our lab's website (https://pcl.cs.dal.ca).

Risks Involved

This study presents evidence on climate change which may change the perspective of people who are not aware of its effects, and/or of those people who do not understand the severe consequences of this phenomenon. Moreover, the interactive story game will have depictions of the future based on your interactions within the story; this may lead to depictions where the future is badly affected by harsh climate. Your participation will mean that you are aware of the risks involved and have agreed to participate regardless of the associated risks.

Withdrawing Participation

Your participation in this research is entirely your choice, and you may leave the study at any time. All you need to do is close your browser. Incomplete surveys will not be used for analyses. However, if you complete the study, removing your information will not be possible as your responses will be anonymized and will not be identifiable.

If You Have Any Questions

For any questions about the study please contact the lead researcher Ashfaq Adib (ashfaq.adib@dal.ca) and/or research supervisor Dr. Rita Orji (rita.orji@dal.ca). If you have any ethical concerns about your participation in this research, you may contact Research Ethics, Dalhousie University at (902) 494-3423, or email ethics@dal.ca (with reference REB file # 2021-5767)."

Start Participation

By clicking the start button below, you consent to participate in the study and declare that you are at least 18 years old. Please use a laptop/desktop computer to participate in this study since the data visualizations and interactive story game is not well supported for mobile browsers.

Appendix D

Pre-Intervention Questionnaire

Demographics Questions

1. Choose your age group
   - ○ 23-30 years
   - ○ 30-40 years
   - ○ 40-50 years
   - ○ Above 50 years
   - ○ Prefer not to answer

2. Select your gender
   - ○ Male
   - ○ Female
   - ○ Prefer not to answer
   - ○ Other: _____

3. What is the highest level of education you have completed?
   - ○ Less than high school
   - ○ High school graduate
   - ○ College diploma
   - ○ Bachelor's degree
   - ○ Master's degree
   - ○ Doctorate degree
   - ○ Prefer not to answer
   - ○ Other: _____

4. What is your marital status?
   - ○ Single
   - ○ Married

- ○ Widowed
- ○ Divorced
- ○ Separated
- ○ Prefer not to answer
- ○ Other: _____

Climate Change Awareness Scale

Questions	Measurement Scale (1-7)
Climate change is one of the greatest threats to humankind.	1 - Strongly Disagree 2 - Disagree 3 - Slightly Disagree 4 - Neutral 5 - Slightly Agree 6 - Agree 7 - Strongly Agree
The numerous storms and the warm winters make it clear that climate change is taking place.	
Climate change is not as dangerous as we are told.	
It is not at all clear that climate change actually exists.	

Perceived Behavior Control Scale

Questions	Measurement Scale (1-7)
Whether or not I try to mitigate global climate change is completely up to me.	1 - Strongly Disagree 2 - Disagree 3 - Slightly Disagree 4 - Neutral 5 - Slightly Agree 6 - Agree 7 - Strongly Agree
I am confident that if I want, I can try to mitigate global climate change.	
I have resources, time, and opportunities to try to mitigate global climate change.	

Willingness to Change Behavior Scale

Questions	Measurement Scale (1-7)
I plan to save household electricity to mitigate climate change.	1 - Strongly Disagree 2 - Disagree 3 - Slightly Disagree 4 - Neutral 5 - Slightly Agree 6 - Agree 7 - Strongly Agree
I plan to drive less to mitigate climate change.	
I plan to avoid using disposable, single-use items to mitigate climate change.	
I plan to use reusable, recyclable products to mitigate climate change.	
I plan to recycle household waste to mitigate climate change.	

Appendix E

Post-Intervention Questionnaire

Perceived Interactivity Scale

Questions	Measurement Scale (1-7)
The climate change data visualizations were interactive.	1 - Strongly Disagree 2 - Disagree 3 - Slightly Disagree 4 - Neutral 5 - Slightly Agree 6 - Agree 7 - Strongly Agree
The climate change data visualizations allowed me to perform a lot of actions on its content.	
The climate change data visualizations allowed me to access information in a variety of ways.	

Perceived Contingency Scale

Questions	Measurement Scale (1-7)
I felt like I was engaged in an active dialogue with the story game.	1 - Strongly Disagree 2 - Disagree 3 - Slightly Disagree 4 - Neutral 5 - Slightly Agree 6 - Agree 7 - Strongly Agree
My interactions with the story game felt like a back-and-forth conversation.	
I felt as if the story game and I were involved in a mutual task of browsing the information.	
I felt as if the information on the story game was well connected to my actions.	
The story game was aware of the actions I performed.	

Defensive Responses Scale

Questions	Measurement Scale (1-7)
I thought the system tried to manipulate my beliefs on climate change.	1 - Strongly Disagree 2 - Disagree 3 - Slightly Disagree 4 - Neutral 5 - Slightly Agree 6 - Agree 7 - Strongly Agree
I thought the climate change information on the system was exaggerated.	
I thought the climate change information on the system was overblown.	
I thought the climate change information on the system was boring.	

System Usability Scale

Questions	Measurement Scale (1-7)
I think that I would like to use this system frequently.	1 - Strongly Disagree 2 - Disagree 3 - Slightly Disagree 4 - Neutral 5 - Slightly Agree 6 - Agree 7 - Strongly Agree
I found the system unnecessarily complex.	
I thought the system was easy to use.	
I think I would need the support of a technical person to be able to use this system.	
I found the various functions in this system were well integrated.	
I thought there was too much inconsistency in this system.	
I would imagine that most people would learn to use this system very quickly.	
I found the system very cumbersome to use.	
I felt very confident using the system.	
I needed to learn a lot of things before I could get going with this system.	

Familiarity with Data Visualization Scale

Questions	Measurement Scale (1-7)
I feel confident using visual data to understand information.	1 - Strongly Disagree 2 - Disagree 3 - Slightly Disagree 4 - Neutral 5 - Slightly Agree 6 - Agree 7 - Strongly Agree
Visual patterns in scientific data helps me learn.	
I can analyze visual data in many different ways.	
I can draw conclusions from visual data.	

Perceived Persuasiveness Scale

Questions	Measurement Scale (1-7)
This feature is personally relevant to me.	1 - Strongly Disagree 2 - Disagree
This feature influences me to be aware of climate change.	3 - Slightly Disagree 4 - Neutral
This feature makes me reconsider my attitude towards climate change awareness.	5 - Slightly Agree 6 - Agree 7 - Strongly Agree

Note: Questions for this scale was repeated for each of the persuasive strategies implemented.

Climate Change Awareness Scale

Questions	Measurement Scale (1-7)
Climate change is one of the greatest threats to humankind.	1 - Strongly Disagree 2 - Disagree
The numerous storms and the warm winters make it clear that climate change is taking place.	3 - Slightly Disagree 4 - Neutral
Climate change is not as dangerous as we are told.	5 - Slightly Agree
It is not at all clear that climate change actually exists.	6 - Agree 7 - Strongly Agree

Perceived Behavior Control Scale

Questions	Measurement Scale (1-7)
Whether or not I try to mitigate global climate change is completely up to me.	1 - Strongly Disagree 2 - Disagree
I am confident that if I want, I can try to mitigate global climate change.	3 - Slightly Disagree 4 - Neutral
I have resources, time, and opportunities to try to mitigate global climate change.	5 - Slightly Agree 6 - Agree 7 - Strongly Agree

Willingness to Change Behavior Scale

Questions	Measurement Scale (1-7)
I plan to save household electricity to mitigate climate change.	1 - Strongly Disagree 2 - Disagree 3 - Slightly Disagree 4 - Neutral 5 - Slightly Agree 6 - Agree 7 - Strongly Agree
I plan to drive less to mitigate climate change.	
I plan to avoid using disposable, single-use items to mitigate climate change.	
I plan to use reusable, recyclable products to mitigate climate change.	
I plan to recycle household waste to mitigate climate change.	

Appendix F

Interview Questions

1. Tell us what you liked and disliked about the data visualization part of the website?
2. Tell us what you liked and disliked about the interactive narrative part of the website?
3. Which part of the website did you like better and why?
4. Were you able to learn anything new from the system?
5. Regarding your perspective on climate change, did anything change after using the system?
6. Was there anything in the system that changed your level of awareness on climate change?
7. Did the system introduce any changes to your ability in mitigating climate change?
8. Did anything from the system cause an attitude change to you towards climate change?
9. Do you have any recommendations in improving the system?