INSTITUTO
UNIVERSITÁRIO
DE LISBOA

A serious game for raising air pollution awareness in children

Tiago Manuel Barreto Relvas

Master in,
Computer Engineering

Supervisor:
PhD Pedro Figueiredo Santana, Assistant Professor,
Iscte-Instituto Universitário de Lisboa

Co-supervisor:
PhD Pedro Lopes da Silva Mariano, Junior Researcher,
Iscte-Instituto Universitário de Lisboa

November, 2021

TECNOLOGIAS
E ARQUITETURA

Department of Information Sciences and Technologies

A serious game for raising air pollution awareness in children

Tiago Manuel Barreto Relvas

Master in,
Computer Engineering

Supervisor:
PhD Pedro Figueiredo Santana, Assistant Professor,
Iscte-Instituto Universitário de Lisboa

Co-supervisor:
PhD Pedro Lopes da Silva Mariano, Junior Researcher,
Iscte-Instituto Universitário de Lisboa

November, 2021

Dedico esta dissertação aos meus pais Jorge e Ana Paula e ao meu irmão João

Agradecimento

Ao longo do desenvolvimento da tese, tive um apoio constante por parte das pessoas mais próximas e importantes na minha vida. Agradeço aos meus pais, tios, avós, irmão e amigos mais próximos que sempre me apoiaram e demonstraram interesse sobre o meu progresso na escrita da tese.

Agradeço também às educadoras do ATL, especialmente às educadoras Sílvia e Eliana, e aos encarregados de educação dos participantes que permitiram a realização dos testes com os participantes, que provou ser bastante complicado devido á pandemia COVID-19.

Queria agradecer aos meus orientadores Pedro Santana e Pedro Mariano por me terem ajudado bastante ao longo do ano, por me terem esclarecido várias dúvidas que iam surgindo durante o desenvolvimento da dissertação e queria também agradecer à investigadora Doutora Marta Almeida pelas sugestões que deu para melhorar o resultado final do trabalho.

Esta dissertação foi desenvolvida no quadro do Projeto ExpoLIS (LISBOA-01-0145-FEDER-032088), financiado pelo FEDER e por fundos nacionais, através da FCT–Fundação para a Ciência e Tecnologia.

Resumo

A poluição atmosférica tem sido um dos temas mais discutidos no mundo nos últimos anos, o que está a afetar a atmosfera do nosso planeta e a nossa saúde em geral. Mais de 2.6 mil milhões de pessoas no mundo sofrem de poluição do ar interior dentro das suas casas, isto diz-nos que são necessários esforços para aumentar a consciência das pessoas sobre a poluição do ar. A utilização de jogos sérios e a gamificação de aplicações têm aumentado a perceção das pessoas, mas estes efeitos acabam por ser de curto prazo. Este trabalho apresenta "Problemas no Ar", um jogo desenvolvido em Unity sobre poluição atmosférica onde o objetivo do jogador é monitorizar a poluição atmosférica interior e exterior com sensores dispostos por várias zonas urbanas e aprender as possíveis causas da poluição em cada zona, tentando promover comportamentos pró-ambientais nas crianças. Este jogo permite que educadores consigam configurar os problemas que o jogador tem de resolver. Questionários pré- e pós-jogo sobre a poluição do ar foram elaborados para avaliar a perceção de vinte alunos do ensino básico antes e depois de jogar o jogo, a pontuação de usabilidade do jogo também foi medida. Os resultados mostram que o jogo teve efeitos positivos na perceção dos participantes, alguns itens foram significativos, outros não tão significativos. Em termos de usabilidade do jogo, o valor médio foi de 75 de 100, o que é aceitável.

Palavras-chave:

Jogo sério, Poluição atmosférica, Perceção, Crianças, Educação

Abstract

Air pollution has been one of the most discussed topics in the world in the last years, due to its effects on the atmosphere of our planet and our health overall. Currently, over 2.6 billion people are exposed to indoor air pollution, which tells us that efforts are needed to raise people's awareness about air pollution. The use of serious games and gamification of apps have raised people's perception, but these effects end up being short-term. This work presents "Problemas no Ar", a game developed in Unity about air pollution where the player's goal is to control a character tasked to monitor indoor and outdoor air pollution with sensors in several city zones. While playing, children are expected to learn the possible causes of pollution in each zone and, this way, the game attempts to promote pro-environmental behaviours. This game allows educators to configure the problems that the player has to solve. Pre- and post-surveys about air pollution were elaborated to evaluate perception of twenty students of an elementary school before and after playing the game. Participants' gameplay experience was also evaluated through a usability score. Results show that the game provided some significant positive effects on participants' perception. In terms of usability scores, the mean value was 75 out of 100, a value that is acceptable.

Keywords: Serious game, Air pollution, Perception, Children, Educational

Index

LIST OF FIGURES ..... **XI**

LIST OF TABLES ..... **XIII**

LIST OF ACRONYMS ..... **XV**

1. INTRODUCTION **1**

1.1 MOTIVATION 1

1.2 CONTEXT 2

1.3 RESEARCH QUESTIONS 2

1.4 GOALS 3

1.5 RESEARCH METHODOLOGY 3

1.6 SCOPE 4

1.7 DOCUMENT STRUCTURE 5

2 LITERATURE REVIEW **7**

2.1 AIR QUALITY MONITORING AND VISUALIZATION 7

2.2 SERIOUS GAMES AND GAMIFICATION 9

2.3 CHILDREN'S POLLUTION PERCEPTION 12

3 GAME DESIGN AND DEVELOPMENT **15**

3.1 EARLY GAME DESIGN DECISIONS 15

3.1.1 Storyline and Storyboard *15*

3.1.2 Minigames *17*

3.1.3 Game Characters *19*

3.2 GAME IMPLEMENTATION 19

3.2.1 Game's City Map and UI elements *20*

3.2.2 Menu Scene and Characters *21*

3.2.3 Controls of Camera and Bicycle *22*

3.2.4 Sensor Minigame *23*

3.2.5 Dilemma Minigame *29*

3.2.6 Configurable Game Dialogue and Minigames *32*

4 EVALUATION **37**

4.1 AIR POLLUTION QUESTIONNAIRE 38

4.1.1 Likert Scale Items and Multiple-Choice Grid Question *39*

4.1.2 Open-Ended Questions *40*

4.2 GAME EXPERIENCE SURVEY 48
4.3 DISCUSSION 50
5 CONCLUSIONS AND FUTURE WORK 53
5.1 CONCLUSIONS 53
5.2 FUTURE WORK 54
REFERENCES 57
ANNEX A. AIR POLLUTION QUESTIONNAIRE 61
ANNEX B. GAME EXPERIENCE SURVEY 65

List of Figures

FIGURE 3.1 HAND-DRAWN STORYBOARD OF GAME. 16
FIGURE 3.2 HAND-DRAWN SKETCH OF CITY 17
FIGURE 3.3 FLOWCHART OF THE SENSOR MINIGAME. 18
FIGURE 3.4 FLOWCHART OF THE DILEMMA MINIGAME. 19
FIGURE 3.5 SCREENSHOT OF BICYCLE AND BANNER "JOGADOR" ABOVE IT. 20
FIGURE 3.6 OVERALL VIEW OF CITY AND UI ELEMENTS OF GAME. 21
FIGURE 3.7 SCREENSHOT OF THE GAME'S MENU SCENE. 21
FIGURE 3.8 UI CONTROL KEYS BEFORE INFORMAL TESTING. 22
FIGURE 3.9 UI CONTROL KEYS AFTER INFORMAL TESTING. 22
FIGURE 3.10 CLASS DIAGRAM OF THE MAIN CLASSES OF SENSOR MINIGAME. 25
FIGURE 3.11 FIXED AND EXPENSIVE SENSOR IN THE CENTRE OF THE IMAGE 25
FIGURE 3.12 PORTABLE EXPENSIVE SENSOR IN THE CENTRE OF THE IMAGE 26
FIGURE 3.13 PORTABLE CHEAP SENSOR IN THE CENTRE OF THE IMAGE 26
FIGURE 3.14 SPRITES REPRESENTING POLLUTION LEVELS. 27
FIGURE 3.15 OUTDOOR POLLUTION TILEMAP 28
FIGURE 3.16 INDOOR POLLUTION TILEMAP. 28
FIGURE 3.17 DILEMMASCRIPT OBJECT. 30
FIGURE 3.18 EXAMPLE OF A DILEMMA 30
FIGURE 3.19 CLASS DIAGRAM OF THE MAIN CLASSES OF DILEMMA MINIGAME. 31
FIGURE 3.20 POSITIVE HEALTH EFFECT REACTION ANIMATION TRIGGERED. 31
FIGURE 3.21 NEGATIVE HEALTH EFFECT REACTION ANIMATION TRIGGERED. 32
FIGURE 3.22 STRUCTURE OF A DILEMMA OBJECT IN DILEMMA MINIGAME XML FILE. 33
FIGURE 3.23 EXAMPLES OF DIALOGUE OBJECTS IN LIST. 34
FIGURE 3.24 A SECTION OF THE LIST OF LOCATION OBJECTS. 34
FIGURE 3.25 STRUCTURE OF GUIDEDIALOGUE. 34
FIGURE 3.26 STRUCTURE OF SENSORLOCATIONDIALOGUE OBJECT IN SENSOR MINIGAME XML FILE. 35
FIGURE 4.1 TEST SETUP. 37
FIGURE 4.2 CORRECT ANSWERS IN MULTIPLE-CHOICE GRID QUESTION IN PRE AND POST-SURVEY. 40
FIGURE 4.3 ANSWERS OF FIRST OPEN-ENDED QUESTION. 41
FIGURE 4.4 WORD CLOUD OF PRE-SURVEY ANSWERS IN OPEN-ENDED QUESTION NUMBER TWO 42
FIGURE 4.5 WORD CLOUD OF POST-SURVEY ANSWERS IN OPEN-ENDED QUESTION NUMBER TWO 42
FIGURE 4.6 BAR CHART OF ANSWERS IN OPEN-ENDED QUESTION NUMBER TWO 43
FIGURE 4.7 WORD CLOUD OF PRE-SURVEY ANSWERS IN OPEN-ENDED QUESTION NUMBER THREE 44
FIGURE 4.8 WORD CLOUD OF POST-SURVEY ANSWERS IN OPEN-ENDED QUESTION NUMBER THREE 44
FIGURE 4.9 BAR CHART OF ANSWERS IN OPEN-ENDED QUESTION NUMBER THREE. 45

FIGURE 4.10 WORD CLOUD OF PRE-SURVEY ANSWERS IN OPEN-ENDED QUESTION NUMBER FOUR 46
FIGURE 4.11 WORD CLOUD OF POST-SURVEY ANSWERS IN OPEN-ENDED QUESTION NUMBER FOUR ... 47
FIGURE 4.12 BAR CHART OF ANSWERS IN OPEN-ENDED QUESTION NUMBER FOUR. 47

List of Tables

TABLE 2.1 AIR QUALITY INDEX SCALE..... 8
TABLE 3.1 EXPECTED LEVEL OF POLLUTION OF EACH CITY ZONE 17
TABLE 3.2 BRIEF DESCRIPTION OF EACH CLASS INVOLVED IN THE SENSOR MINIGAME..... 24
TABLE 3.3 BRIEF DESCRIPTION OF THE MAIN CLASSES INVOLVED IN THE DILEMMA MINIGAME..... 29
TABLE 4.1. LIKERT ITEMS RESULTS OF POST- AND PRE-SURVEY ABOUT AIR POLLUTION. 40
TABLE 4.2. POSITIVE ASPECTS OF GAME. 48
TABLE 4.3. NEGATIVE ASPECTS OF GAME. 49
TABLE 4.4. GAME EXPERIENCE SURVEY LIKERT ITEMS RESULTS. 49

List of Acronyms

CO - Carbon Monoxide

EPA - Environmental Protection Agency

GIS - Geographic Information Systems

IQ - Intelligence quotient

PM - Particle Matter

SUS - System Usability Scale

TAM - Technology Acceptance Model

WHO - World Health Organization

1. Introduction

1.1 Motivation

Air pollution has been a serious issue in recent years that needs to be addressed. The presence of smog in major cities plus the poor indoor air quality in people's homes caused by things such as the use of fireplaces can lead to cancer, respiratory and heart diseases [1]. World Health Organization (WHO) states that 2.6 billion people of low and middle-income countries around the world are exposed to indoor air pollution [2]. Several studies showed that air pollution with high concentrations of polycyclic aromatic hydrocarbons, particulate matter (PM) with diameter less than 2.5 μm (PM2.5) and NO_2 have been affecting children and adults' nervous systems, showing an increase in ADHD (Attention Deficit Hyperactivity Disorder), autism and lower intelligence quotient (IQ) levels in children, and dementia, depression and episodic memory in adults [3] Most children in Lisbon, are also constantly exposed in school to high concentrations of PM2.5 and PM10 [4] on a weekly basis due to bad ventilation. Having also high CO_2 concentrations in poorly ventilated classrooms can impact the student's performance in class [5] [6].

In terms of indoor air quality perception, it has been shown that families with low incomes perceive the air quality through mostly, vision, smell, and comfort in terms of room temperature [7]. They associate a good indoor air quality with how tidy and clean the rooms are and they also think that products such as deodorants, scented candles and cleaning products are ways to improve indoor air quality. This shows the lack of awareness these low-income families have because human senses like vision and smell cannot detect every pollutant and the use of scented candles is harmful to our health due to the particles that they release when lit [8].

Regarding the people's risk perception of air pollution, in recent years there has been an increase in the number of studies evaluating it, several of these studies associate a better risk perception of air pollution from people who have had bad experiences previously with pollution. Overall, studies appeal to the implementation of policies with the purpose of reducing the impacts caused by air pollution, but these laws will only be possible to adopt if populations around the world show their willingness to change their behaviours to a more pro-environmentalist behaviour [9].

These results show that efforts are needed to raise awareness of people regarding air pollution and encourage them to practice more pro-environmental behaviours.

1.2 Context

One of the areas that this dissertation will be focusing on is air pollution and its monitorization. Projects like ExpoLIS [10] focus on building networks of pollution sensors that are attached to public transports to gather air pollution data around the cities [11] to be able to monitor which areas of a city pollute more. Having this kind of monitoring enables people to react and try addressing the areas which have more air pollution with governing entities. Air pollution data from monitoring stations can also be provided to the people through applications [12]. With these applications, users can be more aware of what areas are more polluted and should be avoided.

An area that is related to this dissertation is the representation of air pollution data using game engines, such as Unity. Some previous work has focused on this subject and created 3D environments that allow users to visualise different levels of pollution in a city. "CityOnStats" [13] is an example, where the players control a bus around a 3D representation of an automatically generated city based on existing maps. With this bus, the player would obtain several readings of carbon monoxide (CO) in different parts of the city and visualize levels of pollution in different visual modes. Usability test results showed that participants enjoyed interacting with this visualization tool. Another example is the SwarmCity project [14], which also built a 3D environment using the Unity engine. More related to the smart cities approach, this 3D environment consists in a virtual city where a group of virtual drones are constantly collecting pollution; it is based on real data from the Spanish capital Madrid, including traffic, pedestrian density, and temperature data. Once collected, drones would go to a base station so the data would be processed and presented to the user through a virtual reality headset display.

The second area that this dissertation is also inserted is serious games and gamification, a term that originated in the '70s by Clark C. Abt [15]. He suggested that games should also be used for education, not only for entertainment purposes. Throughout the recent years, this subject has been growing not only for commercial but also for academic purposes [16]. Since this dissertation is focused on air pollution, most serious games and gamification of computer applications about air pollution will be reviewed.

1.3 Research Questions

This dissertation addresses four main research questions, namely:

- What perception of air pollution do elementary school students have currently in Portugal?
- Can a serious game improve elementary school students' awareness of air pollution?
- Can a serious game for environmental awareness still be fun to play?

- Which game mechanics foster air pollution awareness in an entertaining way?

These questions have the utmost importance of knowing their answers since there is not much work that evaluates elementary school students' perception here in Portugal. It is also important to know and validate if serious games can raise air pollution perception to elementary students. Only a few of the reviewed works about serious games' positive effects were aimed at students of these grades. most of the work reviewed aims at students of higher grade levels. It is also imperative to confirm if serious games about environmental awareness provides an enjoyable game experience and what game mechanics students might enjoy and learn from it at the same time.

1.4 Goals

The first goal of this dissertation is to review the state of the art of recent serious games and the effects that they provided in terms of knowledge.

The second goal is to develop a serious game about air pollution to raise awareness regarding indoor and outdoor air pollution to elementary school students.

The third goal is to make the game easily configurable in terms of dialogue and game's length so that educators and teachers that intend to use this serious game as an education tool are able to customise it into their own teaching methods.

Lastly, another goal of this dissertation is to evaluate the participants' gameplay experience to see if the game is intuitive and engaging for the user.

1.5 Research Methodology

Regarding design science research methodology, it was decided to use Peffers et al. method [17], which consists in the following six steps:

- Problem Identification and motivation, where it has been reported that over 2.6 billion people of low and middle-income countries are exposed to indoor air pollution [2] and children in Lisbon are exposed to high concentration of PM2.5 inside classrooms [4]. If children are exposed to these particles for too long, they may cause health impacts on children's nervous system [3]. Therefore, actions are needed to raise awareness and to minimize air pollution exposure overall.

- Objectives of a solution are as mentioned before, the development of a serious game about air pollution that attempts to raise elementary students' awareness about air pollution. Another goal is to evaluate the participants' gameplay experience to see if the developed serious game is adequate in terms of usability.
- As for design and development, participatory design meetings were conducted to assess which features should be developed and implemented in the artefact to tackle the dissertation's problems.
- For demonstration, tests were conducted to check for any anomalies within the artefact and any possible improvements.
- For evaluation, formal testing with surveys were conducted with the targeted participants with the objective to evaluate the effectiveness of the artefact.
- Lastly, the writing of this dissertation serves as a way of communicating the results, limitations, conclusions, and possible future work directions of the artefact.

1.6 Scope

This dissertation presents "Problemas no Ar", a serious game that is aimed mainly towards elementary school students with the purpose of raising awareness towards air pollution. It is developed in the scope of the project ExpoLIS, a project that focuses on monitoring air quality in real-time through sensors implemented on public transports in Lisbon [10]. In this serious game, the player monitors the air quality level of several common city zones through virtual air pollution sensors to realize why there are different levels of pollution in certain city zones, and which ones we should avoid. The game also attempts to promote good practices and provides facts regarding air pollution through questions and dilemmas proposed by non-playable characters in the game. One of the strengths this game presents is the ability to configure the whole dialogue of the game and the possibility to extend or shorten both minigames' length by adding more dilemmas and locations to place sensors. This can be done by editing each XML file that is linked to their minigame. This configurability allows a teacher, educator, or any user to customise their own dialogue and the length of both minigames.

To evaluate the game, playtesting with twenty children was conducted. Identical pre- and post-surveys with Likert scale items and open-ended questions about air pollution were elaborated for comparison between them to see the effects that the game provided towards children's perception and knowledge of air pollution. A game experience survey that was elaborated for evaluation of serious games towards children was used [18]. Results between pre- and post-surveys showed that the game provided some positive effects. In addition, responses to open-ended questions showed that most participants before and after playing the game associated garbage and other types of waste as the main

source of indoor and outdoor air pollution. The average score of the game's usability obtained from the game experience survey shows that the game is usable. These results allow us to conclude that "Problemas no Ar" has the potential to provide positive effects towards elementary school students' perception, which could be amplified if certain features and fixes for the problems that participants reported are addressed in future work.

1.7 Document Structure

This section presents a summary of all chapters that are present in this dissertation.

In chapter 2, the related work of this dissertation is presented. Several previous work about air pollution monitoring and visualisation are mentioned, such as monitoring networks, forecasts with machine learning and creation of 3D environments to visualize real air pollution data. Serious games and gamification of applications is also mentioned, where the background and evolution of development of serious games in a commercial and academic way is pointed out. After that, it is pointed out works of serious games and gamified applications that attempt to raise awareness of several topics but mainly about air pollution.

Chapter 3 describes the early game designs that are considered during the game development, such as the storyline, storyboard, minigames, and characters that compose the game. It also shows the development and implementation of the game's several features, including game map, user interface, menu scene, characters, and controls. The behaviour and architecture of both minigames is also presented, as well as the files that users have the ability to configure the data involved in both minigames.

Chapter 4 presents the evaluation procedures of the game and the results gathered from participants' air pollution pre- and post-survey, as well as game experience survey. Then, a discussion of the results is carried out to discuss the game's strong points and limitations.

In Chapter 5, conclusions of this dissertation are presented, where it is checked if this dissertation managed to fulfil the goals that were set. It is also mentioned a list of game features that could be changed or added to improve results in future work.

2 Literature Review

2.1 Air Quality Monitoring and Visualization

The project ExpoLIS addresses the problem of monitoring air quality in cities, with its first prototype consisting of a sensor node capable of measuring PM 1, PM 2.5, PM 10, CO_2, and NO_2 to be installed in public transports [11]. These sensor nodes are connected through a mobile network with the purpose of providing the gathered sensor data to ExpoLIS users via a set of data visualization tools.

In the ExpoLIS project, the prediction of air pollution through machine learning techniques by using different datasets from mobile sensor networks as training data has also been approached [19]. There were two datasets that were used for training the prediction model, one dataset with only geographical information with attributes of geographical characterization such as buildings area, roads and vegetation that is in the area when monitored. The other data set is based on a time series where the average of air pollution of a location is computed several times for a specific amount of minutes. The prediction model from the time series data set was the most accurate between them. With this prediction model, it is possible to have a system to provide citizens with a forecast of the air pollution of an area at a specific time and, thus, which areas of the city should be avoided throughout the day.

To see air quality index of cities around the world, people can visit websites such as the “World's Air Pollution: Real-time Air Quality Index” [12] website. This website provides information of air quality of over 130 countries around the world and is continuing to grow the number of air quality monitoring stations which is already over 30000 stations monitoring worldwide. Table 2.1 shows the Air Quality Index scale indicated by the United States Environmental Protection Agency (EPA) website [20]. Air quality index values range from zero to 500, where air quality levels can vary from good to very unhealthy. Each of these air quality conditions have a colour representing them, good representing green, moderate representing yellow, unhealthy for sensitive groups is orange, unhealthy is red, very unhealthy is purple and hazardous levels are represented in the colour of maroon.

Regarding indoor air pollution monitoring, to regulate indoor air quality of underground facilities such as subways more efficiently, a smart ventilation control system based on deep reinforcement learning algorithm was proposed [21]. The system was implemented in a subway station in Seoul. Data about outdoor and indoor PM10 concentrations, number of passengers, and subway schedules were collected from several days. The deep reinforcement learning was trained to maintain a decent indoor air quality by minimizing concentrations of PM10 and was also trained to minimize the energy consumption of the ventilation system. After training the deep reinforced learning ventilation system, it was tested for 3 weeks to see if the system managed to maintain acceptable levels of PM10 and at the

same time if it was able to reduce energy consumption. Results showed that the system maintained acceptable levels of PM10 and reduced energy consumption, showing that infrastructures can have a smart management of indoor air quality and be more energy efficient.

Table 2.1 Air Quality Index Scale

Air Quality Index Values	Levels of Health Concern	Symbolized Colours
0-50	Good	Green
51-100	Moderate	Yellow
101-150	Unhealthy for Sensitive Groups	Orange
151 to 200	Unhealthy	Red
201 to 300	Very Unhealthy	Purple
301 to 500	Hazardous	Maroon

Regarding the way that air pollution can be visualised, some previous work has attempted to create visualisation tools using game engines, with 3D environments that allow users to see air pollution in a more fun and interactive way.

With *Unity Engine*, a 3D representation of a smart city system was developed [14]. It monitors not only air pollution but also traffic, pedestrian density, temperature, and their maximum values through data that is collected by a group of drones. The data that is presented and collected by the drones is based on real data of the Spanish capital Madrid. Several of these drones have specific areas to monitor pollution, temperature, traffic and pedestrian density. Once collected, drones go towards a base station where the data is processed and gets updated to the user. Users can interact and visualize the data collected by the drones with a virtual reality headset. Experiments showed that the user was able to see in the virtual reality interface the most recent data given by the drones, which allowed the user to monitor the state of the city.

Other examples of 3D city environments developed in *Unity* to visualise air quality data is the tool "CityOnStats" [13], which procedurally generates virtual cities based on data from OpenStreetMap [22] and populates them with air pollution data available in data sets built from sensor data gathered by sensor networks. In CityOnStats, players are able to explore the city by driving or following a bus in the game while visualizing the pollution levels in the city recurring to different visual modes, such as fog, colour of bus, colour of floor, etc. Users can also control a virtual drone to have a better view of the city. Tests were conducted to check whether participants, after getting used to the application, could perform several tasks and if they enjoyed their experience while interacting with the tool. Results show that most users managed to perform the tasks and enjoyed interacting with it.

2.2 Serious Games and Gamification

The term “Serious Games” is known to be mentioned for the first time around the ’70s by Clark C. Abt [15] where he suggests that games should not only be used as entertainment but at the same time be used to improve education or a specific skill. In the 20th century, dozens of serious games were developed and released throughout the years for different markets but at the turn of the century, from 2002 to 2010 there were already more serious games released within 8 years than in 21 years between 1980 and 2001 [23]. At an academic level, it should also be mentioned that in recent years there has been a gradual increase in the number of publications about serious games [16].

Regarding some of the positive effects that serious games provide, it has been shown that the use of serious games and gamification of applications is a way of leading consumers to practice pro-environmental behaviours, such as energy efficiency and consumption awareness [24]. However, some of these behaviours ended up being short term, which is not ideal.

In elementary schools, surveys evaluating teachers and students’ opinion about the use of educational games have also shown that both students and teachers agreed that games could be used as a motivational tool for learning [25]. Despite agreeing, teachers pointed out limitations such as that not all schools have equipment to use these tools and most teachers would prefer games that enables them to customize the game’s content for their lessons.

There have been many attempts to raise awareness about air pollution through serious games. Feldpausch-Parker A et al [26] created an educational game to raise awareness to students about the pros and cons of CO_2, such as carbon capture and climate change. The authors resorted to the use of storytelling to captivate students during gameplay and the use of melodrama in the story to raise awareness about the topic. Pre- and post-gameplay surveys were given to the students to assess their knowledge about CO_2. Overall, before and after playing the game, results showed an increase in knowledge after playing the game.

Other studies managed to improve awareness and knowledge about health hazards caused to air pollution. Carducci, A. et al [27] managed to increase knowledge and awareness of these health hazards to elementary students using leaflets, cartoons, and video games related to air pollution hazards. Two groups of participants were formed to evaluate the effectiveness of using video games and cartoons. Survey comparison results between before and after the use of these tools as a learning method showed greater efficiency in the group where leaflets, cartoons, and video games were used compared to the group that used only leaflets. It also showed that by using video games together with leaflets and cartoons when teaching these topics, students showed higher motivation on learning these subjects related to air pollution.

Serious games have also been developed to teach middle school students about the negative effects of being exposed to toxic chemicals for too long. In the game "Uncommon Scents" [28], players act as an Environmental Protection Agency (EPA) agent that must solve a case about a toxic spill at a factory. To progress and solve the case, players would have to collect information about the negative health effects that toxic chemicals provoke. The game is split into three episodes with a duration of 30 minutes each. After conducting pre-tests and post-tests about the topic in question and with participants playing the game between these tests, the results show an increase in the student's knowledge and a more negative attitude from the participant towards toxic chemicals.

There is also gamification of augmented reality apps that display air quality data not in a numeric way, but it shows the air quality to users in the shape of a tree with its current health being linked to the air quality data obtained real-time in the application [29]. With additional feedback from participants, more features were added to render the app more interactive and fun where users could take care of the tree by watering it when needed and pruning it, for example. By visualising a tree that has low health due to high air quality index value, it makes users evaluate better the air quality levels in their area.

In other areas related to the environment, a study has shown the value of using a game-based learning approach in Geographic Information Systems (GIS) [30]. The GIS purpose was to raise awareness of the local environment and the species that live in the city, such as frogs. A game version was created, which had a counter for frogs discovered in the game to encourage participants to find the frogs and learn more about them. Participants had a more enjoyable experience and interest about the local and general environment when interacting with the GIS game-version instead of the normal GIS, promoting a better environmental awareness.

Efforts are also being made for other types of pollution, such as solid waste pollution using smart city system approach with game elements applied to it. An example is the work of Briones, Chamoso, Rivas et al [31], which consisted in the development of a system with gamification techniques that encourages citizens to recycle more materials by setting monthly goals in the systems' application. Rewards were given in return if citizens completed their monthly goals regarding the amount of recyclable materials that were deposited in the many recycling containers; the rewards were discounts on garbage monthly fees. The study was done in a city of Spain and consisted in two phases. The first phase measured the quantity of materials that were recycled without the implementation of the system for 2 months, whereas the second phase measured the amount for two months as well, but with the system implemented in the city. Results showed an increase in participation from citizens and an increase in the quantity of recyclable materials deposited when the system was implemented.

An alternative way to encourage change of people's behaviour to a more pro-environmental is using psychological distance and interactivity. Concretely. the work of Fox, McKnight, Sun et al [32] studied the effectiveness of psychological distance and interactivity with the game's environment. Participants

would play a game where they navigate with a kayak down a polluted river. Four conditions were applied in the experiments: near psychological distance, where the authors would trick the participants by telling them that the river shown in the game was a representation of a river located nearby and the river would be in the conditions presented by the game in less than a decade; far psychological distance where the authors would trick the participants by telling them that the river shown in the game was a representation of a river located far away and the river would be in the conditions presented by the game in thirty years; contingent condition gave participants the possibility to pick up the trash in the river and change the river's appearance; non-contingent condition did not give participants the possibility to pick up the trash in the river and change the river's appearance. Results concluded that a near psychological distance and the possibility for the participant to clean up the river by picking up trash increased participants' risk perception of the environment as well as an increased support for implementation of environmental policies.

The use of eco-guilt to encourage change in people's behaviours to a more pro-environmental behaviour has also been attempted in the work of Moore and Yang [33], where they have made two studies with several experiments in each one with an ecology-based game. The first study had one group of participants watching the trailer of the game, which showed throughout the video the impacts on the environment caused by human interaction. One group would play the game for twenty minutes and another group would serve as a control group where they did not watch the game trailer nor played the game. All groups filled pre- and post-surveys to evaluate participants attitudes towards the environment. Results from the first study showed that the people who played the game showed a greater eco-guilt but compared to other groups of participants, it was not significant enough. The second study had the same experiments, excluding only the gameplay experience group from the previous study. Results have shown that post-surveys from participants who have watched the trailer showed greater eco-guilt and intention to change their behaviours to a more pro-environmental behaviour.

Other ways that risk perception of air pollution was evaluated was through the games created by participants about climate change, a study made by Puttick and Tucker-Raymond [34], in which a four-day workshop was made for visual programming environment. Participants learned about the causes and effects of climate change through an animated video and learned using visual programming software Scratch, which was used to create their games. After the learning process, the authors challenged the participants to create a game of their choice using Scratch. Results showed most participants ended up creating games about various topics related to climate change such as CO_2, with included messages in-game to raise awareness and show the importance of some of the topics related to CO_2 (carbon sinks, sources of CO_2 emissions) to users that would play these games, which tells us that the participants showed a good understanding of the topic in the video and will to raise awareness to people through these games that they created.

2.3 Children's Pollution Perception

Since this dissertation attempts to address air pollution awareness through the use of a serious game, a few studies were reviewed to see the air pollution perception and pollution perception overall, of people around the world from preschool and elementary students.

Few previous work evaluated air pollution perception of children through their drawings. This was a technique used by Shepardson [35]. The author asked several groups of students of different grade levels to give their own idea about what an environment is through drawings and students had to explain it after. Most students would end up drawing scenes that would have animal life in it. Özsoy and Ahi [36] evaluated elementary students' perception of what the environment will be in a near future with this same technique. The main topics obtained from the drawings were a clean, polluted, and technological environment. They observed also that perceptions vary from where each student lives. Most students in urban environments perceived a more polluted environment and students in rural environments showed the contrary. Perception of a polluted and technological environment was indicated more times by older students while the younger students showed a perception of a clean future environment.

That same technique was applied in another study which allowed to obtain the air pollution perception of children in a preschool in Turkey [37]. Children between the ages of three and six were asked to draw pictures about environmental pollution and would also be interviewed about the same subject. After drawing them, children explained what was drawn in the paper and answers were collected. Topics that were most mentioned in their answers about the concept of environment, human, buildings and vehicles and about abiotic elements such as sea. Throwing garbage and picking up garbage were the main answers regarding on how to pollute and reduce pollution respectfully. As for the drawings, they showed that children managed to indicate more factors that pollute the environment that most did not refer such as smoke, showing us that children managed to express a better pollution perception by drawing.

This literature review shows that there is several previous work that attempts to monitor and predict air quality in urban environments. Visualization of real air pollution data in 3D environments have also been addressed in order to make users easily understand and have a better perception of air pollution overall. Serious games and gamification of applications have also been developed with the purpose to foster user engagement while playing the game and at the same time make them more aware of important subjects, such as air pollution and several types of pollution. However, the several serious games that were reviewed, none focuses on the engineering aspect on how to obtain air pollution data, which is through the use of sensors. Regarding the children's perception about air pollution, their perceptions vary from where they live in and older children tend to have a perception of a more polluted

environment. Children also referred mostly garbage as the main contributor to environmental pollution but pointed out other factors such as smoke when expressing their opinion through drawings.

This dissertation presents an isometric serious game that is mainly focused on elementary school students with the purpose of teaching them pro-environmental behaviours and raising awareness of both outdoor and indoor air pollution through air pollution monitoring of a city that has several levels of pollution in different areas. The strengths that this serious game has is the ability to configure the whole dialogue of the game and the possibility to extend or shorten both minigames' length by adding more dilemmas and locations to place sensors. This can be done by editing each XML file that is linked to their minigame. This configurability allows a teacher, educator, or any user to customise their own dialogue and the length of both minigames. With different configurations being applied, the positive effects that the game can provide to the child can vary for each configuration. Previous work do not have this kind of configurability of content for their games.

3 Game Design and Development

3.1 Early Game Design Decisions

In an early stage of the game design, participatory design meetings were conducted in which an environmental expert was present. The conclusions of that meeting were that the topic should be focused on air pollution in a city and one of the main goals would be monitoring the air quality around it. Other ideas for the game were considered such as addressing other types of pollution as well (e.g., soil, water) and having other minigames such as picking up trash from the streets and sea and have a villain related to pollution overall. However, with all these possible additions of minigames, the minimum gameplay time would be too much for the time slot envisioned as adequate for children to play in the classroom which was between fifteen to twenty-five minutes. Therefore, it was decided to focus only on air pollution and create an ordinary city with several zones, with different pollution levels, that could be familiar to the participants, such as downtown, residential areas of flats and houses, industrial and forest areas where the player would have to monitor the air pollution with sensors. In terms of the game's look-and-feel, it was also decided to present the game with an isometric perspective with 2D sprites because it allows the player to have an overview of the city to see the several zones and their pollution levels. Another reason is that sprite-based games are less computationally demanding than 3D counterparts, which is beneficial for serious games that may have to run in low-end devices.

3.1.1 Storyline and Storyboard

For better planification towards making the game and to increase the children's interest into the game, an original and engaging storyline was devised with the contribution of the environmental expert to ensure its pedagogical value.

The storyline goes as follows. The main character is currently living in a city and has a scientist friend that will perform the role of mentor throughout the game, explaining problems related to air pollution. One day, the scientist starts to realize that people in the city are being affected by something in the air. As a result, he and the main character decide to form a group named "Amigos Para o Ambiente" (*Friends for the Environment*), which focuses on studying the air pollution present in the city. The main character manages to convince four friends in joining the newly formed environmental group, but they still have a lack of knowledge about air pollution and are going to face dilemmas that may affect their health. The main character, which is controlled by the player, will help his friends in

solving these dilemmas by telling them what he thinks is right or wrong to do in each scenario. The scientist has also an idea of what could be affecting the people's health in the city and, so, he proposes to the player to ride his bicycle and place different types of air quality monitoring sensors throughout the different city zones. Then, the scientist evaluates and explains to the player, via the main character, the possible causes regarding the air quality being displayed by each sensor that is placed in the several zones in the city. Figure 3.1 presents an early sketch of the game's storyboard, which depicts key moments of the game's storyline such as the inhabitants coughing due to air pollution, the creation of the environmental group and the recruitment of the main character's four friends. The second row of rectangles depicts the minigames present in the game, such as the dilemmas of the main character's friends, the scientist explaining each type of sensor, and an explanation of the readings obtained from the sensor when placed.

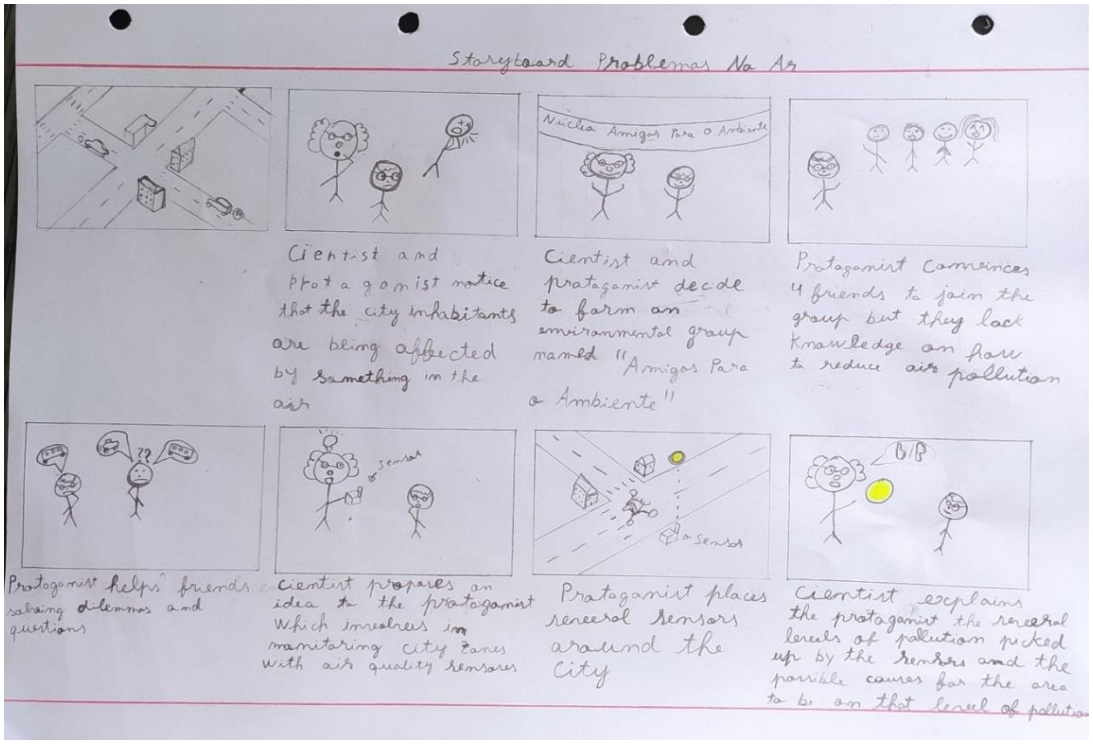


Figure 3.1 Hand-drawn storyboard of game.

After creating a storyline and a storyboard, a sketch of the city map was elaborated. Since one of the main goals of the game was to monitor the air quality around a city, several common city areas such as downtown, residential zones with houses and flats, industrial zones, forest zones and parks were created, and most areas would have a different level of air pollution consistent to what is expected in real life. An early sketch of the map can be seen in Figure 3.2 where it shows the several zones such as the industrial area which would have the worst pollution levels, city centre would be in the middle of the map with an above average pollution level, residential area of flats would have an acceptable

pollution level, and forest and residential zone of houses would have a low pollution level. Table 3.1 shows the expected pollution levels for each city zone.

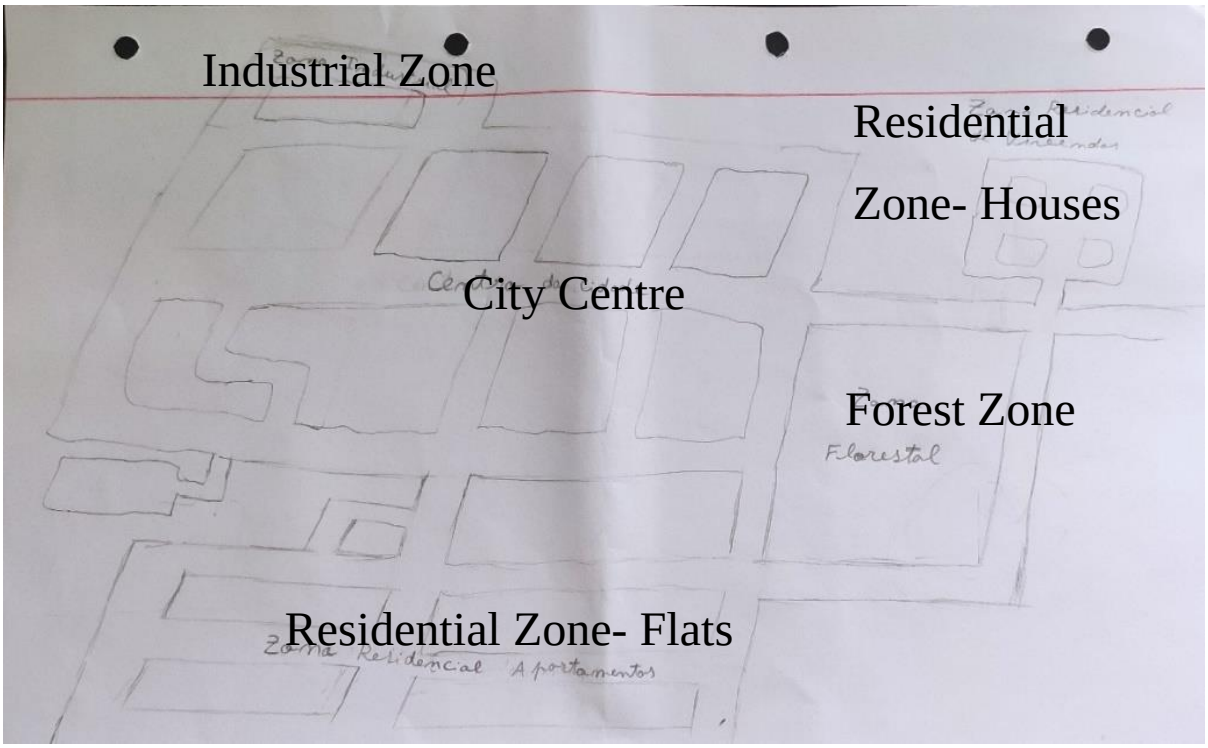


Figure 3.2 Hand-drawn sketch of city.

Table 3.1 Expected level of pollution of each city zone

City Zones	**Expected level of pollution**
Downtown	Unhealthy for sensitive groups (Orange)
Forest Zone	Healthy (Green)
Industrial Zone	Very Unhealthy (Purple)
Residental Zone- Flats	Moderate (Yellow)
Residental Zone- Houses	Healthy (Green)

3.1.2 Minigames

The game includes two minigames: (1) the *sensor* minigame and (2) the *dilemma* minigame. As mentioned in the storyline, the sensor minigame's main goal is for the player to control the main character that is riding a bicycle, to place several types of sensors in various zones that are present in the city. The goal and the reason this minigame was created is to show the player what typical city zones

can have a good, satisfactory, and bad air quality, with the scientist saying to the player which areas are safe to be in and areas that should be avoided when placing the sensor.

There are three types of sensors to be placed around the city. Sensors of the first type are fixed and expensive that once they are placed, they cannot be picked up. These represent the most accurate sensors in reading the pollution levels in a certain area. The remaining two sensor types are portable, which means that these can be picked up and placed in different zones in the city. One is an expensive portable sensor, concretely, a mobile sensor that has a similar accuracy compared to the fixed sensor. The other is a portable cheap sensor which has the worst accuracy of them all and can exhibit big variations in air quality readings from time to time, which attempts to simulate the behaviour of a sensor in real life.

Each type of sensor that is picked up can be considered a stage or level of the sensor minigame. Once the player monitors with the sensor, all locations suggested by the scientist, that sensor is removed from the player's inventory and the game will check if there are more sensors to be placed and for the player to try and see their different behaviours in the minigame. If there are other types of sensors to be placed and tested, player goes to pick up the new sensor. But if there are no more sensors to be placed, that means that the sensor minigame is over. Figure 3.3 shows a flowchart of the sensor minigame.

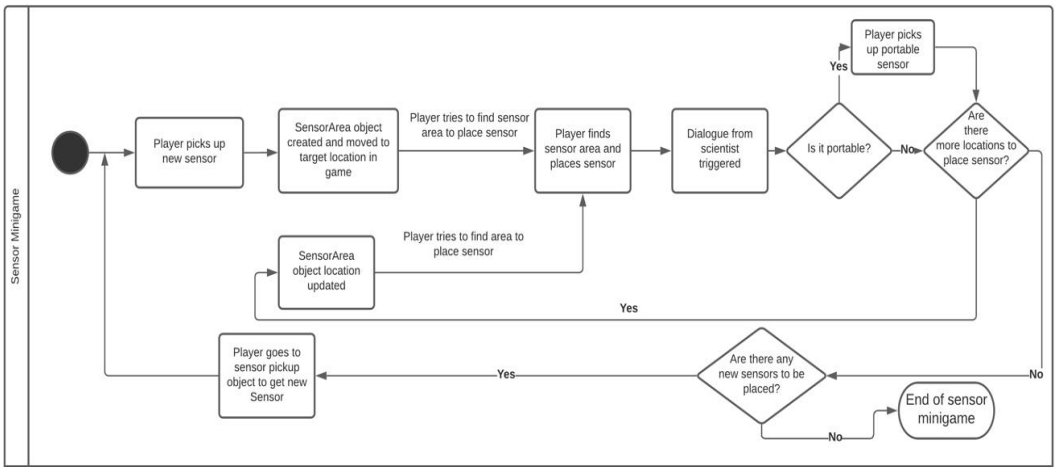


Figure 3.3 Flowchart of the sensor minigame.

The dilemma/question minigame consists of educational questions and dilemmas about the good and bad practices regarding air pollution. Each dilemma or question has two possible answers which can impact friend's health in a positive way, a negative way, or in a neutral way in case if it is a question. To solve these dilemmas and questions, the player should head towards a dilemma marker, a marker that represents a friend of the main character in the map when he or she needs help in solving a dilemma. Once within range, the player can solve these dilemmas if the player has enough skill points. These skill points are obtained by placing sensors in the city, which encourages the player to focus on both minigames to progress in the game. The main reason this dilemma minigame was applied into the game is that it is another way of teaching the player what good and bad practices are in certain scenarios

related to air pollution. The game shows these good and bad practices to the player through the main character's friend's reaction after choosing an option in the dilemma. This could tell the player that his or her actions and advices could impact a friend's health in a positive or negative way. A flowchart of the dilemma minigame can be seen in Figure 3.4.

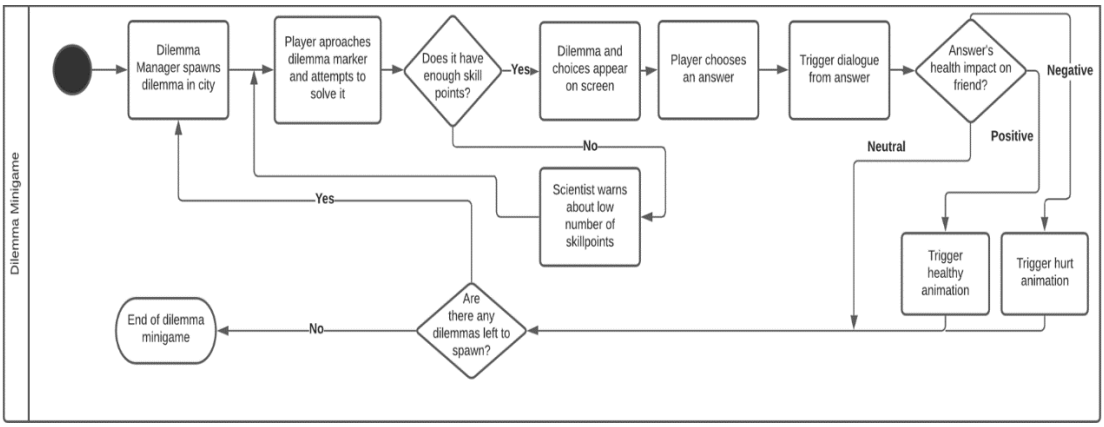


Figure 3.4 Flowchart of the dilemma minigame.

3.1.3 Game Characters

Regarding the game's characters, each one of them is linked to one of the minigames or both. The scientist character is linked to both minigames as he will explain possible causes of why the air monitor sensor is showing a specific pollution level in the several zones around the city in the sensor minigame. He is also involved in the dilemma minigame, where he adds additional comments and explains why the answer the player chose is right or wrong. He also guides the player in the sensor minigame by reminding the player where to place or pickup sensors after a long period of time of the player not doing any of those actions.

The other characters, which are the four friends of the main character, are linked only to the dilemma minigame, where their only purpose is to present the dilemmas that they have to the player and react in a positive, negative, or neutral way based on the player's answer choice.

3.2 Game Implementation

After elaborating the storyline and storyboard, the tilemaps, UI elements, scripts, animations, vehicle behaviour, dialogue, minigames, sprites and menus were implemented to recreate what was planned in

the game design section. In this section, implementations of the several game features that were previously mentioned are described in more detail. This serious game was developed using Unity Engine due to the engine and its libraries being easy to learn and get used to. Therefore, for programming language, C# was used for programming the game's scripts.

3.2.1 Game's City Map and UI elements

After making a sketch of the city map as shown in the game design section (see Section 3.1.1), tile maps were created to paint the different layers such as the base (green tiles), roads, trees, buildings. Extras like lamp posts, garbage bins, benches would be on a separate tile map to be easier to place them over sidewalks or grass tiles from the base tilemap. Figure 3.6, shows an overall view of the city and UI elements of the game through the game's camera point of view. It is visible that, above the different city zones, there are panels with different colours and with the city's zone name on it. The panel with the colour pink represents the residential zone of flats, the dark blue panel represents a residential zone of houses, the green panel represents the forest zone, the light blue panel represents the city centre zone and the yellow panel represents the industrial zone. These have been implemented to serve as guidance to the player when trying to place a sensor in a certain zone. To draw the player's attention to the target zone, the panel of the target zone plays an animation where it blinks and moves left and right, it is also visible the control keys and the minimap of the city. It should also be mentioned that Figure 3.5 shows a screenshot of the player's bicycle, which has a banner above saying "Jogador" (Player). This banner's purpose is to help the player to track the bicycle in the map.

Figure 3.5 Screenshot of bicycle and banner "Jogador" above it.

Figure 3.6 Overall view of city and UI elements of game.

3.2.2 Menu Scene and Characters

When the game starts, the menu is the first scene that is loaded. It shows an overview of the city and the characters that are present in the game. The menu has simple features, such as the play game button, which takes the player to the game scene, the "how to play" button, which shows a panel with text explaining what is happening in the city and what are the player's objectives. There is also a settings button, which allows the user to control the volume level of the game and a quit game button, which closes the game. The menu screen also shows the sprites of all characters that are part of the game, where the group of four sprites represent the four friends of the main character which appears below them, beside the scientist. A screenshot of the menu scene can be seen in Figure 3.7.

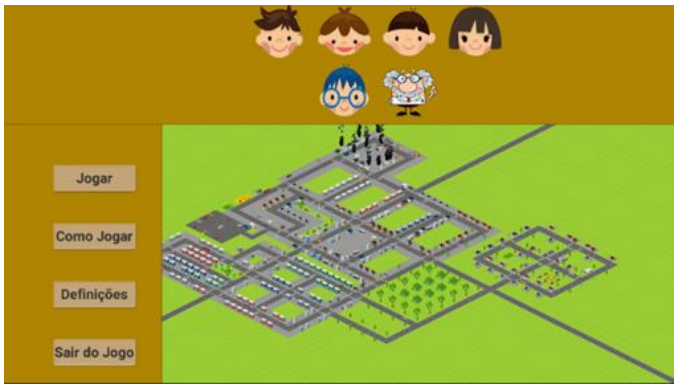


Figure 3.7 Screenshot of the game's menu scene.

3.2.3 Controls of Camera and Bicycle

For the controls of the camera, several features were implemented such as zoom and dragging the camera to help the player navigate and search around the city for any dilemmas that are yet to be solved and for hints of the next location to place the sensor. After moving the camera, the player might want the camera to be focused on the bicycle again to steer it into the desired path, so a UI button "Focar no Jogador" (*focus on the player*) was implemented with the purpose of centring the camera on the bicycle. This action is also done automatically if there is no input from mouse after a couple of seconds.

For the bicycle controls, UI buttons were used to control it instead of the actual keyboard, this way they would only have to use the mouse to play the game. Figure 3.8 shows the UI controls for the bike in early versions where the player could turn right or left based on the bicycle's perspective. After conducting informal tests, the feedback received was that the controls were too confusing to navigate in the city. Due to the game being presented in an isometric style, the way the arrow keys were displayed, was confusing for players as the arrow keys would not exactly match the streets' directions in isometric and there was also less freedom with only 2 keys. Therefore, UI buttons with sprites that looked like arrow keys from keyboards were implemented for every direction and were aligned with the roads' available directions. Figure 3.9 shows the control key buttons implemented for the isometric style and the UI button that focus the camera on player after receiving feedback from informal testing.

Figure 3.8 UI control keys before informal testing.

Figure 3.9 UI control keys after informal testing.

3.2.4 Sensor Minigame

Table 3.2 shows a brief description of each main class involved in the sensor minigame. Figure 3.10 depicts the class diagram of the sensor minigame. It shows the main classes and scripts that are involved in the sensor minigame, where most of the operations occur especially at a SensorManager class. There are several classes that the SensorManager interacts with.

The PollutionSensor script is responsible for the sensor's behaviour when monitoring the air and reacting when the player enters the sensor's collider area when it is placed in the map. It will tell the SensorManager to show a UI button to pick up the sensor. It is also visible that the PollutionSensor contains an Enumeration type defining three types of sensors: the fixed sensor (FIXED); the expensive portable sensor (EXPENSIVE); and the cheap portable sensor (CHEAP). With this enumeration, the SensorManager can behave in a different way when it is a portable or a fixed sensor. The fixed, portable expensive, and cheap sensors, can be seen in Figure 3.11, Figure 3.12, and Figure 3.13, respectively, it can be seen that all sensors have a circular sprite above them, this sprite will always be coloured with the pollution level.

The SensorArea script is attached to a GameObject named areaForSensor. A GameObject in Unity is a base class for all objects that are present in the game scene. They can be used as attributes in classes to enable the possibility to instantiate an object several times in the game. This object serves as the target area to place a sensor in the city. Once the player has a sensor and enters the SensorArea's collider area, the script tells the SensorManager to show a UI button to place the sensor.

The ItemPickup script is also attached to a GameObject, which serves as a pickup place for new sensors that the player has not picked up yet. This GameObject is only active when the player has placed a sensor in all locations that are mentioned by the scientist. As for the SensorLocationDialogue class, this class indicates what sensor, dialogue, location to place sensor, guide dialogue, type of monitoring (indoor or outdoor), and what location name it is to be used whenever a sensor is picked up or placed. The attributes for this class is mostly id or index numbers for the dialogues, guide dialogues, and locations. With these ids, it is possible to point out what dialogue, location, and guide dialogues are needed from the arrays of Dialogue, GuideDialogue, and Location objects. These arrays are collected through a deserialization of the XML file in the auxiliary nested class SensorsInfoXML that is declared inside the SensorManager and are stored inside attributes of the SensorManager. Lastly, the DialogueManager's role in this minigame is to simply display and type the dialogue that is given by the sensor manager.

Regarding the monitoring or air pollution from the PollutionSensor, this script uses a class that generates a Gaussian random (GaussianRandom) value based on a mean of 0 and a standard deviation,

set for each type of sensor. This class simulates the sensor's inaccuracy when reading the air pollution in the zone. The standard deviation of the gaussian random value was set for each type, several values were tested to see if their precision and inaccuracies would match with their type of sensor. Based on the Box-Muller transform [38], it first generates random variables with a normal distribution as the equation (1) shows:

$$v = \sqrt{-2 \ln U_1} \cos(2\pi U_2). \quad (1)$$

In equation (1), variables U_1 and U_2 represent two random uniformly distributed variables set in a range of 0 to 1. This equation returns a random number that is normally distributed, v. Once obtained, v is then multiplied by the standard deviation that was set for each sensor and the mean is added, which is set to zero for every sensor. Equation (2) shows the final equation to obtain a random Gaussian generated number x:

$$x = \mu + \sigma v. \quad (2)$$

Once obtained, it will be added to the variables that are responsible for obtaining a colour, which affects the readings of the sensor. Section 3.2.4.1 describes the whole process of obtaining a colour with the addition of a random Gaussian generated number.

Table 3.2 Brief description of each class involved in the sensor minigame.

Class Name	Description
SensorManager	Class that handles most operations of sensor minigame
DialogueManager	Class responsible for displaying the dialogue
ItemPickup	Class of object that represents the pickup place for new sensors
SensorArea	Class of object that represents the target location to place sensor
GaussianRandom	Class responsible for generating a Gaussian random value as noise for sensor
PollutionSensor	Class responsible for the sensor's behaviour
GuideDialogue	Class that contains dialogue that serves as guidance to player
Dialogue	Class that contains dialogue lines
Location	Class that contains grid cell coordinates to place sensor
SensorLocationDialogue	Class that contains index numbers to get specific dialogue, type of sensor, Location and GuideDialogue of lists obtained from XML

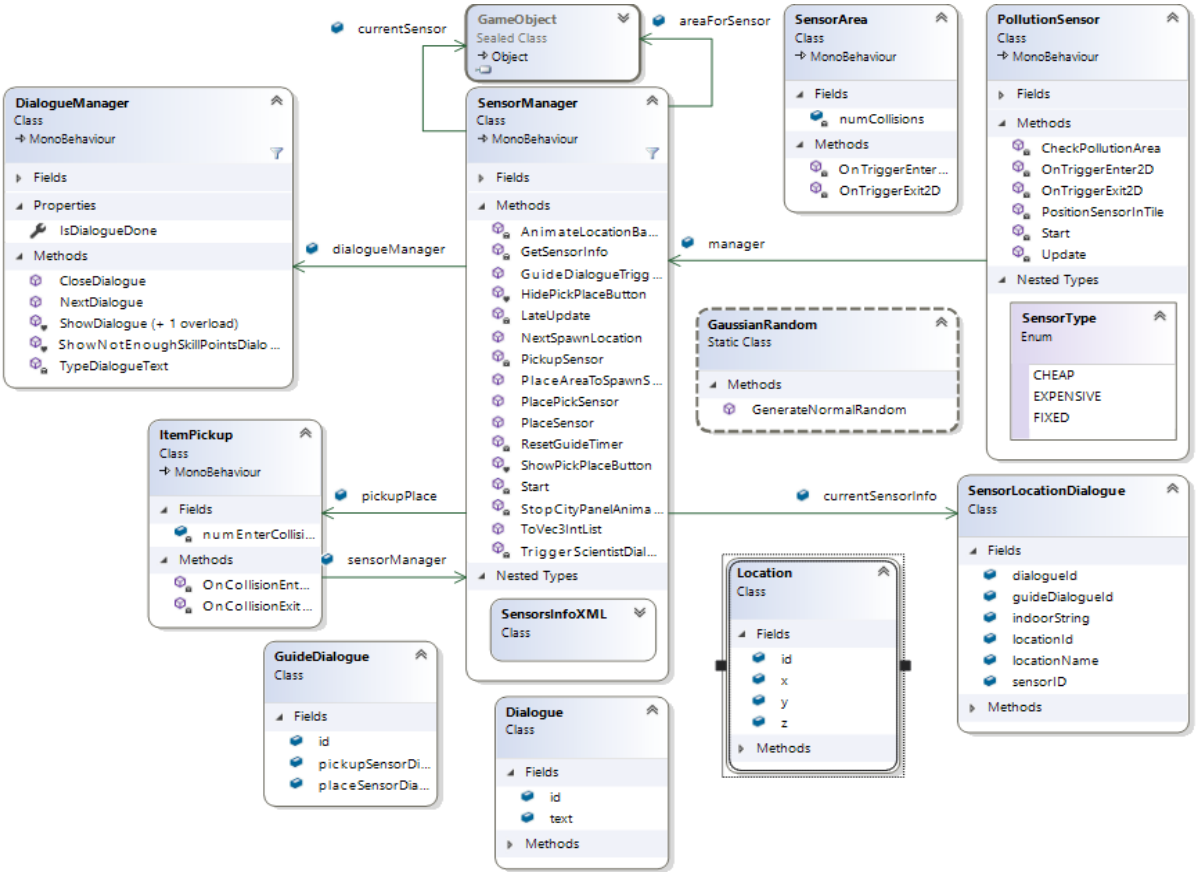


Figure 3.10 Class diagram of the main classes of sensor minigame.

Figure 3.11 Fixed and expensive sensor in the centre of the image (indicated with an overlaid circle). Above the sensor it shows a green coloured circular sprite, this indicates that the air quality in this zone is good.

Figure 3.12 Portable expensive sensor in the centre of the image (indicated with an overlaid circle). Above the sensor it shows an orange coloured circular sprite, this indicates that the air quality in this zone is unhealthy for sensitive groups.

Figure 3.13 Portable cheap sensor in the centre of the image (indicated with an overlaid circle). Above the sensor it shows a red coloured circular sprite, this indicates that the air quality in this zone is bad.

3.2.4.1 Pollution Tile Maps and Sensor Monitoring

For the sensors to display a colour that represents the air quality level in a city zone, five of the colours that are used to represent the levels in air quality index websites (green, yellow, orange, red and purple) were obtained through the website [12] and the colours' info (RGB values) is stored on a list that is an attribute of the PollutionSensor class. To be able to monitor a specific area in the city and display the pollution level through the sensor, tile maps were created to represent outdoor air pollution and indoor air pollution. Sprites were painted with the same five colours as seen in Figure 3.14 and were used to paint the tile maps. These tile maps are not visible in the game as they are rendered behind the several tile maps that make the city. Figure 3.15 and Figure 3.16 show both pollution tile maps for outdoor and indoor, respectively.

With these tile maps, sensors calculate air quality based on counting the numbers of tiles that have a certain image (sprite), which represent those said colours. In this case, the sensors check an area of 5x5 tiles or 3x3 when it is to monitor outdoor or indoor air pollution, respectively. After counting each number of sprites that are in the area, a random Gaussian distribution value is added for each sprite counter to alter the expected readings in the area, simulating an imprecise measure by the sensor. After that addition of noise, it is checked which sprite counter has the highest number and the sensor's circle sprite, which represents the air pollution level obtained from the sensor in the area, is coloured with the sprite's colour with the highest count. Looking back at Figure 3.13, it is possible to see the inaccuracy level of a cheap sensor. In the same zone, the fixed sensor produced readings of pollution that represents the colour orange, whereas the cheap sensor generated readings of pollution that represent the colour red.

Figure 3.14 Sprites representing pollution levels.

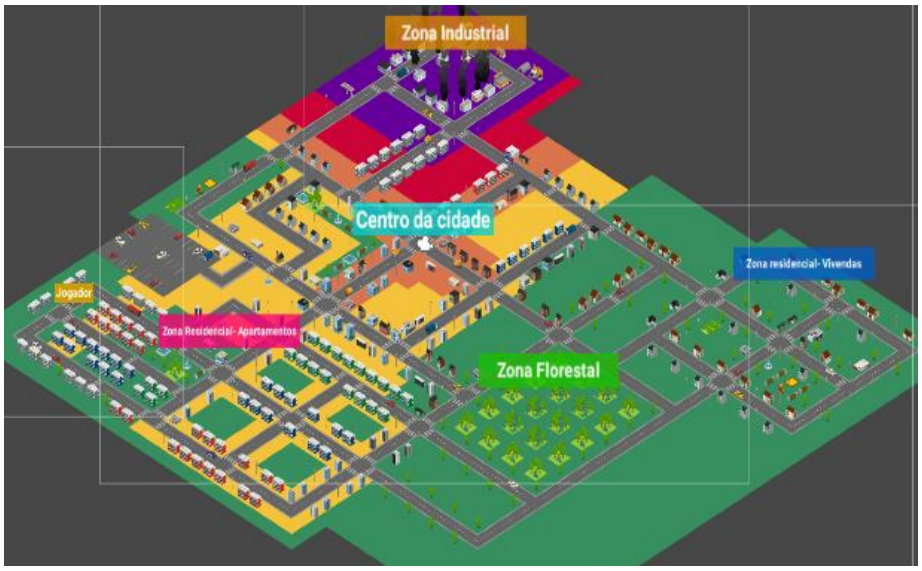


Figure 3.15 Outdoor pollution tilemap. Green tiles are placed in the forest zone and residential zone of houses, which indicates that the pollution levels here are low. The city centre has a mix of yellow and orange tiles, indicating that it has a mix of moderate and unhealthy for sensitive groups pollution levels. The industrial zone has purple and red tiles, meaning that pollution levels here are unhealthy. The residential zone of flats exhibits a mix of moderate and healthy pollution levels, with yellow and green tiles.

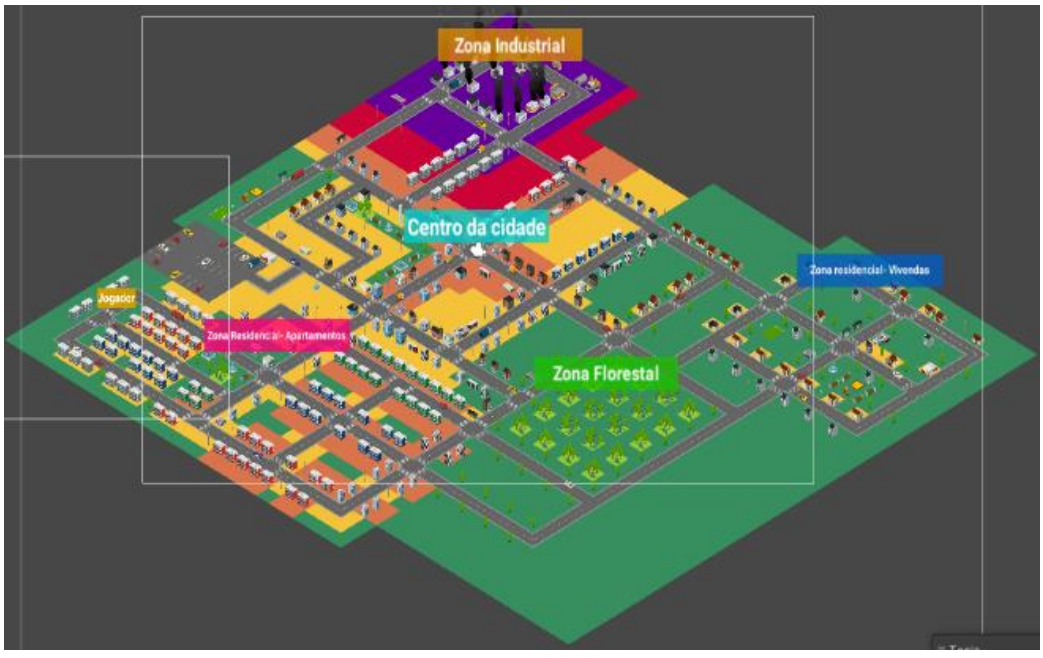


Figure 3.16 Indoor pollution tilemap. Similar to the outdoor pollution map (see Figure 3.15) but with some changes in the colour of tiles in some zones, especially in most of the tiles that are below buildings

3.2.5 Dilemma Minigame

In terms of structure and implementation of the dilemma minigame, it is much simpler compared to the sensor minigame. Table 3.3 shows a brief description of the key classes in the dilemma minigame. Figure 3.19 shows a class diagram with the scripts and objects involved in this minigame.

Table 3.3 Brief description of the main classes involved in the dilemma minigame.

Class	Description
Answer	Class that contains info of answer, the text to be displayed, the dialogue that is triggered when choosing an answer and the health impact the answer causes to a friend
Dilemma	Class that contains the dilemma information of a friend such as skill points needed, possible answers and which friend is presenting the dilemma
DilemmaManager	Class that handles most operations of dilemma minigame
DilemmaScript	Class of object that represents a dilemma marker, that reacts to player's proximity
FriendScript	Class of object that represents the friends present in the UI, it triggers a positive or negative reaction animation of friend, based on the player's answer in the dilemma

Like the sensor minigame, the dilemma minigame also has a "manager" script named "DilemmaManager", which handles most of the behaviours that are part of the minigame. It is responsible for showing the dilemma and its associated dialogue using the UI elements, react to the player's choice and instantiate objects in the map that the player needs to approach to solve these dilemmas. Information of the dilemma or question, answers, and health impact that each answer has on a friend is stored in Dilemma objects. These objects store the question or dilemma text to display through the UI, an ID to see which friend is presenting the dilemma, the number of skill points that are required to solve a dilemma, and an array of the object Answer that represents the answers that the player can choose in a specific dilemma. Each Answer object stores inside the text of the answer, a dialogue between the main character and scientist that is triggered when the answer is chosen, a value is also stored which represents the positive or negative health impact on a friend (pollutionImpact) when choosing the answer. It is a positive health impact when value is below zero, negative if it is above zero; if it is zero, then there is no positive or negative impact on friend. The DilemmaScript script is attached to the game object that represents the dilemma in the map. The game object looks like a GPS marker but with a sprite of the friend that is linked to this dilemma. This friend sprite changes through the friendID attribute in the Dilemma object. The DilemmaScript purpose is to show a UI button on the screen if the player collides and is inside its collider area as seen in Figure 3.17. By clicking the UI button, if the player has enough skill points, the DilemmaManager displays the dilemma for the player

to solve as seen in Figure 3.18. Once solved, this object is removed from the scene and the DilemmaManager checks if there are any dilemmas left to solve; if yes, then it spawns a new game object with a DilemmaScript attached. The FriendScript is attached to UI objects that represent the four friends in the game. This script's purpose is to trigger an animation and to take or give health to the friend object that is attached. The animation varies based on the player choice. Figure 3.20 and Figure 3.21 show a screenshot of a positive and negative reaction of the animation, respectively.

Figure 3.17 DilemmaScript object. Displayed as a marker in the centre of the image, reacts to player's proximity by displaying the UI button above "Jogador" (player) that is used to interact with the dilemma.

Figure 3.18 Example of a dilemma. A friend wants to play football with friends but is undecided if he asks his parents a lift by car or if he goes by bike.

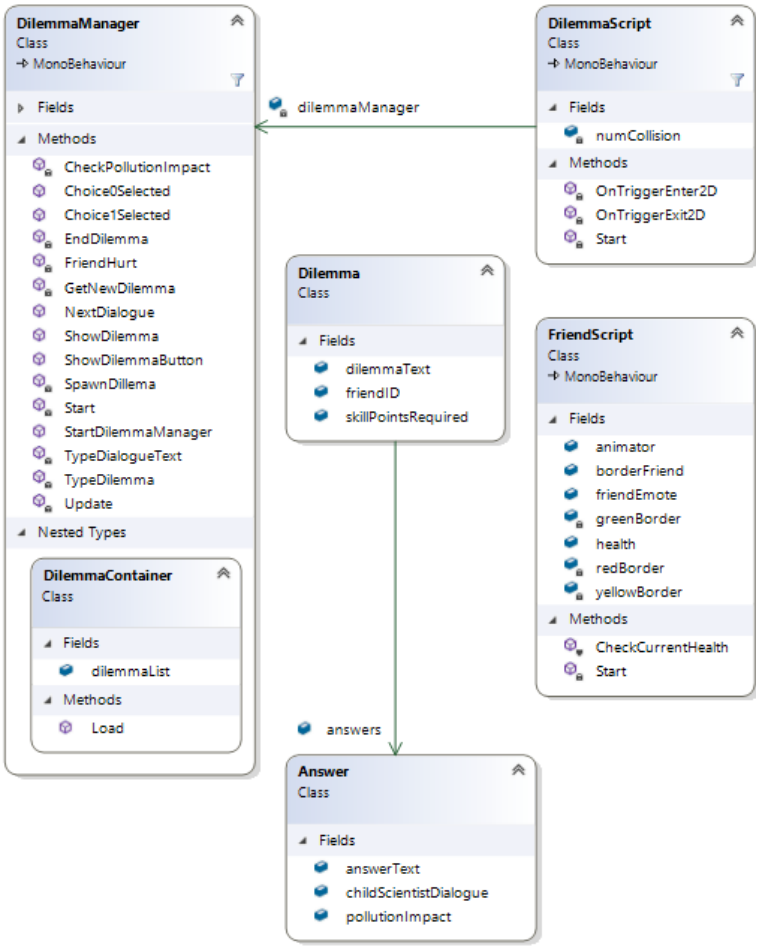


Figure 3.19 Class diagram of the main classes of dilemma minigame.

Figure 3.20 Positive health effect reaction animation triggered. If player chooses an answer that is considered good behaviour towards the environment, an animation on the friend's image is triggered and a bright green colour appears around him.

Figure 3.21 Negative health effect reaction animation triggered. By choosing an answer that is considered bad towards the environment, an animation from character's friend is triggered where he/she shakes and changes to a facial expression looking like he/she is hurt. A bright red is coloured around him/her to tell the player that he answered incorrectly.

3.2.6 Configurable Game Dialogue and Minigames

To make sure the dialogue would not be teaching participants about uncertain and not entirely true statements about pollution causes and solutions to it, dialogue from both minigames went through careful proofreading from people that are inserted in the environmental area. However, if someone would like to change, remove, add more dialogue, or even change the positions to place sensors, it is possible to do it by editing an Extensible Markup Language (XML) file.

The game includes two XML files, one for the dilemma minigame and another one for the sensor minigame. These two files store all information necessary for each minigame. In the dilemma minigame, the XML file named "dilemmas.xml" contains a list of the object Dilemma, which contains an array of answers representing the options that the player can choose in a dilemma. Each of these answers has a set of dialogue lines between the main character and the scientist that are triggered if a certain answer is chosen, and it could also influence one of the friends' health. An example of the object Dilemma in XML can be seen in Figure 3.22.

As for the XML file for the sensor minigame named "sensor_locations.xml", it has several lists of objects. As seen in Figure 3.23, it contains a list of "Dialogue" objects where each one contains a specific id and the text of that dialogue. As seen in Figure 3.24, the file also contains a list of "Location" objects

where each one of them has a specific id and the grid cell coordinates for where to place the sensors in the game. Figure 3.25 shows a list of objects “GuideDialogue” that are also in the file. Each object contains a specific id and two text of dialogue. The purpose of this object in the game is to guide players on what to do next in the sensor minigame, which only happens when player stopped placing or picking up sensors for a while and need help to see where to go next. Lastly, Figure 3.26 shows a list of objects “SensorLocationDialogue” that are in the XML file, a SensorLocationDialogue contain ids from each of the previously mentioned objects that are in their lists. This object serve as a guide for the scripts that handle the sensor minigame overall, by indicating which dialogue should be typed, what is the next location to place the sensor and what type of sensor is to be used by checking what “sensorId” is. This “sensorId” is an attribute of a SensorLocationDialogue object. The XML file can also indicate in each location if the sensor is supposed to monitor indoor or outdoor air pollution, which can have different readings in the same zone or not between outdoor and indoor monitoring. This can be done by defining a “true” value in the string attribute “isIndoorString”. If value has the word “true”, then it will monitor indoor pollution and if it is “false” or no value is defined for the attribute, by default, it will monitor outdoor pollution.

With this feature implemented, these files allow educators and teachers, who try to use this game as a teaching tool, to customise the game’s dialogue to become more readable for their students, add more locations to place sensors and dilemmas. These files are located inside the game’s data folder from the build, inside a folder named “StreamingAssets”. It should also be mentioned that, in case of needing to change the how to play text that is present in the menu scene, this text can be altered by editing the “.txt” file named “HowToPlay.txt” which is also stored in the same said folder.

```
<Dilemma dilemmaText= "Quero ir jogar futebol com os meus amigos, devo ir de carro ou de bicicleta?">
    <friendID>1</friendID>
    <skillPointsRequired>10</skillPointsRequired>
    <Answers>
        <Answer answerText= "Carro">
            <pollutionImpact>15.0</pollutionImpact>
            <childScientistDialogue>
                <string>Eu diria de carro.</string>
                <string>Hmmm... Apesar de ser um meio de transporte mais rápido, a adição de mais um carro ao trânsito irá contribuir no aumento da poluição da cidade.</string>
            </childScientistDialogue>
        </Answer>


        <Answer answerText= "Bicicleta">
            <pollutionImpact>-15.0</pollutionImpact>
            <childScientistDialogue>
                <string>De bicicleta.</string>
                <string>Das duas opções, esta é a que não produz poluição. Boa escolha!</string>
            </childScientistDialogue>
        </Answer>


    </Answers>

</Dilemma>
```

Figure 3.22 Structure of a Dilemma object in dilemma minigame XML file. This dilemma example is an XML representation of the dilemma depicted in Figure 3.18. The XML file shows the possible answers, the dialogue for each answer, and the pollution impact that is caused by each answer.

```
<Dialogue id="0">

    <Text>Coloca o sensor #1</Text>

</Dialogue>

<Dialogue id="1">

    <Text>Colocaste o sensor #1</Text>

</Dialogue>
<Dialogue id="2">
    <Text>Colocaste o sensor #1.
    Podemos ver que o sensor apresenta cores como o laranja e o amarelo como no sensor anterior.
    Mas por vezes, o sensor pode apresentar leituras nunca antes obtidas nesta zona.
    Essa grande variação de cor no sensor deve-se também ao facto de o sensor ter pouca precisão.
    Agora vamos apanhar o sensor para monitorizar outra zona.</Text>
</Dialogue>
```

Figure 3.23 Examples of Dialogue objects in list. Contains an id and the text for the dialogue in variable Text. The "#1" inside the string variables serves only to replace it with a segment of text such as the name of the location to place or pick the sensor. To be able to split the dialogue into smaller parts, at the end of each dialogue line there is a ". "(dot + space). When displaying the dialogue, the text of Dialogue is split into an array of string variable. It is the ". " that makes the dialogue text be separated into smaller dialogue line. This is done to avoid overflowing of information to user as much as possible.

```
<LocationList>
    <Location id="0">
    <!-- centro da cidade -->
        <x>2</x>
        <y>-8</y>
        <z>0</z>
    </Location>

    <Location id="1">
    <!--Zona residencial de Vivendas-->
        <x>11</x>
        <y>-30</y>
        <z>0</z>
    </Location>
```

Figure 3.24 A section of the list of Location objects. Each Location contains an id and coordinates x, y, and z of the grid cell map.

```
<GuideDialogueList>
    <GuideDialogue id="0">
        <pickupSensorDialogue>Não te esqueças de apanhar o sensor #1 para continuarmos com a nossa investigação.</pickupSensorDialogue>
        <placeSensorDialogue>Não te esqueças de colocar o sensor #1 para obtermos mais conhecimento da poluição na cidade.</placeSensorDialogue>
    </GuideDialogue>



</GuideDialogueList>
```

Figure 3.25 Structure of GuideDialogue. It contains an id and two strings that serve as dialogue lines that are displayed when player needs guidance. If player has not placed the sensor for a long time and needs guidance, dialogue text from *string* placeSensorDialogue is shown, whereas if the player has not picked up a portable sensor for a long time and needs guidance, dialogue text from *string* pickupSensorDialogue is shown. The "#1" inside the string variables serves only to replace it with a segment of text such as the name of the location to place or pick the sensor. This is also used in text from Dialogue object, where both can be replaced with the text in variable LocationName of SensorLocationDialogue object that is visible in Figure 3.26.

```
<SensorLocationDialogue sensorId="1">
    <DialogueId>29</DialogueId>
    <GuideDialogueId>0</GuideDialogueId>
    <LocationName>na casa de um amigo na zona de apartamentos</LocationName>
    <IsIndoor>true</IsIndoor>
</SensorLocationDialogue>
```

Figure 3.26 Structure of SensorLocationDialogue object in sensor minigame XML file. Contains specific id for sensor, Dialogue and GuideDialogue. LocationName is the text info for the location for the sensor to be picked or placed. It also contains a variable named “IsIndoor”, if this variable is with value true, the sensor will monitor the indoor air quality of the area using the indoor tilemap. If variable or value is omitted in the XML file, by default the sensor will monitor the outdoor air quality using the outdoor tilemap.

4 Evaluation

To test the game's gameplay experience and effects towards children's perception about air pollution, formal summative tests sessions were conducted throughout the month of October in an elementary school located in the county Sintra, in Lisbon district, in Portugal. Surveys about air pollution were elaborated and had proofreading treatment as well from a senior researcher in the air quality monitoring area. A game experience questionnaire was also created to assess whether players had a good experience playing the game. The setup that was used to play the game was a laptop and the game was played only with mouse or the laptop's touchpad if participants preferred. An image of the test setup can be seen in Figure 4.1.

Figure 4.1 Test setup.

The number of participants that were involved in the evaluation of the serious game was a total of twenty elementary students between the age of seven and nine, where eleven (55%) were male and nine female (45%).

The test session would begin by explaining the participant what the purpose of this test was and what the participant would be doing. After explaining the testing procedure to the participant, she/he was asked for permission to begin the formal testing if she/he desired to continue. First, the participant was asked to fill the pre-survey about air pollution to evaluate their perception before playing the game. Participants then would have a 25-minute gameplay session to play the game.

Right before playing the game, a summary of the game in terms of story, characters, goals, and controls were given to the participants. When beginning to play, participants also had a game tutorial to have a better comprehension of the controls and goals when they started playing it. After playing the game, participants would be asked to fill a post-survey about air pollution, which was identical to the pre-survey, to evaluate the participant's perception of air pollution and compare the results with the pre-survey results. Lastly, participants were asked to fill the game experience questionnaire to evaluate the game overall. Due to the current situation of the COVID-19 pandemic, disinfectant products were used before and after conducting tests for each participant for precaution.

The pre-survey and post-survey are identical to compare the answers provided for each item. These identical surveys are composed of 5 Likert scale items with answers between 1 (Completely Disagree) to 5 (Completely Agree) to assess the children's opinion regarding several statements about air pollution. A multiple-choice grid question about what pollution level (good, moderate, unhealthy for sensitive groups, unhealthy and very unhealthy) is associated to one of the colours that were mentioned previously (green, yellow, orange, red, purple), where one point would be added for each correct association. In the next section of the survey, open-ended questions were asked to the participants to give their own opinion regarding indoor, outdoor pollution and air pollution overall. The answers to these open-ended questions were audio-recorded with a phone.

After obtaining answers from the pre- and the post-survey, the mean was calculated for each Likert item and multiple-choice grid question for each survey and values were later compared between the two surveys. Regarding the answers of open-ended questions, audio recordings were analysed and compared between pre-survey and post-survey answers. The pre- and post-survey can be seen in Annex A.

As for the game experience survey, this was only filled by the participant once after playing the game. This survey was purposely elaborated in a previous work as a questionnaire for evaluation of serious games towards children [18]. The survey is based of SUS [39] and TAM [40], and has also been adjusted for children [41]. This survey consists in nine Likert scale of 1 (Strongly Disagree) to 5 (Strongly Agree) items, some positive and some negative items, evaluating the game's components, such as enjoyment, alternative to traditional teaching methods, intuitiveness, learning gain perception, and ease of use. This survey also measures whether participants would recommend this game to a friend. After the 9 Likert scale items, two open-ended questions were asked to the participant about what she/he enjoyed the most and what disliked the most in the game. The answers were audio-recorded using a mobile phone and the audio files were analysed afterwards. Finally, the final section of the game experience survey included questions about basic participants' info like age range, gender, and how frequent do they play video games overall. After conducting the tests, answers for each item were analysed and usability scores were calculated. Despite the survey being inspired by SUS and TAM and has only 9 Likert scale items, usability scores were calculated using the SUS score technique [39] and were adjusted [42] to provide additional information about the serious game in terms of usability. Annex B shows the game experience that was elaborated and used.

4.1 Air Pollution Questionnaire

After conducting the formal tests, answers from the air pollution questionnaire before and after playing were analysed and were compared between them. In the Likert scale section of the questionnaire, mean

values of each Likert scale answer in pre- and post-survey were calculated and the mean difference between pre- and post-survey (ΔM) as well. To see if there was a significant change in opinion towards the several statements, p values were obtained by performing the Student's t-test [43] with a confidence interval of ninety-five percent ($p<0.05$) and two-sided p values was the one considered between the pre- and post-survey answers of each Likert scale item.

4.1.1 Likert Scale Items and Multiple-Choice Grid Question

Results of the 5 Likert scale items, in the first item where the statement was "All air pollution is visible", the mean shows that most participants did not agree or disagree and a few of them agreed with this statement in the pre-survey (M=3.4), whereas in the post-survey the mean shifted to a more negative opinion, but mostly stayed neutral towards the statement (M=2.9). Practically, it was significant enough to reject the null hypothesis at ninety percent level of confidence (t=-1.70, p=0.106, n=20).

For the second statement ("There is air pollution inside our homes."), the mean between the participants in the pre-survey showed a slightly negative but almost neutral opinion towards the phrase (M=2.75). After playing the game, participants agreed more towards the statement (M=3.75) significantly (t= 2.44, p=0.025, n=20). In the third statement ("The use of scented candles and air fresheners contributes to good air quality inside our homes."), participants had a slightly positive opinion towards it before playing the game (M=3.5). After playing the game, the mean of participants opinion towards the phrase slightly decreased (M=3.35), showing no significant difference of opinion towards it (t = -0.57, p=0. 577, n=20).

Regarding the fourth item's statement ("The use of cleaning products contributes to good air quality inside our homes."), before playing the game, participants overall stayed neutral in their opinion towards the phrase (M=3.2), which barely changed to a more negative opinion after playing the game (M=3.15), with no significance of difference (t= -0.14, p=0.893, n=20). Finally, regarding the results obtained for the last sentence ("The existence of gardens and vegetation near our houses can improve air quality in the area."), participants showed a highly positive opinion before playing the game (M=4.55), whereas after playing the game, surprisingly, participants showed a less positive opinion (M=4.1), significantly different (t =-2.27, p=0. 035, n=20).

The mean results obtained from the Likert scale items and the differences of mean values between both surveys (ΔM) can be seen in Table 4.1. As for the mean results from the multiple-choice grid question about the colours that are associated with pollution levels, a slight increase occurred between pre-survey (M=1.85, STD = 1.236) and post-survey (M=2.3, STD = 1.487) though not significantly enough (t=1.308, p= 0.206, n=20). Figure 4.2 shows a box plot of the correct answers of the multiple-choice grid question about the colours and their associated pollution level.

Table 4.1. Likert items results of post- and pre-survey about air pollution. *ΔM* represents the difference between the mean of post-survey and mean of pre-survey (N=20)

Items	Mean Pre-survey	Mean Post-survey	Δ*M*	t	p
1. All air pollution is visible	3.4	2.9	-0.5	-1.70	.106
2. There is air pollution inside our homes.	2.75	3.75	1	2.44	.025
3. The use of scented candles and air fresheners contributes to good air quality inside our homes.	3.5	3.35	-0.15	-0.57	.577
4. The use of cleaning products contributes to good air quality inside our homes.	3.2	3.15	-0.05	-0.14	.893
5. The existence of gardens and vegetation near our houses can improve air quality in the area.	4.55	4.1	-0.45	-2.27	.035

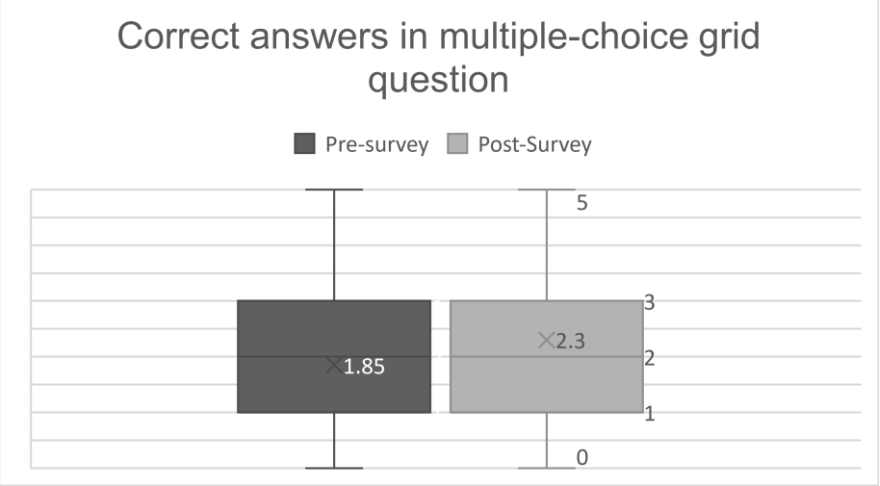


Figure 4.2 Correct answers in multiple-choice grid question in pre and post-survey.

4.1.2 Open-Ended Questions

In the first open-ended question, where participants were asked if they think there could be air pollution inside our homes, in the pre-survey, half of the participants said no (N=10), over a third said that there

can be air pollution indoors (N=7), while the remainder did not know or did not respond. After playing the game, more than half of the participants said that there could be air pollution indoors (N=13), a quarter of the participants said no (N=5), one participant did not know, and one said that there was "more or less" air pollution inside our homes. Figure 4.3 shows the comparison of answers between both pre- and post-survey.

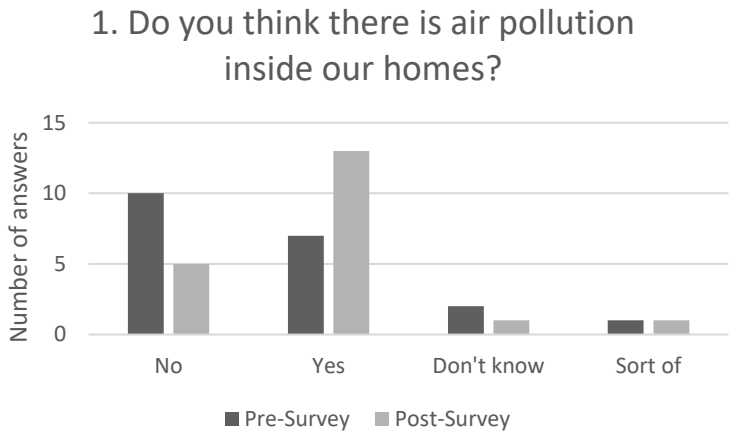


Figure 4.3 Answers of first open-ended question.

In open-ended question number two, where participants were asked about what they think that can pollute the air inside their homes, several topics were mentioned in their answers about possible pollution sources inside our houses. In the pre-survey, the topic that stands out was garbage and other types of waste such as plastic, cardboard and glass were mentioned the most (N=10). Some participants did not answer or did not know any possible sources (N=4). Some other terms were also mentioned, such as smoke, candles, cleaning products (N=3). Finally, there were some terms that were only mentioned once, such as bugs, fires, air fresheners, flies, plastic bags from outdoors, outdoor air, and bad odour (N=1).

After playing the game, post-survey results show that some of the topics from the pre-survey were mentioned again, new ones appeared, and some topics from the pre-survey were not mentioned in the post-survey. Despite being mentioned fewer times, garbage and other types of waste (plastic, cardboard and glass) were still the most mentioned topics (N=7). Two of the topics got more mentions, namely, cleaning products (N=5) and candles (N=4). Smoke maintained the same number of mentions from the pre-survey (N=3); only one participant did not know after playing the game. The remainder of the topics were mentioned only once (bugs, air fresheners, outdoor air, bad odours, gas, machines, strong lights, germs, dirtiness, toxic products, fireplaces). Word clouds of pre- and post-survey answers can be seen in Figure 4.4 and Figure 4.5, respectively. Both Figures show that the answer garbage and other types of waste was the most mentioned before and after playing but there were more mentions of candles and cleaning products being pollutants of indoor air pollution after playing it. Figure 4.6 shows the number

of times each topic was mentioned in the pre- and post-survey answers in open-ended question number two.

Figure 4.4 Word cloud of pre-survey answers in open-ended question number two (What do you think can pollute the air inside our homes?). There were eleven topics mentioned (without counting "Do not know" answers) and garbage was the most mentioned one.

Figure 4.5 Word cloud of post-survey answers in open-ended question number two (What do you think can pollute the air inside our homes?). There were 16 topics mentioned (without counting "Do not know" answers) and the most mentioned topic was garbage overall.

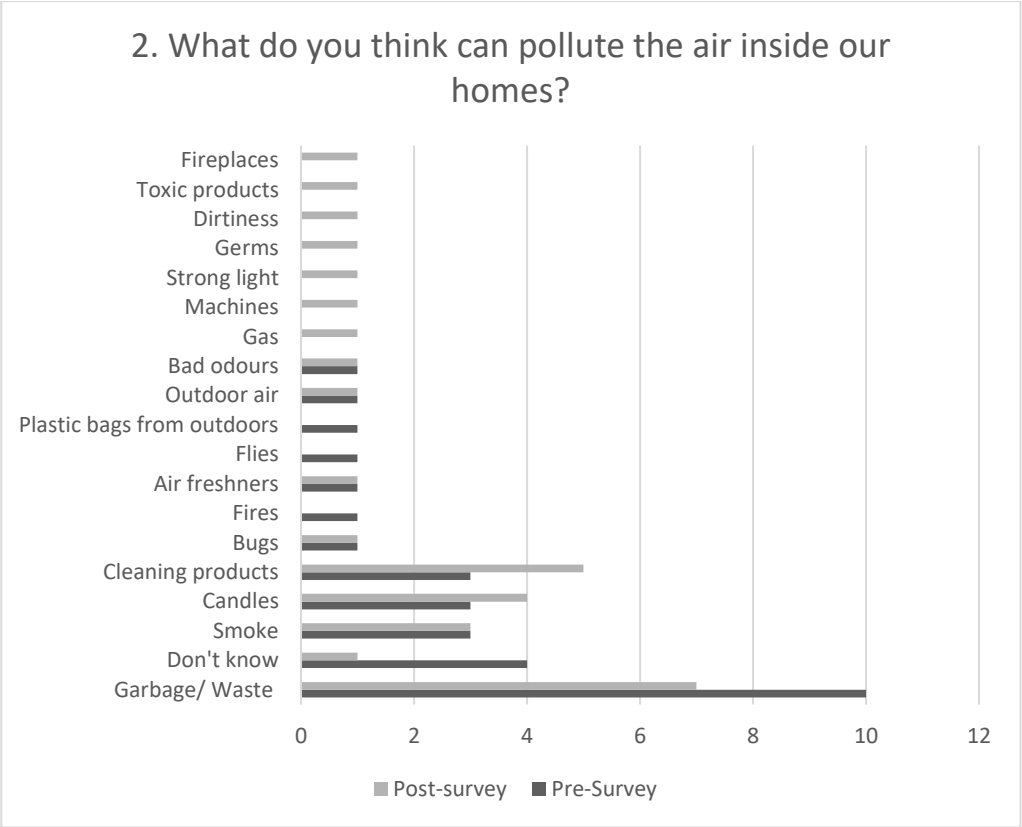


Figure 4.6 Bar chart of answers in open-ended question number two.

For the third question, participants gave their opinion of what is in the air when it is polluted. The pre-survey shows most participants mentioning garbage and other types of waste in this answer as well (N=11). Smoke and germs were mentioned the same number of times (N=3). Few participants did not respond or did not know (N=3). Other topics like bugs, factories, perfume, chewing gum, light pollution, wind, toxic products, flies, bits of food, obesity, leaves, dirtiness were mentioned only once. After playing the game, post-survey results show that the topic garbage was mentioned fewer times (N=8), that there is an increase in number of mentions for the topics smoke (N=6), germs (N=4) and bugs (N=2), and that there was a lower number of people who did not respond or did not know (N=2). Topics such as factories, chewing gum, wind, toxic products, flies, bits of food, obesity, dirtiness, and new topics such as pigeons and fossil fuels were mentioned only once (pigeons and fossil fuels). Word clouds of the answers obtained from pre- and post-surveys can be seen in Figure 4.7 and Figure 4.8 respectively. Just like in question 2, the most mentioned answer was garbage. Smoke was mentioned more times compared to the pre-survey. Figure 4.9 shows the number of times each topic was mentioned in the pre- and post-survey answers in open-ended question number three.

Figure 4.7 Word cloud of pre-survey answers in open-ended question number three (What do you think is in the air when it is polluted?). A total of 15 topics were mentioned without counting "Do not know" answers. Garbage was the most mentioned.

Figure 4.8 Word cloud of post-survey answers in open-ended question number three (What do you think is in the air when it is polluted?) where 14 topics were mentioned (without counting "Do not know" answers). Smoke was mentioned more times after playing the game.

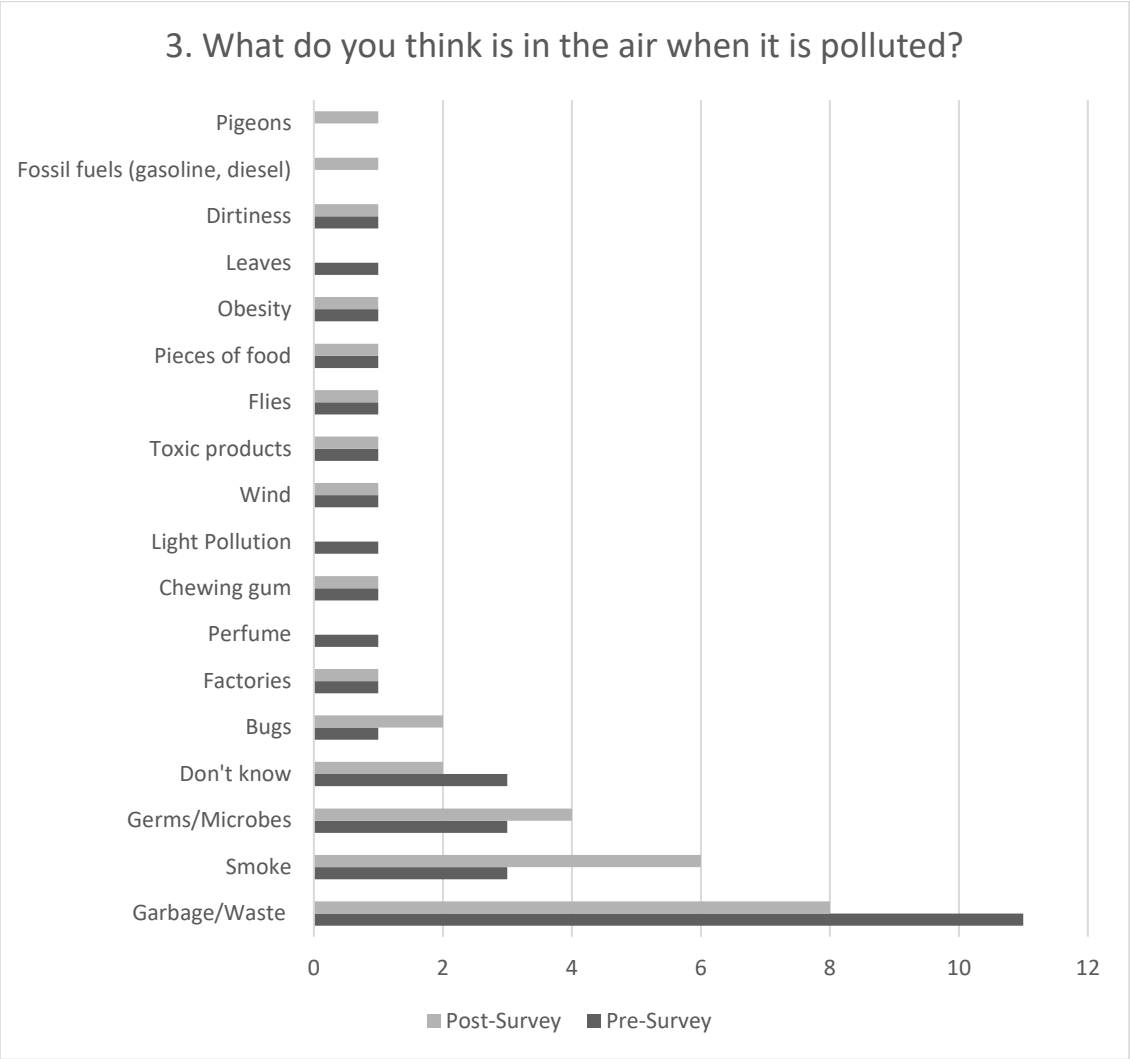


Figure 4.9 Bar chart of answers in open-ended question number three.

As for the fourth question, participants gave their opinion on how people can mitigate the outdoor air pollution. In the pre-survey, the topics more mentioned were cleaning or picking up garbage (N=8). Some participants did not respond or did not know (N=5), whereas a few responded with vague answers, such as stop polluting, not polluting the environment, and some were more specific with it by saying to not litter the streets. There was also an equal number of mentions from participants who said that there should be fewer factories (N=2). The rest of the suggestions were mentioned only once, such as more gardens and vegetation, reduce the use of cars and motorcycles, use less electricity, candles, air fresheners, detergents, reuse of materials, have good odours (for example from flowers), conserve things and, also, the suggestion of creating a group that teaches people to not litter. In the post-survey, a higher number of suggestions were given by the participants, the most suggested action being picking up or clean up garbage again (N=7). The number of participants who did not know or did not answer maintained the same as the pre-survey (N=5). A higher number of participants suggested to not pollute the environment (N=3) and more people suggested more vegetation and

gardens, while others suggested a more frequent use of bicycles (N=2). The remainder of suggestions were mentioned only once: fewer factories, lesser use of cars and motorcycles, candles and air fresheners, conserve things, more walking, fewer fires, help pollute, avoid smoke from factories and cars, use more public transports, clean things with cleaning products and create a group that incentive people to not litter. Surprisingly, after analysing the audio recordings, one participant mentioned the action "help pollute" after playing the game. But after analysing the other topics that this specific participant mentioned, he also suggested the topic "Stop polluting". This can indicate that the participant had a lack of knowledge or maybe he was not sure what to say. Word clouds of the answers obtained from the pre- and post-survey answers for this question can be seen in Figure 4.10 and Figure 4.11, respectively. Figure 4.12 shows the number of times each topic was mentioned in the pre- and post-survey answers in open-ended question number four.

Figure 4.10 Word cloud of pre-survey answers in open-ended question number four (How do you think we can reduce the air pollution we have outside?). There were 12 topics mentioned (without counting "Do not know" answers) and the action clean or pick up trash was the most mentioned.

Figure 4.11 Word cloud of post-survey answers in open-ended question number four (How do you think we can reduce the air pollution we have outside?). There were 15 topics mentioned (without counting "Do not know" answers) and the topic clean or pick up trash was the most mentioned.

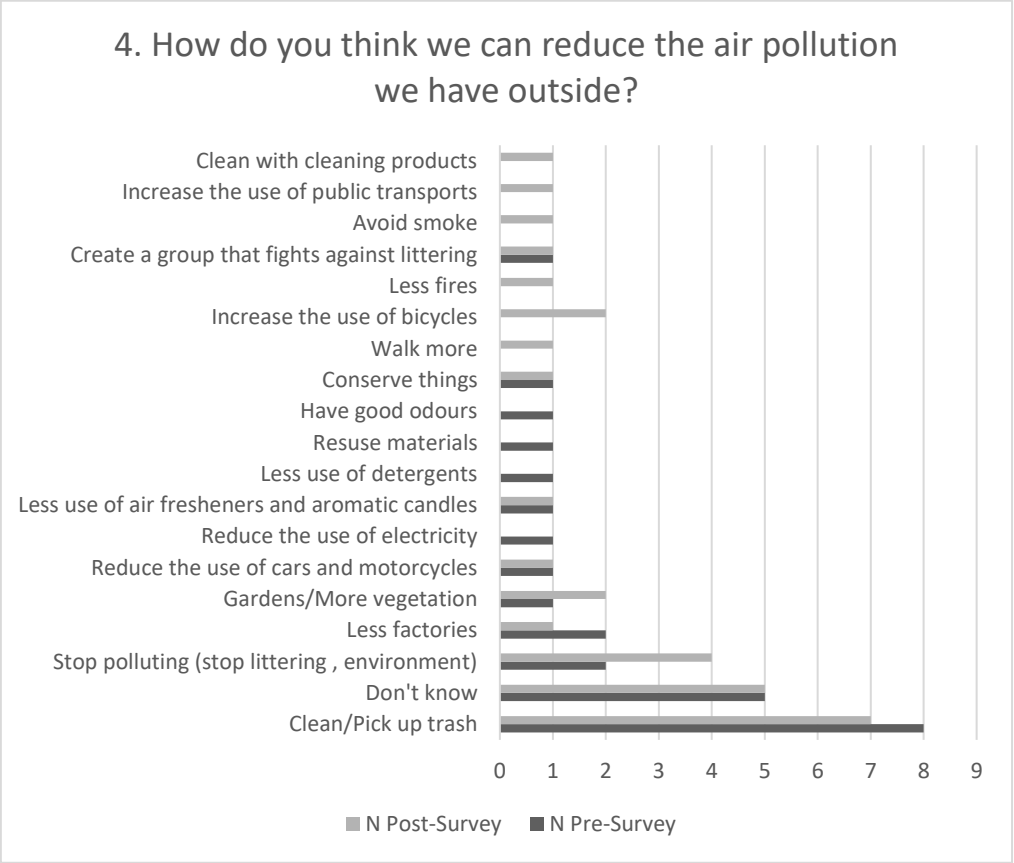


Figure 4.12 Bar chart of answers in open-ended question number four.

4.2 Game Experience Survey

Looking at the results about the participants' feedback on the game experience survey through a mixture of positive and negative 9 items of Likert scale answer type, feedback was overall positive. In the first item ("If we had more time, I would like to continue playing the game."), participants tended to agree on it (*M*=4.35). In the second ("I would like my teacher to use this kind of game in the classroom.") and third item ("If I had this game at home, I would like to play it a lot more often") most participants agreed with both of them (*M*=4.25). For the fourth item, participants agreed that they learned a lot about pollution when playing this game (*M*= 4.55). As for the fifth item, participants slightly agreed that they felt confused several times when playing (*M*=3.55). In the sixth item, they tended to be more neutral (*M*=2.95) about if they needed help from an adult while playing. Participants also agreed overall that they would learn more about pollution if they played the game several times (*M*=4.65) and that their friends would learn more about pollution by playing this game (*M*=4.6); however, they only slightly agreed that their friend would enjoy playing this game (*M*= 3.85). Results of each item can be seen in Table 4.4. As for the usability score, the mean obtained was 75 out of 100, which is considered acceptable.

Open-ended questions were also asked to the participants about what they liked and disliked the most while playing the game. Regarding of what they liked the most, as seen in Table 4.2, most frequent answers were the sensor minigame (N=11), controlling the bike and the dilemma minigame (N=7), there were other less frequent answers such as learning new things about pollution (N=4) and dialogue (N=1).

In Table 4.3, we can see the number of negative aspects of the game that were given. Results show that some participants had nothing negative to report (N=8), while others mostly pointed out the controls as a negative aspect (N=7). The second most negative aspect was excessive dialogue (N=2), answers like too many things to do, placing sensors to answer dilemmas and the guide feature that kept calling trying to guide the player were mentioned only once (N=1).

Table 4.2. Positive aspects of game. Shows info of positive aspects that were mentioned N (number of mentions) times

Aspects	**N**
Liked sensor minigame	11
Controlling the bike	7
Liked dilemma minigame	7
Learn new things about pollution	4
Dialogue	1

Table 4.3. Negative aspects of game. Shows info of negative aspects that were mentioned N (number of mentions) times.

Aspects	**N**
Nothing	8
Problems with controls	7
Too much dialogue	2
Lot of things to do	1
Placing sensors to answer dilemmas	1
Guide feature kept calling	1

Table 4.4. Game experience survey Likert items results. Shows info about question formulation ("Positive" means that a higher mean value is better and "Negative" means that a lower mean value is better), mean (M) and standard deviation (STD) results.

Item	**Question Formulation**	***M***	**STD**
1. If we had more time, I would like to continue playing the game	Positive	4.35	0.813
2. I would like my teacher to use this kind of game in the classroom	Positive	4.25	0.851
3. If I had this game at home, I would like to play it a lot more often	Positive	4.25	1.020
4. With this game I learned a lot of new things about pollution	Positive	4.55	0.686
5. I felt confused several times while playing	Negative	3.55	1.234
6. To play this game, I feel that I need help from an adult	Negative	2.95	1.356
7. If I played this game more often, I would learn a lot more about pollution	Positive	4.65	0.489
8. My friends will really enjoy this game	Positive	3.85	1.040
9. My friends will learn a lot about pollution with this game	Positive	4.6	0.598

4.3 Discussion

Results from pre- and post-surveys evaluating the children's perception of air pollution before and after playing the game overall shows that participants had a better perception after playing the game when comparing the mean values between both surveys and seeing the answers given in the open-ended questions. Item 1 (all air pollution is visible.) was almost significant, and item 3 (the use of scented candles and air fresheners contributes to good air quality inside our homes.) and 4 (the use of cleaning products contributes to good air quality inside our homes.) were also positive but less significant.

Conversely, items 2 (there is air pollution inside our homes.) and 5 (the existence of gardens and vegetation near our houses can improve air quality in the area.) were significantly different, where in item number two, the game managed to increase the participants' environmental awareness regarding the existence of indoor air pollution. Surprisingly, the game decreased perception in item number five regarding the positive effects on air quality in zones with more vegetation which was unexpected due to the fact that the game's dialogue associated vegetation, trees, and parks to a good air quality. Perhaps after playing the game, participants showed a perception that just planting trees or building parks is not enough to improve air quality overall and other actions are needed. This raises questions that could be studied in future research. The p-value for the hypothesis testing in item 1 is almost reaching the significance threshold with a ninety percent of confidence ($p<0.1$) to be able to reject the null hypothesis, meaning that would be fruitful to run an additional set of tests to enlarge the sample size. Items 3 and 4 are related to the perception about air quality indoors when using aromatic candles and cleaning products inside houses. One reason that there was barely visible any change after playing the game could be due to the fact that some of the players may have not reached the level of the sensor minigame and dilemmas that address this subject more, which could have led to a large amount of participants having an almost indifferent opinion towards these statements after playing the game. Possibly, if participants had more gameplay time, they could have reached that part of the level and have a different opinion in the post-survey. An additional in-depth statistical analysis of the obtained results should be conducted in order to assess this issue. As for the multiple-choice grid question to check whether players had learned what each colour represents in terms of pollution level in an area after playing the game, despite having an increase of the mean value after playing, this is not statistically significant. It is left to analyse whether more tests, i.e., a larger sample size, would result in a different conclusion.

In the open-ended questions, when participants were asked if air pollution exists inside our homes, half of them said no before playing, whereas after playing the game more than half of the participants said yes. This shows that there were positive effects on participants' perception about air pollution indoors.

In question 2, when asked about what participants think can pollute the air inside our homes, the most mentioned topic in the pre- and post-survey was garbage and other types of waste (plastic, cardboard, and glass); other topics, such as smoke, candles and cleaning products were also mentioned several times, the last two being mentioned more times after playing the game. Some participants also did not know what to answer in the pre-survey, a number that was greatly reduced after playing the game. This shows that after playing the game, participants had an increased perception about air pollution and more children managed to answer the question which is a positive result.

For question 3, which addresses what participants think is in the air when it is polluted, the most mentioned topic in both surveys was also garbage and other types of waste. Some participants also referred smoke and germs. These two answers were mentioned more often after playing the game, despite the game not mentioning anything about germs. The increased mentions of topics related to air pollution such as smoke shows that the game managed to increase some of the participants' perception of air pollution. As for the increased number of answers for germs, it was unexpected due to the fact that the game never addressed the germs topic specifically. This result may indicate that some participants had a better air pollution perception than it was thought since they did not show it in the pre-survey. The most frequent answers from the two previous questions in pre- and post-survey, which was garbage, show that most participants might perceive bad air quality and pollution mostly through bad odours and dirtiness.

For the last open-ended question, participants gave their opinion about what actions they think are needed to reduce air pollution from outdoors. The pre-survey results show a higher number of participants that mentioned actions such as picking up trash that is on the floor, a few suggested to have fewer factories and others suggested to stop littering and ruining the environment; however, there were also answers that were more related to air quality indoors than outdoors such as a less use of cleaning products, candles and air fresheners. In the post-survey, results show that most of the participants maintained the suggestion of cleaning garbage from the floor, there were less people suggesting fewer factories, and there were more suggesting stopping littering. There were also more answers about adding more gardens and vegetation. New suggestions have also come up where a few of the participants suggested an increase in the use of bicycles as a mean of transport. Overall, results show that after playing the game, there were more mentions of topics that are considered pro-environmental behaviours, which indicates that there was an increase in participants' perception of air pollution.

Results from game experience survey were analysed and were used to calculate a usability score. Despite the survey being based not only on SUS but TAM as well and having nine items instead of the traditional ten-item survey, calculations of a usability score were done and adjusted to have an approximate value that would be obtained in the ten-item survey of SUS [42]. The survey had also a mix of positive and negative items (seven positive and two negative). Calculations for each item were

done as suggested in the traditional SUS for each positive and negative item. Since this survey was not only based on SUS, it is not possible to evaluate the usability as good or excellent with high SUS scores. So, it was considered the score of 50 out of 100 as the baseline of our score and the game's usability would be considered acceptable if our score is equal or above 50 and not acceptable if below 50. Scores ranged from 94 to 53 and the mean of all scores obtained was 75 out of 100, which according to our baseline is acceptable in terms of usability. Thus, the goal of designing a usable game has been achieved, which is important given that we do not want usability to be in the way of learning and enjoyment.

Open-ended questions about what participants liked and disliked the most were also analysed, and results showed that participants liked the sensor minigame the most. Some of them also mentioned the dilemma minigame and controlling the bike. As for the negative aspects, several of them did not like the controls that were implemented for this game, which can be because of the way the game was presented in an isometric style. Participants might have become confused with the streets' orientations, despite the control keys being aligned for each possible direction, players would take some time to get used to it which could have affected their progress in the game. Controls need to be more intuitive in the future so participants can have a better gameplay experience right from the start. Few participants also mentioned that there was too much dialogue. This excessive dialogue would make some participants skip some dialogue midway through their gameplay session. Other participants would read most of the dialogue but some of these elementary students have more difficulties in reading than others and, therefore, some of them spent a considerable of the gameplay reading the dialogue lines and progressed in a much slower pace. Both observations may have affected the possibility of participants having a bigger increase in their perception of air pollution overall. Dialogue needs to be shorter and more direct to avoid boredom and to ease the reading for participants. The dialogue can be easily changed by editing the XML files that contain the dialogue of each minigame.

This work also had a few limitations which limited the number of participants that were involved in formal testing of the game which could have affected results. Since formal testing only started during the school year, this made scheduling of tests more time restricted thus limiting the number of tests to one per day mostly. During testing phase several classes were also quarantined at home due to positive cases of COVID-19 among those classes, which led to a much lower number of possible participants and restrictions were applied in school regarding the entry of non-teaching staff for several weeks. The game sometimes also showed a few bugs: when in pause mode it had an unpredictable behaviour, where sometimes nothing would happen and sometimes the program would stop responding and the application had to be closed. Although in testing it was rare to pause the game, unfortunately it happened at least once or twice during testing which could have caused some frustration for the participants who suffered this problem.

5 Conclusions and Future Work

5.1 Conclusions

In conclusion, this dissertation presented "Problemas no Ar", an isometric serious game developed in Unity about air quality monitoring that can be configurable in terms of dialogue and minigames' length. Educators and teachers can create new dialogues, locations to place sensors and dilemmas in order to raise awareness about air pollution. This can be done by editing each XML file that is linked to their minigame.

Identical pre- and post-surveys with Likert scale items and open-ended questions about air pollution were elaborated for comparison between them to see the effects that the game provided towards children's perception of air pollution. Results between pre- and post-surveys showed that the game provided some positive effects significantly. Open-ended questions showed that most participants before and after playing the game, associated garbage and other types of waste as the main source of indoor and outdoor air pollution. A game experience survey that was elaborated for evaluation of serious games towards children was also used [18]. A usability score using the SUS score technique was calculated based on the survey's answers in the Likert items. Participants also answered open-ended questions about the positive and negative aspects of the game. The average score of the game's usability obtained from the game experience survey answers was 75 out of 100, which means that the game can be considered usable since it was above the defined baseline value of 50. Answers from open-ended questions showed that children pointed out the sensor minigame as the most positive aspect of the game and mentioned the controls as the most negative aspect of the game. Based on these results, the following paragraphs show what answers were obtained regarding the research questions that were defined in this dissertation.

Regarding the first research question about elementary students' perception about air pollution we addressed this with surveys and open-ended questions. Answers from open-ended questions showed that, before or after playing the game, participants would mostly refer trash and other types of waste, such as plastic as the main pollution source in indoors and outdoors.

Regarding the second research question, can a serious game improve elementary school students' awareness of air pollution, results from pre- and post-surveys showed an improvement overall. When comparing answers of open-ended questions before and after playing the game, there were more mentions of topics related to indoor and outdoor air pollution such as smoke and candles, indicating that there was an increase in their air pollution perception. Overall, most of the mean values of Likert scale items between pre- and post-survey shifted to a better and expected value after playing the game. The

results also show that one of the items' mean value shifted to a significantly worse and unexcepted value after playing the game, which raised interest and should be investigated further in future work.

As for the third research question, can a serious game for environmental awareness still be fun to play, usability score obtained showed that "Problemas no Ar" is acceptable in terms of usability. The usability score obtained was 75 out of 100. This score can be improved by addressing the negative aspects of the game that were mentioned by participants such as controls and dialogue.

Lastly, for the fourth research question, which game mechanics foster air pollution awareness in an entertaining way, the feedback given by students, mention the sensor minigame as the most common answer. Students also enjoyed controlling the bike. The dilemma minigame was also mentioned. Overall, more than half the students enjoyed a game mechanic related to air pollution awareness.

The results show that the game manages to provide positive effects towards elementary school students' perception on air pollution overall. Despite a few not being significant enough, results overall show that "Problemas no Ar" has the potential to be used as a learning and teaching tool, which has the possibility to become more effective by addressing the issues that participants complained the most, which were related to controls and excessive dialogue.

5.2 Future Work

For future work, the game's controls need to be more intuitive to improve the player experience. Dialogue needs to be simpler and more direct to children to avoid possible boredom when reading long texts of dialogue and to ease the reading for participants who struggle more and take more time when reading, this can be resolved easily by changing the dialogue in the XML files of both minigames.

The game could also have the addition of new minigames to add more variety of tasks in the game. These new minigames could also focus on other subjects related to environmental pollution such as marine and soil pollution.

Since most of the dilemma minigame is configurable through the XML file, it can also be used to address other types of pollution such as soil, marine and air pollution, making this game focused not only about air pollution but pollution overall.

To have a better evaluation of the effectiveness of this serious game towards children's air pollution perception, a bigger test sample of elementary students is needed to see if it is possible to reject the null hypothesis in some of the items.

As mentioned in Section 4.3, an unexpected bug was encountered when pausing the game, which would make the application to stop responding, requiring the participant to redo some of the actions, possibly causing some frustration. Although it was rare to pause the game, this bug should be located and fixed. A checkpoint save and load feature should also be added so that the participant can resume the game after a break.

Other possible features to be added is the possibility of cars to worsen the air quality levels in the pollution tilemap in tiles where traffic density is high. Another possibility is to have the opposite feature, namely the air quality levels can improve when there is less traffic density.

To address the negative and unexpected effect that the game provided regarding the Likert item number 5 ("The existence of gardens and vegetation around our houses can improve air quality in the area"), a feature which enables the player to place parks and trees to improve air quality in certain areas could be added. This last feature could be considered in another minigame for future participants to play. However, their perception regarding this item's statement should be evaluated more in-depth as to why they disagreed more about vegetation and parks improving air quality around them after playing the game.

Another idea for future work is to test the game on mobile devices instead of a laptop, practically the whole game is interactable only through mouse and no keyboard input is needed. Most controls and interacting buttons are on the screen. If touch features are implemented that allow users to interact with buttons and camera in the game via touch, this can easily be an application for tablets or smartphones. We could also test the usability with mobile devices and compare it to the usability results that were obtained from playing on the laptop.

References

[1] "WHO Air Pollution Overview," [Online]. Available: https://www.who.int/health-topics/air-pollution#tab=tab_1. [Accessed 10 January 2021].

[2] WHO, "World health statistics 2021: monitoring health for the SDGs, sustainable development goals," World Health Organization, Geneva, 2021.

[3] R. J. Sram, M. J. Veleminsky, M. S. Veleminski and J. Stejskalová, "The impact of air pollution to central nervous system in children and adults," *Neuroendocrinology Letters,* vol. 38, no. 6, pp. 389-396, 2017.

[4] T. Faria, V. Martins, C. Correia, N. Canha, E. Diapouli, M. Manousakas, K. Eleftheriadis and S. M. Almeida, "Children's exposure and dose assessment to particulate matter in Lisbon," *Building and Environment,* vol. 171, no. 6, pp. 1384-1397, 2020.

[5] D. A. Coley, R. Greeves and B. K. Saxby, "The Effect of Low Ventilation Rates on the Cognitive Function of a Primary School Class," *International Journal of Ventilation,* vol. 6, no. 2, pp. 107-112, 2007.

[6] P. Wargocki, J. A. Porras-Salazar, S. Contreras-Espinoza and W. Bahnfleth, "The relationships between classroom air quality and children's performance in school," *Building and Environment,* vol. 173, p. 106749, 2020.

[7] S. Kim, J. A. Senick and G. Mainelis, "Sensing the invisible: Understanding the perception of indoor air quality among children in low-income families," *International Journal of Child-Computer Interaction,* vol. 19, pp. 79-88, 2019.

[8] R. Massoudi and A. Hamidi, "Some Candles Emit Hazardous Materials for Human Health and are Indoor Air Pollutants," *International Journal of Tropical Disease & Health,* vol. 24, no. 2, pp. 1-10, 2017.

[9] L. Cori, G. Donzelli, F. Gorini, F. Bianchi and O. Curzio, "Risk Perception of Air Pollution: A Systematic Review Focused on Particulate Matter Exposure," *International Journal of Environmental Research and Public Health,* vol. 17, no. 17, p. 6424, 3 September 2020.

[10] "Expolis: Welcome," [Online]. Available: http://expolis.ctn.tecnico.ulisboa.pt/index.html. [Accessed 24 11 2021].

[11] P. Santana, A. Almeida, P. Mariano, C. Correia, V. Martins and S. M. Almeida, "An Affordable Vehicle-Mounted Sensing Solution for Mobile Air Quality Monitoring," in *5th International Conference on Smart and Sustainable Technologies*, Split, Croatia, 2020.

[12] "World's Air Pollution: Real-time Air Quality Index," [Online]. Available: https://waqi.info/. [Accessed 14 June 2021].

[13] B. Teles, P. Mariano and P. Santana, "Game-like 3d visualisation of air quality data," *Multimodal Technologies and Interaction,* vol. 4, no. 3, p. 54, 2020.

[14] J. J. Roldán-Gómez, P. Garcia-Aunon, P. Mazariegos and A. Barrientos, "SwarmCity project: monitoring traffic, pedestrians, climate, and pollution with an aerial robotic swarm," *Personal and Ubiquitous Computing,* 2020.

[15] C. C. Abt, Serious Games, University Press of America, 1983.

[16] Y. Zhonggen, "A Meta-Analysis of Use of Serious Games in Education over a Decade," *International Journal of Computer Games Technology,* vol. 2019, p. 4797032, 2019.

[17] K. Peffers, T. Tuunanen, M. A. Rothenberger and S. Chatterjee, "A Design Science Research Methodology for Information Systems Research," *Journal of Management Information Systems,* vol. 24, no. 3, pp. 45-77, 2007.

[18] J. Fernandes, "Uma experiência joguificada para crianças em realidade aumentada para interação tangível com dados de poluição do ar," Master's Thesis, ISCTE-Instituto Universitário de Lisboa, 2021.

[19] P. Mariano, S. M. Almeida and P. Santana, "On the automated learning of air pollution prediction models from data collected by mobile sensor networks," *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects,* 2021.

[20] "Air Data Basic Information | US EPA," [Online]. Available: https://www.epa.gov/outdoor-air-quality-data/air-data-basic-information. [Accessed 26 November 2021].

[21] S. Heo, K. Nam, J. Loy-Benitez, Q. Li, S. Lee and C. Yoo, "A deep reinforcement learning-based autonomous ventilation control system for smart indoor air quality management in a subway station," *Energy and Buildings,* vol. 202, p. 109440, 2019.

[22] "OpenStreetMap," [Online]. Available: https://www.openstreetmap.org/. [Accessed 26 November 2021].

[23] D. Djaouti, J. Alvarez, J.-P. Jessel and O. Rampnoux, "Origins of Serious Games," in *Serious Games and Edutainment Applications,* M. Minhua , O. Andreas and C. J. Lakhmi, Eds., London, Springer, 2011, pp. 25-43.

[24] L. Morganti, F. Pallavicini, E. Cadel, A. Candelieri, F. Archetti and F. Mantovani, "Gaming for Earth: Serious games and gamification to engage consumers in pro-environmental behaviours for energy efficien," *Energy Research and Social Science,* vol. 29, pp. 95-102, 2017.

[25] B. Anđić, S. Kadić, R. Grujičić and D. Malidžan, "A comparative analysis of the attitudes of primary school students and teachers regarding the use of games in teaching," *IAFOR Journal of Education,* vol. 6, no. 2, pp. 5-16, 2018.

[26] A. M. Feldpausch-Parker, M. O'Byrne, D. Endres and T. R. Peterson, "The Adventures of Carbon Bond: Using a melodramatic game to explain CCS as a mitigation strategy for climate change," *Greenhouse Gases: Science and Technology,* vol. 3, no. 1, pp. 21-29, 2013.

[27] A. Carducci, B. Casini, G. Donzelli, M. Verani, B. Bruni, E. Ceretti, C. Zani, E. Carraro, S. Bonetta, F. Bagordo, T. Grassi, M. Villarini, S. Bonizzoni, L. Zagni, U. Gelatti and M. Group, "Improving awareness of health hazards associated with air pollution in primary

school children: Design and test of didactic tools," *Applied Environmental Education and Communication,* vol. 15, no. 3, pp. 247-260, 2016.

[28] Y. Klisch, L. M. Miller, S. Wang and J. Epstein, "The Impact of a Science Education Game on Students' Learning and Perception of Inhalants as Body Pollutants," *Journal of Science Education and Technology,* vol. 21, no. 2, pp. 295-303, 2012.

[29] J. Prophet, Y. M. Kow and M. Hurry, "Cultivating Environmental Awareness: Modeling Air Quality Data via Augmented Reality Miniature Trees," in *Augmented Cognition: Intelligent Technologies*, Las Vegas, NV, USA, 2018.

[30] N. Polys, J. Hotter, M. Lanier, L. Purcell, J. Wolf, W. C. Hession, P. Sforza and J. D. Ivory, "Finding Frogs: Using Game-Based Learning to Increase Environmental Awareness," in *Proceedings of the 22nd International Conference on 3D Web Technology*, New York, NY, USA, 2017.

[31] A. G. Briones, P. Chamoso, A. Rivas, S. Rodríguez, F. De La Prieta, J. Prieto and J. M. Corchado, "Use of Gamification Techniques to Encourage Garbage Recycling. A Smart City Approach," in *Knowledge Management in Organizations*, Žilina, Slovakia, 2018.

[32] J. Fox, J. McKnight, Y. Sun, D. Maung e R. Crawfi, "Using a serious game to communicate risk and minimize psychological distance regarding environmental pollution," *Telematics and Informatics journal,* vol. 46, 2020.

[33] M. M. Moore and J. Z. Yang, "Using Eco-Guilt to Motivate Environmental Behavior Change," *Environmental Communication,* vol. 14, no. 4, pp. 522-536, 2020.

[34] G. Puttick and E. Tucker-Raymond, "Building Systems from Scratch: an Exploratory Study of Students Learning About Climate Change," *Journal of Science Education and Technology,* vol. 27, no. 4, pp. 306 - 321, 2018.

[35] D. Shepardson, "Student Ideas: What Is an Environment?," *Journal of Environmental Education,* vol. 36, 2006.

[36] S. Özsoy and B. Ahi, "Elementary School Students' Perceptions of the Future Environment through Artwork," *Educational Sciences: Theory & Practice,* vol. 14, no. 4, pp. 1570-1582, 2014.

[37] M. Duran, "Perception of preschool children about environmental pollution," *Journal of Education in Science, Environment and Health (JESEH),* vol. 7, no. 3, pp. 200-219, 2021.

[38] G. E. P. Box and M. E. Muller, "A Note on the Generation of Random Normal Deviates," *The Annals of Mathematical Statistics,* vol. 29, no. 2, pp. 610-611, 1958.

[39] J. Brooke, "SUS: A 'Quick and Dirty' Usability Scale," in *Usability Evaluation In Industry*, London, CRC Press, 1996, pp. 207-212.

[40] F. D. Davis, "Perceived usefulness, perceived ease of use, and user acceptance of information technology," *MIS Quarterly: Management Information Systems,* vol. 13, no. 3, pp. 319-340, 1989.

[41] C. Putnam, M. Puthenmadom, M. A. Cuerdo, W. Wang and N. Paul, “Adaptation of the System Usability Scale for User Testing with Children,” in *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems*, Honolulu, HI, USA, 2020.

[42] J. R. Lewis and J. Sauro, “Can I Leave This One Out? The Effect of Dropping an Item From the SUS,” *Journal of Usability Studies,* vol. 13, no. 1, pp. 38-46, 2017.

[43] Student, “The Probable Error of a Mean,” *Biometrika,* vol. 6, no. 1, pp. 1-25, 1908.

[44] A. Bangor, P. T. Kortum and J. T. Miller, “An Empirical Evaluation of the System Usability Scale,” *International Journal of Human–Computer Interaction,* vol. 24, no. 6, pp. 574-594, 2008.

Annex A. Air Pollution Questionnaire

Air Pollution Questionnaire

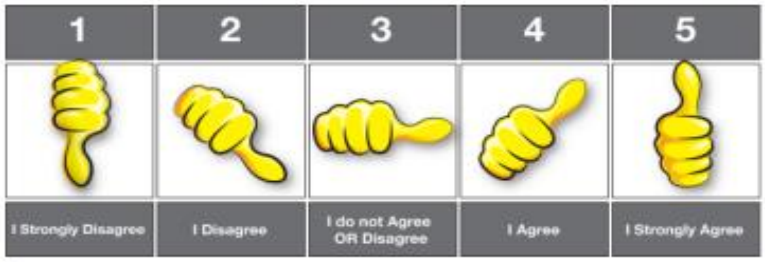
This questionnaire aims to evaluate your knowledge about air pollution before playing the game and after playing the game. This questionnaire will also help evaluate the effectiveness of the game in teaching participants about the topic.

1. All air pollution is visible.

Marcar apenas uma oval.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

2. There is air pollution inside our homes.



Marcar apenas uma oval.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

3. The use of scented candles and air fresheners contributes to good air quality inside our homes.

Marcar apenas uma oval.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

4. The use of cleaning products contributes to good air quality inside our homes.

Marcar apenas uma oval.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

5. The existence of gardens and vegetation near our houses can improve air quality in the area.

Marcar apenas uma oval.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

6. Match each colour to the level of air quality you think is associated with it.

Marcar apenas uma oval por linha.

	Good	Moderate	Unhealthy for sensitive groups	Unhealthy	Very unhealthy	Do not know
Green	◯	◯	◯	◯	◯	◯
Orange	◯	◯	◯	◯	◯	◯
Yellow	◯	◯	◯	◯	◯	◯
Purple	◯	◯	◯	◯	◯	◯
Red	◯	◯	◯	◯	◯	◯

7. Do you think there could be air pollution inside our homes?

8. What do you think can pollute the air inside our homes?

9. What do you think is in the air when it is polluted?

10. How do you think we can clean up/reduce the air pollution we have outside?

Annex B. Game Experience Survey

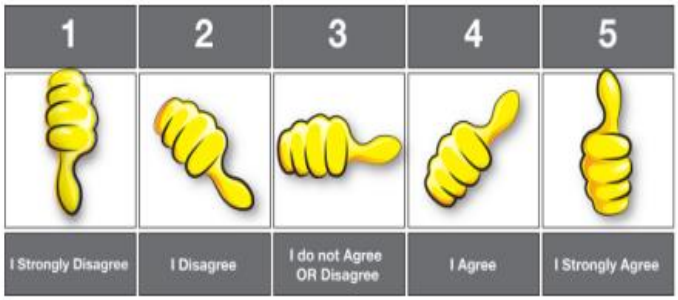
Gaming Experience Survey - Introduction

This survey aims to get an opinion from you about the game overall after you have played it.
The following questions will evaluate various components of the game, these questions will be answered using scales from 1 to 5 for each item.

Gaming Experience Survey

Please indicate how you felt while playing the game for each of the items, on the following scale from 1 to 5:
1- Strongly disagree; 5- Strongly agree;

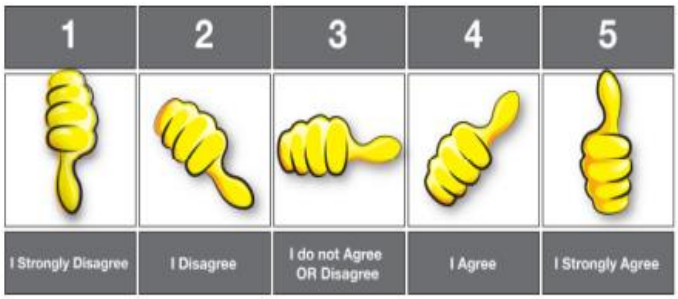
1. If we had more time, I would like to continue playing the game



Marcar apenas uma oval.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

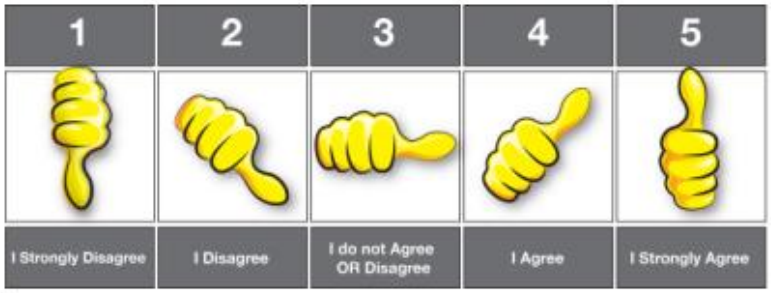
2. I would like my teacher to use this kind of game in the classroom



Marcar apenas uma oval.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

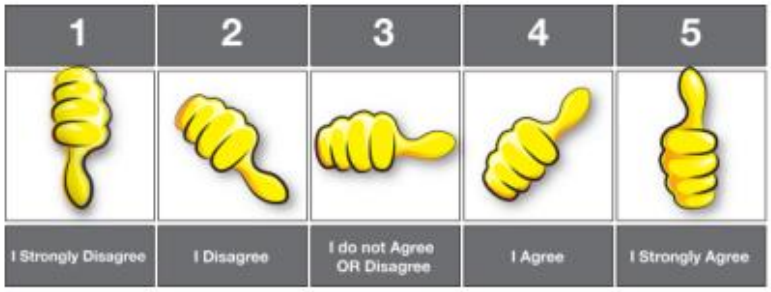
3. If I had this game at home, I'd like to play it a lot more often



Marcar apenas uma oval.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

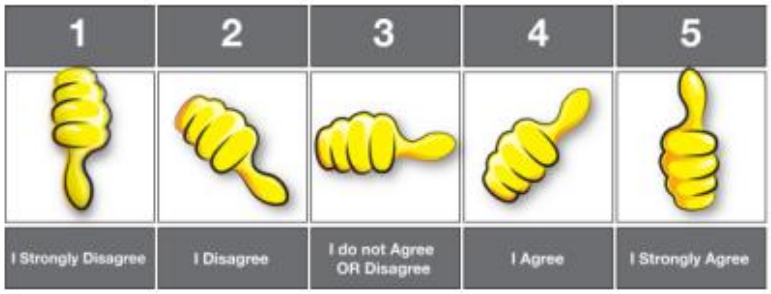
4. With this game I learned a lot of new things about pollution



Marcar apenas uma oval.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

5. I felt confused several times while playing



Marcar apenas uma oval.

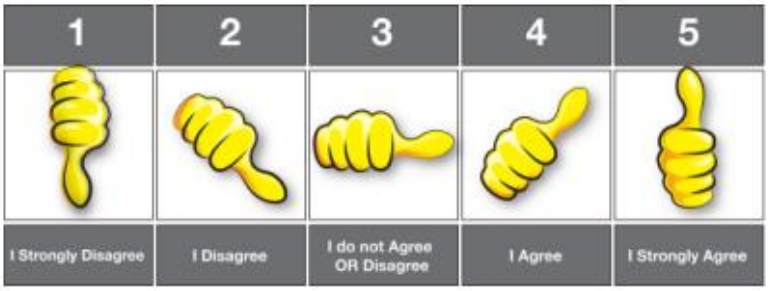
	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

6. To play this game, I feel I need an adult's help

Marcar apenas uma oval.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

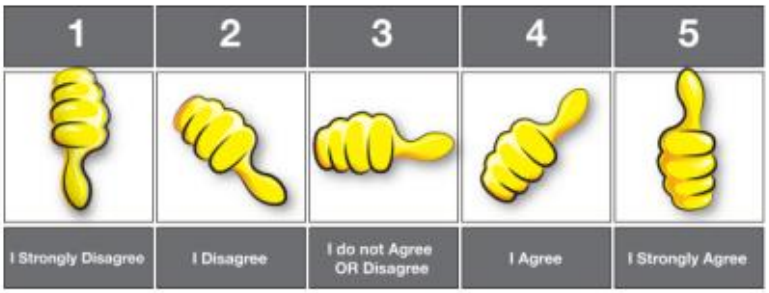
7. If I played this game more often, I would learn a lot more about pollution



Marcar apenas uma oval.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

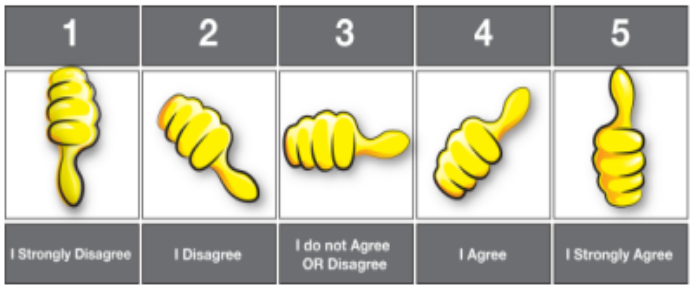
8. My friends will really enjoy this game



Marcar apenas uma oval.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

9. My friends will learn a lot about pollution with this game



Marcar apenas uma oval.

	1	2	3	4	5	
Strongly Disagree	◯	◯	◯	◯	◯	Strongly Agree

Open-ended questions

10. What did you like the most about the game?

11. What did you like the least about the game?

Basic Participant Information

Before finishing this questionnaire, we need basic information about your age and gender for statistical purposes.

12. How old are you?

Marcar apenas uma oval.

- ◯ 6 years or less
- ◯ Between 7 and 9 years old
- ◯ 10 to 11 years
- ◯ More than 11 years

13. What is your gender?

Marcar apenas uma oval.

- Male
- Female
- I prefer not to say
- Outra: _____

14. Do you play games often?

Marcar apenas uma oval.

	1	2	3	4	5	
Never						Very often